INSA DE LYON

Laboratoire d'InfoRmatique en Images et Systèmes d'information

INSA de Lyon, Bâtiment Blaise Pascal
20, Avenue Albert Einstein
F-69621 VILLEURBANNE Cedex (France)

POLITECNICO DI MILANO

Dipartimento di Ingegneria Idraulica, Ambientale, infrastrutture viarie, Rilevamento
SEZIONE RILEVAMENTO

Politecnico di Milano, pad. Sud
Piazza Leonardo da Vinci, 32
I-20133 MILANO (Italie)

ISAL *****

PhD

Jointly submitted at
the Institut National des Sciences Appliquées de Lyon
(Ecole Doctorale Informatique, Information pour la Société)
and the Politecnico di Milano
(Scuola di Dottorato in Geodesia e Geomatica)

By

Alice POZZOLI

DATA AND QUALITY METADATA FOR CONTINUOUS FIELDS: TERRAINS AND PHOTOGRAMMETRY

Supervisors:
Pr. Robert LAURINI, INSA de Lyon
Pr. Luigi MUSSIO, Politecnico di Milano

Reviewers:
Pr. Norbert BARTELME, TU of Graz
Pr. Alessandro CAROSIO, ETH Zürich
Pr. Christophe CLARAMUNT, Ecole Navale de Brest
Pr. Pierre GRUSSENMEYER, INSA de Strasbourg

PhD committee:
Pr. Norbert BARTELME, TU of Graz
Pr. Riccardo BARZAGHI, Politecnico di Milano
Pr. Alessandro CAROSIO, ETH Zürich
Pr. Christophe CLARAMUNT, Ec. Navale de Brest
Pr. Gianfranco FORLANI, Università di Parma
Pr. Pierre GRUSSENMEYER, INSA de Strasbourg
Pr. Robert LAURINI, INSA de Lyon
Pr. Luigi MUSSIO, Politecnico di Milano

CONVENTION POUR LA PREPARATION D'UNE THESE EN COTUTELLE

CONVENZIONE PER LA PREPARAZIONE DI UNA TESI IN COTUTELA

Dans le cadre de l'arrêté du 25/09/1985 relatif aux modalités de dépôt, signalement et reproduction des thèses ou travaux présentés en soutenance en vue du doctorat; de l'arrêté du 18/01/94 relatif à la création d'une procédure de co-tutelle de thèse, et de l'arrêté du 22/05/2002 relatif aux études doctorales, il est prévu une convention:

Visti: il decreto del 25/9/1985 relativo alle modalità di deposito, catalogazione e riproduzione delle tesi o lavori presentati in vista dell'ottenimento del dottorato, il decreto del 18/01/94 relativo alla creazione di una procedura di cotutela di tesi, e il decreto 22/05/2002 relativo agli studi di dottorato, si stipula la seguente convenzione:

Entre / *Tra*

INSTITUT NATIONAL DES SCIENCES APPLIQUEES DE LYON
20 avenue Albert Einstein, 69621 VILLEURBANNE Cedex
par la suite désigné par "INSA de LYON" / *qui di seguito indicata con "INSA de Lyon"*
représenté par son Directeur Adjoint de la Recherche, Délégué aux Etudes Doctorales, le Professeur Jean-Michel JOLION/ *rappresentato dal suo Direttore Aggiunto della Ricerca, Delegato per gli Studi di Dottrato / il* Professeur Jean-Michel JOLION

et / *e*

POLITECNICO DI MILANO
Piazza Leonardo da Vinci 32, Milano- Italia
par la suite désignée par "POLIMI" / *qui di seguito indicata con "POLIMI"*
représenté par son Délégué pour les Relations Internationales, le Professeur Giancarlo SPINELLI, comme identifié par le Décret Italien du Recteur de délégation n. 94/AG du 14 janvier 2003./*rappresentata dal suo Delegato del Rettore per le Relazioni Internazionali, Prof. Giancarlo SPINELLI, secondo decreto rettorale italiano di delega n. 94/AG del 14 gennaio 2003.*

pour la CO-TUTELLE DE THESE concernant **Alice POZZOLI**, de nationalité italienne,
per la COTUTELA DI TESI riguardante ***Alice POZZOLI****, di nazionalità italiana,*

Discipline: Ecole Doctorale « Informatique et Information pour la Société »
Disciplina: Scuola Dottorale «Informatica ed Informazione per la Società»

Titre de la thèse: «Données et Metadonnées de Qualité pour les Champs Continus: Modèles de Terrain et Photogrammétrie»
Titolo della tesi: *" Dati e Metadati di Qualità per i Campi Continui: DEM e Fotogrammetria "*

Titre I: MODALITES ADMINISTRATIVES
Parte I: MODALITÀ AMMINISTRATIVE

Article 1 / *Articolo 1*
La première inscription en thèse au Politecnico di Milano de GEODESIA E GEOMATICA est faite pour l'année universitaire 2003/2004. Elle sera inscrite à l'INSA de LYON à compter de l'année universitaire 2004/2005 sous réserve de l'obtention de la dispense de Master.
La durée prévue des travaux de recherche est de trois années universitaires consécutives à partir de cette première inscription comprise.
La recherche sera menée pendant périodes alternées à peu près équivalentes dans les laboratoires suivants: DIIAR sez. Rilevamento (POLIMI) - LIRIS (INSA de LYON)

La prima iscrizione al dottorato di GEODESIA E GEOMATICA presso il Politecnico di Milano viene fatta per l'anno accademico 2003/2004. Si iscriverà al dottorato presso l'INSA de LYON durante l'anno 2004/2005, sotto riserva dell'ottenimento di una dispensa al diploma di Master.
La durata prevista dei lavori di ricerca è di tre anni accademici consecutivi compreso quello di prima iscrizione.
La ricerca sarà condotta nel corso di periodi alternati, circa equivalenti, nei laboratori seguenti: DIIAR sez. Rilevamento (POLIMI) - LIRIS (INSA de LYON)

Article 2 / *Articolo 2*
Alice POZZOLI prendra une inscription annuelle dans chacun des deux établissements pour chacune des années de préparation de la thèse; elle réglera le montant des droits d'inscription au POLITECNICO di Milano, et bénéficiera de l'exonération des droits par INSA de Lyon. L'inscription de l'année 2005/2006 sera payée en France.

Alice POZZOLI *si iscriverà annualmente in ciascuna delle due Università per ciascuno degli anni di preparazione della tesi; si farà carico degli eventuali oneri di iscrizione presso Il* POLITECNICO *di Milano, e beneficerà dell'iscrizione gratuita presso* INSA de Lyon. *L'iscrizione dell'anno 2005/2006 sarà pagata in Francia.*

Article 3 / *Articolo 3*
Lors de son inscription, Alice POZZOLI doit s'assurer de sa couverture sociale en France.

Al momento della iscrizione, Alice POZZOLI *dovrà assicurarsi di poter usufruire di una assistenza sanitaria in Francia.*

Article 4 / *Articolo 4*
L'hébergement de Alice POZZOLI durant ses séjours à Lyon sera pris en charge par l'étudiante.

Gli oneri per l'alloggio di Alice POZZOLI *durante i suoi soggiorni a* Lyon *saranno a carico della studentessa.*

Titre II: MODALITES PEDAGOGIQUES
Parte II: MODALITÀ PEDAGOGICHE

Article 5 / *Articolo 5*

Les Directeurs de thèse exerçant la cotutelle sont:

- pour INSA de LYON: Prof. Robert LAURINI,
- pour POLIMI: Prof. Luigi MUSSIO.

Les deux Directeurs de thèse proposent en commun le sujet de thèse et s'engagent à exercer pleinement la fonction de tuteur de l'étudiante. La coordination de leur action se traduira notamment par des échanges d'informations et des rencontres périodiques. Les modalités de prise en charge des frais de séjour et de voyage restent à la charge des financements spécifiques des deux Pays.

I Relatori di tesi esercitanti la cotutela sono:

- *per* INSA de LYON: *Prof.* Robert LAURINI,
- *per POLIMI: Prof. Luigi MUSSIO;*

I due Relatori propongono di comune accordo l'argomento della tesi e si impegnano a esercitare pienamente la funzione di tutori della studentessa. Il coordinamento della loro azione avverrà in particolare attraverso scambi di informazioni e periodici incontri. Le spese di viaggio e soggiorno saranno a carico degli specifici finanziamenti dei due Paesi.

Article 6 / *Articolo 6*

La thèse est reconnue par les deux Universités et les deux Pays concernés, en particulier:

le POLITECNICO di Milano délivrera à Alice POZZOLI le titre de "Dottore di Ricerca" à la fin des 3 années de cours, après l'obtention des crédits prévus par le programme d'études et à la suite de l'évaluation du Jury final du Dottorato in Geodesia e Geomatica, établi par le Politecnico di Milano.

L'INSA de Lyon délivrera le grade de "Docteur", à la fin des 3 années de cours, à la suite de l'évaluation du Jury défini dans l'art. 7 et après validation des modules de formation complémentaire.

La tesi è riconosciuta dalle due Università e dai due Paesi in questione, in particolare:

Il POLITECNICO di Milano rilascerà a Alice Pozzoli, *il titolo di "Dottore di Ricerca", al termine dei 3 anni di corsi, previo raggiungimento dei crediti previsti dal programma di studi, a seguito della valutazione della Commissione giudicatrice finale del Dottorato in Geodesia e Geomatica. definita dal Politecnico di Milano.*

INSA de Lyon rilascerà il titolo di "Docteur", al termine dei 3 anni di corso, a seguito della valutazione della Commissione, definita all'art. 7 e in seguito a convalida de moduli di formazione complementare.

Article 7 / *Articolo 7*

La thèse sera soutenue devant un Jury composé à parité de représentants scientifiques des deux Pays; il sera désigné conjointement par les deux établissements et devra obtenir l'agrément du Recteur de POLIMI et du Directeur de l'INSA de Lyon.

Le Jury comprendra au moins 4 membres et au plus 6 membres dont les deux Directeurs de thèse.

La discussione della tesi di dottorato avverrà di fronte a una Commissione giudicatrice composta da un ugual numero di rappresentanti scientifici dei due Paesi; sarà designata congiuntamente dalle due Università e approvata rispettivamente dal Rettore di POLIMI e dal Direttore dell'INSA de Lyon.
La Commissione sarà costituita da un minimo di 4 e da un massimo di 6 membri, tra cui i due Relatori di tesi.

Les frais pour le voyage et le séjour des professeurs membres du jury seront pris en charge par l'université d'origine de l'étudiante.

Le spese derivate dai viaggi e dalla permanenza dei professori che devono formare parte della commissione giudicatrice andranno a carico dell'università di appartenenza della studentessa.

Article 8 / *Articolo 8*
La protection du sujet de thèse ainsi que la publication, l'exploitation et la protection des résultats de recherche issus des travaux de Alice POZZOLI dans les deux établissements seront assujetties à la réglementation en vigueur et assurées conformément aux procédures spécifiques à chaque Pays impliqué dans la cotutelle.

La protezione del soggetto di tesi, nonché la pubblicazione, lo sfruttamento e la protezione dei risultati delle ricerche svolte da Alice POZZOLI *nelle due Università saranno assoggettati alla regolamentazione in vigore, e garantiti conformemente alle procedure specifiche di ciascuno dei Paesi implicati nella cotutela.*

Pour le Directeur de l'INSA de Lyon

Professeur Jean-Michel JOLION
Directeur adjoint de la recherche
pour le Directeur

Politecnico di Milano

Professor Giancarlo SPINELLI
Delegato del Rettore
per le Relazioni Internazionali
Giancarlo Spinelli

Professeur Robert LAURINI
Directeur de Thèse
……………………………………

Professor Luigi MUSSIO
Relatore di Tesi
……………………………………

14 DIC. 2004
……………………………………

Alice POZZOLI
………Alice Pozzoli…………

INDEX

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

1. RESUME ETENDU

Ce résumé est destiné aux lecteurs francophones. Il vise à donner une idée globale du contenu de cette thèse. Nous prions le lecteur intéressé par plus de détails de se reporter au manuscrit en anglais.

1.1. INTRODUCTION

Le sujet principal de ma thèse est le traitement de données en géomatique allant de l'acquisition de données photogrammétriques à la représentation cartographique. Grâce à la convention de cotutelle signée entre l'INSA de Lyon (LIRIS) et le Politecnico di Milano (DIIAR), j'ai eu la possibilité d'enrichir ce sujet avec des connaissances nouvelles qui lient la Géomatique à l'Informatique.

L'objectif de ma recherche est ainsi l'utilisation des techniques statistiques pour le traitement de données géomatiques afin de créer des modèles numériques de terrains en partant des données photogrammetriques et les coder en XML.

1.1.1. Etat de l'art

Cette thèse est divisée en deux parties fondamentales : la photogrammétrie et le traitement de données. Dans le cadre de la photogrammétrie à partir des années 80, est née la possibilité de traiter et manipuler les images par de plus amples détails [162]. Avec cette nouvelle frontière l'automatisation de tous les processus analytiques d'orientation sont devenus objet de recherche. Parallèlement au développement de machines, il existe celui de la vision robotisé. La reconstruction des objets, automatique et de qualité, devient point-clé pour les applications en temps réel (comme l'identification des objets, le contrôle de production et de qualité, conduite des véhicules et robots, etc.). Le nombre des capteurs doit être limité au minimum possible, et de nombreux algorithmes ont été développés pour permettre la résolution de diverses configurations géométriques (sans nécessité d'approximation) et l'utilisation des capteurs non calibrés (caméra et caméra-vidéo). Ont été développés des méthodologies basées sur la matrice essentielle [96] et sur la matrice fondamentale [80], des algorithmes qui intègrent l'auto-calibration du capteur [68], des applications à la vision en mouvement [163] et des techniques différentes d'estimation par la méthode classique des moindres carrés [37]. En conséquence aussi de nombreux technologies de mise en concordance ont fleuri [80]. Pour accroître la redondance des observations, une troisième image a été introduite dans la procédure d'orientation, et une procédure d'orientation d'un triplet d'images (capteur trifocal) a fait augmenter la qualité [180][162] [37].

L'automation de la totalité du processus d'orientation photogrammétrique a fait grandir la quantité de données à stocker. Les données géographiques ont rayonné au tour du monde et sont devenues fondamentales dans de nombreux champs d'application soit scientifique ou non. Pendant les vingt cinq dernières années l'idée d'un échange des données « compréhensibles » est devenue toujours plus concrète. Le grand nombre de système travaillant avec des données géographiques et les formats très différents de stockage ont empêché un simple échange des données. Pour résoudre ce problème de normalisation des données, des organisations internationales (CEN [1], ISO [5], OGC [8], etc.) sont nées avec le but de trouver une solution pour l'interopérabilité entre systèmes différents. Par rapport aux données photogrammetriques un intéressant projet a été développé dans les dernières années, ARPENTEUR [73] : c'est un outil sur le web qui permet d'exécuter les différents processus photogrammétriques et d'avoir les données sauvegardées automatiquement en un format standard, XML. Une norme pour la description des capteurs a été codifiée et incluse dans la base de données SensorML [10]. Pendant notre travail on a développé un exemple de base de données pour le processus automatique d'orientation photogrammetrique. On a décidé d'un stockage en langage GML, très spécifique pour les données géographiques. De plus, il est nécessaire une intégration de notre base des données avec d'autres bases des données déjà existantes (SensorML et base de données de systèmes de références).

PARTIE I. DONNEES GEOMATIQUES ET PHOTOGRAMMETRIQUES

1.2. CONCEPTS D'INFORMATION GÉOGRAPHIQUE

1.2.1. Données Géographiques et Interopérabilité

Dans notre recherche on part des données géographiques provenant de la photogrammétrie pour arriver à la construction de modèles numériques statique et dynamique de la surface de l'eau. La plupart des données géographique sont continues et pour leur codification il est nécessaire de considérer tout le processus qui nous amène à reconstruire leur continuité, car des mesures continues ne sont jamais possibles. Les données géographiques sont très différentes entre elles ; en effet aujourd'hui un grand nombre de dispositifs pour déterminer le relief d'un territoire collecte des données variées ; et en conséquence avoir un standard unique pour toutes les données devient très difficile. Pour ces raisons, il est très important de focaliser l'attention sur le processus de stockage de données, sur le modèle de transfert et sur le langage standard utilisé pour ce propos. De plus est nécessaire de connaître et de définir la qualité de données et des métadonnées.

Souvent, nous devons utiliser des données existantes incompatibles avec le système utilisé. De toutes façons il est très difficile de trouver une solution pour un standard global, surtout parce que chaque utilisateur a ses propres besoins et exigences.

Dans la norme ISO 2382-1 (Organisation Internationale de Normalisation) on trouve la définition d'interopérabilité, qui est la capacité des produits et services informatiques disparates à échanger et à utiliser des données et des informations en vue de fonctionner ensemble dans un environnement en réseau. L'interopérabilité signifie aussi une utilisation en parallèle de différents systèmes d'informations géographiques, dans lesquels on échange requêtes et réponses, sans avoir la nécessité d'échanger les données de base elles-mêmes.

Une méthode de transfert de données doit être adaptable pour une vraie interopérabilité. Une méthode de transfert basée sur un modèle est très utile pour un échange entre différents logiciels, extensions locales ou régionales et pour pouvoir s'adapter à des mutations pendant le temps (des produits et des technologies). Pour une méthode de transfert basé sur un modèle il est nécessaire d'inclure :

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

- un langage standard pour la description conceptuelle des données, lequel est défini univoquement et avec la logique la structure des données à transférer ;
- une procédure pour obtenir un transfert standard de la structure des données.

Un standard très diffusé pour les données géographiques est GML (Geographic Markup Language) [9] basé sur la grammaire de XML [14].

1.2.2. Standardisation et Information Géographique

Des langages standards sont strictement nécessaires pour une réelle interopérabilité entre une infrastructure des données.

En 1992 est né le CEN TC 287 (Comité Européen de Normalisation). Ce comité technique a terminé en 1999 le draft de standard expérimental pour l'information géographique (ENV). En 1994 l'association internationale de normalisation (ISO) est née d'une stricte collaboration entre différents partenaires qui utilisent les standards pour l'échange de données. Le ISO/TC 211 et le CEN/TC 287 ont conclu un accord pour définir de manière définitive et unique la norme ISO pour l'information géographique/géomatique.

En 1994 est né aussi un autre comité, l'Open GIS Consortium (actuellement Open Geospatial Consortium). C'est un ensemble de producteurs de systèmes informations géographiques, producteurs des données, administrations, organisations et instituts de recherche, dans le but de définir des interfaces de logiciels « ouverts » indépendants des producteurs, de favoriser la standardisation des techniques de SIG et de promouvoir la technologie SIG.

De plus, OGC et ISO/TC 211 ont un accord pour se soutenir réciproquement pour un alignement de leurs développements respectifs. Ils réalisent une révision mutuelle et les développements des drafts. OGC adopte la norme standard ISO et les implémente. Quand une spécification OGC satisfait certaines conditions, ISO l'adopte comme standard officiel [22].

Dans le tableau suivant on cherche à résumer toutes les normes liées au concept d'interopérabilité et de description de données, rédigées par les organisations, comités et consortia de normalisation de l'information géographique.

Norme	Titre	Etat	Description
OMG UML	Unified Modeling Language	Diverses versions. 191xxx basées sur UML 1.3	Diagrammes de classes
ISO 19103	Conceptual Schema Language	DTS	Restrictions de l'UML + types de données de base comme texte, chiffre, etc.
ISO 19109	Rules for application schema	DIS	Métamodèle (=langage de modélisation). Superflu, puisque UML and 19103 définissent le langage de modélisation !
ISO 19107	Spatial Schema	IS	Type de données géométriques (incluant la topologie)
ISO 19108	Temporal Schema	IS	Type de données temporelles (incluant la topologie)
ISO 19111	Spatial Referencing by coordinates	IS	Modèle de données pour les systèmes de références spatiales par cordonnées
ISO 19112	Spatial referencing by geographic identifiers	IS	Modèle de données pour les noms géographiques

ISO 19123	Schema for coverage geometry and functions	DIS	Modèle de données – Couverture
ISO 19115	Metadata	IS	Modèle de données pour métadonnées
ISO 19118	Encoding	DIS	Détermine les règles de codification pour le transfert de données. Doit être en premier défini de manière univoque et complète pour l'interopérabilité !
W3C XML	XML	1.0 (rarement 1.1)	Format de texte flexible
W3C XML-Schema	XML-Schema	1.0	Langage de description pour des données XML
ISO 19136	Geography Markup Language	IS (GML 3.2)	Spécification commune de l'OGC et l'ISO pour le transfert des données

Figure 1.1. Norms ISO (WD: Working Daft; CD: Committee Draft; DIS/DTS: Draft International Standard/Drat; Technical Specification; FDIS: Final Draft International Standards; IS: International Standard) [22]

1.2.3. XML (eXtensible Markup Language) et ses extensions[1]

Le langage XML a été conçu pour faciliter l'implémentation des applications interopérables sur la base du Standard Generalized Markup Language (SGML) et du Hypertext Markup Language (HTML). XLM est la base de nombreuses extensions spécifiques pour la description et l'échange des données géographiques.

Les objectifs déterminant la conception de XML sont :

- XML doit être directement utilisable sur l'internet.
- XML doit reconnaître une grande variété d'applications.
- XML doit être compatible avec SGML.
- l'écriture des programmes de traitement des documents XML doit être aisée.
- le nombre des caractéristiques optionnelles dans XML doit être tenu au strict minimum, idéalement à zéro.
- les documents XML doivent être lisibles par un humain et raisonnablement clairs.
- la conception de XML doit être préparée rapidement.
- la conception de XML doit être formelle et concise.
- les documents XML doivent être faciles à créer.
- la concision dans le balisage XML est de peu d'importance.

XML est un standard puissant pour la description des données géographiques, même s'il n'a été pas conçu pour ce but. Il est un point de départ optimal pour des langages plus spécifiques conçus expressément pour des données géographiques. XML peut être étendu pour les données territoriales et pour des applications plus complexes.

L'intérêt principal pour des extensions de XML est :

[1] Cet paragraph est part des specifications du W3C et peut etre trouvé intagralement au [14].

- d'alléger la charge des serveurs ;
- d'alléger les échanges client-serveur ;
- de permettre des requêtes-client ;
- et d'installer des traitements locaux au niveau client.

Les principales extensions géographiques de XML sont :

- **SVG** (Scalable Vector Data) est une application de XML dont l'objectif est la description d'objets graphiques vectoriels en 2 dimensions. Il a été développé pour augmenter les fonctions graphiques de HTML, avec le but de créer un standard pour la représentation de données vectorielles sur le web.
- **GML** (Geographic Markup Language) est une extension de XML développée par l'OGC (Open Geospatial Consortium), dans le but de définir un langage standard pour l'échange des données géographiques sur le web. Cette extension est spécifique pour le stockage et le transport de géo-données, en préservant la géométrie et les propriétés des éléments géographiques.
- **LandXML** est un projet d'Autodesk et EAS-E (Engineering and Surveying-Exchange) commencé en 1999. LandXML définit un format pour le génie civil et l'arpentage, facilite le transfert entre les acteurs, l'archivage à long terme, et l'échange des données sur le web. Il sépare le standard utilisé pour la description des données du logiciel utilisé.

Durant ces dernières années de nombreuses extensions pour les géo-données sont en continues évolution et développent. Une des plus intéressantes est CityGML [2]. CityGML est né comme un modèle sémantique pour la description 3D des objets urbains. Ce modèle a été développé depuis 2002 par les membres du groupe « SIG 3D », dans le cadre de l'initiative allemande « Geodata Infrastructure North-Rhine Westphalia ». C'est un modèle des données ouvert basé sur XML. La spécification de CityGML est une extension de GML 3 qui a été transmise à l'OGC. CityGML définit les classes et les relations pour la plupart des objets topographiques dans les villes et dans les modèles régionaux respectivement à leurs propriétés géométriques, topologiques, sémantiques et d'apparence. Ils incluent la généralisation hiérarchique entre classes thématiques, les relations entre les objets et les propriétés spatiales. Ces informations thématiques sont au delà du format graphique d'échange et permettent d'utiliser de modèles virtuels 3D des villes pour des analyses complexes et ce dans différents domaines d'applications. On a décidé de ne la pas considérer entre les possibles choix car seulement en Juliet 2007 il est devenu un standard approuvé pas l'OGC, et aussi parce que il paraître plus approprié pour le modèle 3D des villes que pour des modèle numérique des terrains.

1.2.3.1. Comment choisir une extension pou les données géographiques ?

Chaque langage est strictement lié à la structure des données qui doit être décrit et aux objectifs que les auteurs se sont fixés. Un langage peut être approprié pour une fin mais pas du tout pour une autre, même si les données sont les mêmes. De ce fait il est opportun d'effectuer une analyse coût-bénéfice avant de choisir le langage à utiliser. Les trois extensions analysées précédemment sont basées sur une grammaire XML. SVG est complètement indépendant de la plate-forme d'utilisation et il permet de travailler directement sur le format. LandXML a nombreux balises qui le rend difficile pour l'écriture avec un éditeur de texte, alors que GML peut être directement exporté avec certaines logiciels. Toutes ces trois extensions ont des normes consultables, mais seulement GML peut être utilisé parmi de logiciels non commerciaux. Les trois extensions représentent un standard ouvert et facilement compréhensible par un utilisateur. LandXML et GML prévoient l'association de métadonnées à la base des données décrites. Une importante différence est la gestion de la troisième dimension : SVG ne prévoit pas la gestion de données 3D. Cette caractéristique nous a fait éliminer SVG comme possible langage pour décrire nos données. Le principal avantage qui nous a fait choisir GML, est sa flexibilité et ses développements spécifiques pour la description des données géographiques.

Dans le tableau suivant sont résumées les caractéristiques, et les différences, principales des trois majeures extensions de XML. Ce tableau doit être un aide pour un choix de l'extension optimale selon le type de données qui doit être décrit.

L'efficacité de chaque langage est identifiée par une valeur qui va de 1 (bas efficace) à 5 (haut efficace).

Critères	GML	SVG	LandXML
Lisible à l'œil	5	5	3
Extensibilité? (Possibilité de définir de nouvelles balises…)	5	0	3
Standardisation (OGC, ISO, W3C…)	4	5	3
Format libre	5	5	4
Représentation temporelle	5	5	2
3D	3	0	5
Eléments de base 2D	5	3	5
Eléments de base 3D	4	0	5
Possibilité de créer des éléments complexes	5	5	5
Possibilité de visualisation (PC, browser, PDA…)	1	5	5
Possibilité de rendu	1	5	3
Navigation dans l'image	Propre au visualisateur	5	3
Possibilité de stocker des données associées aux données géographiques	5	5	5
Interactivité des éléments (réponses à des événements)	0	4	5
Applicable pour des professionnels	5	5	---
Possibilité d'associer à des scripts externes	1	5	5

Figure 1.2. Comparaison entre trois extensions de XML pour les données géographiques[2]

[2] De [78].

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

1.2.4. Standard ISO et GML[3]

Comme dit précédemment, GML est une codification de XML pour la modélisation, l'échange et la sauvegarde de l'information géographique, que les éléments géographiques aient des propriétés spatiales ou non. Il a été développé initialement par l'OGC. La norme ISO 19136 a été préparée par le comité technique 211 de l'association internationale de normalisation en stricte collaboration avec l'OGC. Cette norme essaye d'harmoniser les spécifications de deux organismes. GML a été conçu pour :

- la codification de l'information spatiale, échange et stockage ;
- le soutien de champs d'applications aussi larges que possible (des données non spatiales peuvent être aussi représentées) ;
- GML comme base d'applications pour des SIG Internet ;
- la codification efficace de la géométrie (compression des données) ;
- La séparation des contenus spatiaux de ceux non-spatiaux ;
- l'intégration facile de données non-spatiales déjà existantes en XML ;
- et la mise à disposition d'un ensemble d'objets géométriques de base, pour permettre l'interopérabilité entre applications développées de façon indépendantes.

GML comprend la description d'une grand variété d'objets pour la description de la géographie, et inclut aussi la description des features (objets avec des propriétés), systèmes de référence de cordonnées, géométrie, topologie, temps, unité de mesure et valeurs généralisées.

Les développeurs peuvent décider de sauvegarder les schémas d'application géographique et les informations en GML, ou peuvent décider de les convertir depuis d'autres formats de stockage des données et utiliser GML seulement comme schéma et transport des données.

1.2.5. Organisation des Données Géographiques

La base des données est une technique optimale pour organiser un grand nombre de données (soit géographiques, soit d'autres types). Les bases de données sont organisées autour des modèles des données, qui représentent la perception que les personnes ont de la réalité de manière abstraite. Le modèle de données est utilisé pour décrire l'architecteur (contenu des données, relations et contraintes, structure des données et stockage physique ou format des données) d'une base de données.

Le langage unifié de modélisation (UML) a été sélectionné comme langage de spécification normative par l'ISO/TC211 depuis 1998, alors que l'OGC utilise le langage UML de manière non normative. ISO/TC211 a focalisé son attention vers les modèles indépendants des plates-formes écrits en UML, et utilise une architecture dirigée par les modèles pour indexer les données en XML. En revanche OGC est en train d'implémenter une spécification pour des technologies multiples.

[3] Partie du paragraphe est prise de [9].

La principale différence entre ISO et OGC est la méthode utilisée pour échanger les données : ISO veut échanger les données, et une approche dirigée par les modèles est indispensable pour un transfert des données interopérables ; alors que l'OGC ne nécessite pas une méthode dirigée par les modèles, parce qu'il veut transférer seulement les questions et les réponses. Ce point de vue très différent fait que ces deux organisations suivent des stratégies très différentes.

Dans notre recherche le but fondamental est celui du transfert de données ; dès lors une approche dirigée par les modèles paraît très opportune et facilement utilisable pour différentes applications dans le domaine des données géographiques.

1.2.5.1. Schème Conceptuel

L'expérience du comité technique 211 de l'ISO montre que la standardisation de l'information géographique est possible seulement parmi des systèmes indépendants au niveau conceptuel. En effet on doit échanger données entre systèmes avec différentes structures de données et la solution est concevoir le modèle des données au niveau conceptuel et de transformer les données correspondantes à l'aide d'un outil de l'approche dirigée par le modèles.

Le niveau conceptuel décrit le type d'information qui est sauvegardée dans le modèle. A ce niveau on définit précisément le contenu des données, les relations entre elles et les contraintes que doivent respecter ces données. Cette description conceptuelle des données est appelé schéma conceptuel de la base des données. Les schémas conceptuels peuvent être décrits à l'aide de différentes techniques. Une des plus connus est la langage UML, déjà mentionné, adopté par l'ISO (ISO 19103).

1.2.5.2. UML et INTERLIS

UML est un langage simple, très populaire et très général pour concevoir les applications. Il est officiellement défini par l'Object Management Group (OMG). UML est indépendant des logiciels utilisés pour l'écrire et il est un catalyseur pour le développement de l'approche dirigée par le modèles (MDA). UML permet une description graphique des données. Dans notre travail on utilise l'approche de diagrammes des classes. Cette approche organise les données en classes correspondant à l'objet réel qu'on doit stocker, et chaque classe possède ses attributs différents, qui correspondent aux différents attributs de l'objet.

La description du modèle UML dans la norme ISO 19115/2003 est trop générale pour une vraie application. Pour cette raison, la Suisse a détaillé la création du modèle UML parmi un langage standard INTERLIS2[4]. Ce langage permet la modélisation des données avec une notation UML, il est la forme textuelle du langage UML, il est similaire à un langage de programmation et peut être facilement amélioré et intégré avec différent outils. INTERLIS2 fixe les règles de génération automatique de schéma XML ou GML. Ces schémas sont lisibles par divers ordinateurs et peuvent être utilisés pour la génération de la base des données et ses applications. Grâce aux règles de codification automatique du schéma XML ou GML à partir du modèle conceptuel en UML, on n'est pas obligé à dessiner à la main le Schéma GML/XML, nous préservant ainsi de nombreuses erreurs.

Un outil très utile d'INTERLIS est son éditeur UML. Cet éditeur nous aide à la construction du modèle conceptuel, définit la trace sémantique à partir du modèle original jusqu'au final, fournissant les paramètres nécessaires pour la conversion du système INTERLIS (ICS). Seulement après l'ICS peut générer automatiquement les données finales à partir des données originales en format standard.

[4] La Suisse fait partie du CEN (Comité Européen de Normalisation). CEN est le représentant Européen pour l'ISO. La Suisse a considéré les normes ISO pour la création des règles du standard nationale (INTERLIS2).

Grâce à l'éditeur UML d'INTERLIS il est aussi possible de dériver automatiquement le schéma GML des données correspondant en partant du modèle conceptuel UML. INTERLIS fournit des règles uniques pour la codification du schéma GML. Il nous permet de dériver plusieurs schémas GML/XML du même modèle conceptuel et aussi de relier différents modèles entre eux. Une fois généré le schéma XML/GML il est aussi possible de rétro-concevoir le processus et dériver le modèle conceptuel UML à partir du texte XML/GML.

1.2.5.3. Approche Dirigée par le Modèle (MDA)

L'approche dirigée par le modèle (MDA) est une stratégie très utile pour le transfert des données indépendant du format ou du système utilisé. Il est basé sur une exacte description de la structure des données qui doit être transférée. Cette description est le modèle conceptuel ou schéma conceptuel. Le format de transfert peut être dérivé automatiquement du modèle conceptuel en accord avec des règles par un compilateur. L'approche dirigée par le modèle (MDA) est décrit dans la Figure 1.3 à côté.

L'approche dirigée par le modèle peut être résumée en deux phases : une première phase, avant qu'aucune donnée ne soit échangée, reformatée ou traitée par un autre service, on décrit exactement la structure des données à un niveau conceptuel indépendamment du système ou du format ; et une deuxième phase où, à partir du schéma conceptuel, une fois vérifiée la justesse syntaxique par un compilateur, est décrite automatiquement la description du format correspondant de transfert en accord aux règles fixées [74].

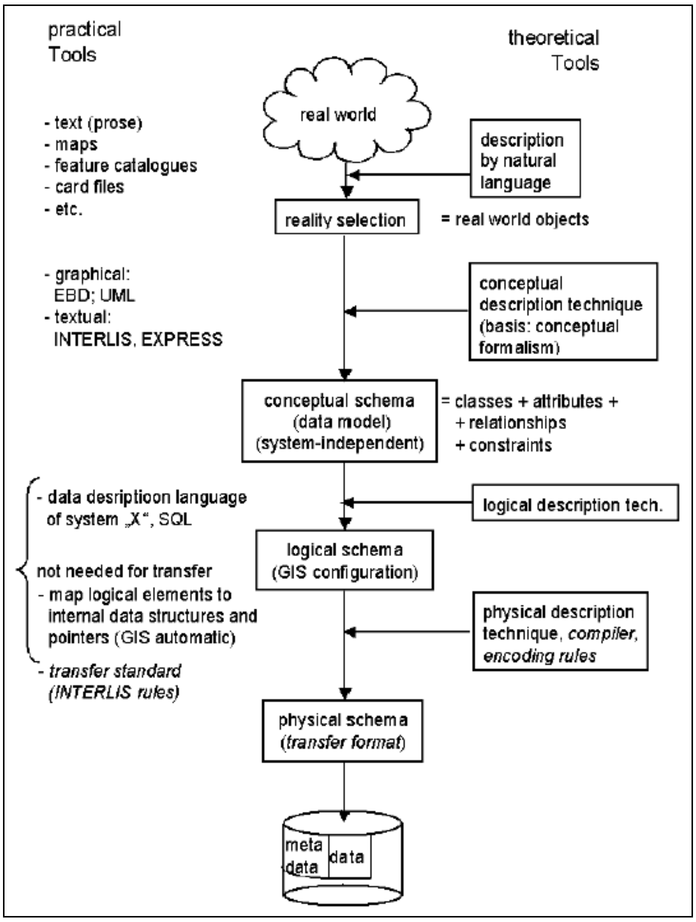


Figure 1.3. Procédure de modélisation des données [74]

1.2.5.4. Différentes Approches à la Modélisation des Données

Durant cette recherche, le modèle UML des données a été défini selon les règles et les restrictions des spécifications de GML, et on a utilisé les types des données définis par GML (ISO 19103 et ISO 19107). Ensuite on peut appliquer les règles de codification du modèle caractérisé par GML et obtenir le format de transfert.

Comme déjà mentionné, GML peut être employé en deux façons différentes :

- comme application de stockage : les informations sont sauvegardées directement en GML ;

- seulement comme schéma et transport des données : les informations sont converties depuis d'autres formats de stockage.

Avec l'introduction de GML, on a deux différentes approches pour la modélisation des données :

- le modèle UML comme moyen de visualisation ; le schéma GML comme norme ;
- le modèle UML comme norme ; le schéma GML comme format de transfert.

Dans ce travail on a décidé de partir du modèle UML pour la description conceptuelle des données photogrammétriques, et de l'utiliser comme standard de référence. En effet quand une modèle est définie, des décisions décisives sont prises, le modèle UML devient décisif et le schéma GML déduit automatiquement sert seulement au transfert de données.

Avantages de cette approche :

- d'autres formats de transfert peuvent être générés,
- le modèle UML ne décrit que la structure du contenu, les problèmes relatifs à l'utilisation du format sont réglés par les règles de codification.

Inconvénients :

- certaines possibilités de GML ne peuvent pas être utilisées puisque il manque les règles de transformation de UML à GML dans 19136 (annexe E) ;
- une traduction du modèle UML est nécessaire pour le format de transfert concret. Pour l'utilisateur, il suffit d'appuyer sur un bouton, mais pendant la réalisation le développeur de logiciel doit avoir en tête le modèle UML, le format de transfert et les règles de traduction.

1.2.6. Description des géo-données

La diffusion de masse d'Internet, de GPS mobiles (système de positionnement par satellite) et des dispositifs GPRS (General Packet Radio Service) a fait augmenter énormément la quantité de donnée proviennent de sources différentes et non conventionnelles. Il est plausible que dans un futur prochain un réseau de capteurs contrôlera et échangera les données géographiques pour des applications différentes et non-homogènes. Le SIG est ainsi devenu le support de base pour plusieurs décisions dans le domaine social, et de plus en plus est présent le risque que ces décisions ne soient pas basées sur des données de qualité. De plus l'investissement le plus onéreux est celui de l'acquisition des données ; ainsi pour éviter le risque de redondances et de gaspillages (de temps et argent) la définition d'un standard et une évaluation de la qualité des données devient nécessaire.

1.2.6.1. Qualité des Données et Métadonnées

L'ISO a définit certains standards pour évaluer la qualité des données et métadonnées :

- ISO 19113 –Information Géographique – Principes de qualité
- ISO 19114 – Information Géographique – Procédure d'évaluation de la qualité.

Il est dès lors très important de définir que veut dire une donnée de qualité. Certains éléments d'appréciation peuvent être les suivants :

- **Origine** : source des données et méthodes pour les obtenir, et aussi les transformations qu'elles ont subies ;
- **Précision Thématique** : (attributs non-spatiaux) différence entre la valeur de l'attribut et sa valeur réelle. C'est l'inverse de l'erreur, et peut être déterminé seulement à l'aide d'une comparaison avec les valeurs les plus justes qu'on puisse jamais obtenir ;
- **Précision Temporelle** : date d'origine, fréquence et validité de mise à jour ;
- **Précision Positionnelle** : niveau de conformité des données lié à la réalité ou au terrain nominal ;
- **Intégrité** : informations sur les caractéristiques, et les critères des définitions et sélections ;
- **Cohérence Logique** : fiabilité des relations sauvegardées, liées aux contraintes définiespar les standards. Pour son évaluation il est possible d'appliquer des tests avec les contraintes mathématiques, logiques ou topologiques ;
- **Cohérence thématique** : les objets, les relations et les attributs doivent être correctement codifiés en relation avec la norme générale et selon les spécifications des standards.

L'évaluation de la qualité des données peut être effectuée par :

- le producteur des données : avec l'utilisation de tests conformes aux stratégies ;
- l'utilisateur final : grâce aux métadonnées fournies par le producteur, l'utilisateur peut évaluer leur qualité (malheureusement les producteurs des données n'ont pas toujours un retour d'information depuis les utilisateurs pour pouvoir corriger les erreurs des données) ;
- les utilisateurs : grâce aux spécifications des standards les informations sur la qualité des données sont bidirectionnelles, ainsi les producteurs ont un retour d'information depuis les utilisateurs et peuvent intervenir sur les données.

L'ISO a défini un standard pour les Métadonnées (ISO 19115), et une implémentation de ce standard a été développé en XML (ISO 19139). La norme ISO 19115 (Information Géographique : Métadonnées) fixe le schéma nécessaire pour décrire l'information géographique et les services liés. Elle fournit les informations sur l'identification, l'extension, la qualité, le schéma spatial et temporel, la référence spatiale, et les règles de la distribution des données géographiques.

Pour mieux comprendre la signification des métadonnées pour l'information géographique on ajoute les définitions suivantes :

- les métadonnées sont structurées et permettent la description de ressource d'informations qui les rendent facilement identifiables ;
- les métadonnées sont des informations qui peuvent être lues par des ressources électronique ou par d'autres dispositifs.

Les métadonnées donnent une exacte description des contenus des géo-données. Elles aident l'utilisateur à avoir plus d'information sur la précision, la fiabilité, le modèle, le format et les autres informations additionnelles pour mieux comprendre si les géo-données satisfont les critères demandés.

1.2.7. Conclusion de la Partie II

Dans ce chapitre on a décrit toutes les motivations de nos choix en rapport à la stratégie adoptée pour la description des données photogrammétriques. En conclusion on peut dire qu'une méthode dirigée par le modèle est une bonne solution pour la description et le transfert des données géographiques, et en plus il est l'unique solution pour un transfert des données interopérables. Avec l'aide du langage INTERLIS et son éditeur UML il est devenu facile d'avoir un modèle conceptuel cohérent et le passage au schéma GML a été complètement automatisé (en conséquence affecté de moins d'erreurs). Grâce aux normes et aux spécifications sur les géo-données la procédure de transfert des données est bien documentée et contrôlée à un haut niveau aussi bien pour la qualité des données que celle des métadonnées.

PARTIE II. ACQUISITION ET TRAITEMENT DES DONNEES

1.3. SEQUENCES MULTIPLE DE SCENES EN STEREO AVEC LA PHOTOGRAMMETRIE

1.3.1. Formation du Modèle et Reconstruction de l'Objet

La fonction principale de la Photogrammétrie est la transformation des données en partant de l'espace-image à l'espace-objet. On peut réaliser cette transformation avec les équations de colinéarité d'une façon directe, ou avec une procédure en deux étapes qui sépare la formation du modèle de la reconstruction de l'objet original. Dans ce travail, nous avons choisi la procédure en deux étapes pour définir différemment le problème de l'orientation absolue de celui de l'orientation relative. Nous avons proposé une solution pratique pour l'orientation automatique à partir de trois images.

En premier lieu, chaque couple d'images du triplet doit être orienté relativement. Normalement la solution de cette procédure peut être obtenue après une linéarisation du modèle fonctionnel non-linéaire, où les valeurs approximées des paramètres inconnus sont indispensables. Avec cette nouvelle solution, on utilise une recherche exhaustive des valeurs (des paramètres) approximées d'orientation relative.

1.3.2. Orientation Relative de trois images avec une recherche exhaustive des valeurs (des paramètres) approximées

La recherche exhaustive des valeurs approximées des paramètres nous permet d'automatiser la procédure d'orientation relative et de ne pas nécessiter de ces valeurs a priori. Cette méthode non conventionnelle donne des bons résultats pour l'orientation de couples d'images, après avoir considéré certaines informations de base pour discriminer entre les quatre solutions obtenues après ce premier pas. La procédure automatique d'orientation implique l'absence d'intervention humaine grâce à l'introduction de la troisième image, qui permet de résoudre l'ambiguïté de manière automatique.

En [229] et [230] est présentée de manière détaillée une solution pour l'orientation relative des images parmi une recherche exhaustive des valeurs approximées des paramètres. Avec l'exploration de l'espace 3D avec un pas de $\pi/4$ il est possible de trouver ces valeurs préliminaires. L'idée est de ne pas passer pour une linéarisation des fonctions d'orientation et de suppléer le manque d'informations de la position et des angles d'attitude (angles de roulis, lacet, tangage) de l'image.

Pour effectuer une recherche exhaustive des valeurs approximées des paramètres on doit nous référer aux paramètres d'orientation relative symétriques. Pour définir l'orientation externe de deux images avec les équations de colinéarité on a besoin de douze paramètres (X_1, Y_1, Z_1, X_2, Y_2, Z_2 coordonnées des centres de projection, et ω_1, φ_1, κ_1, ω_2, φ_2, κ_2 angles d'attitude des deux capteurs). En revanche si nous séparons la formation du modèle de celui de l'objet, on définit l'orientation absolue parmi sept paramètres : t_x, t_y, t_z (vecteurs de translations, λ (facteur d'échelle), Ω, Φ, K (angles de Cardan), alors que pour définir l'orientation relative on a besoin de de cinq paramètres : φ_1, κ_1, ω_2, φ_2, κ_2 (Orientation Symétrique Relative), ou b_y, b_z, ω_2, φ_2, κ_2 (Orientation Relative Asymétrique).

Le choix d'une orientation relative symétrique nous nous permet d'effectuer la recherche exhaustive de toutes les rotations possibles, relatives d'un corps en rapport à un autre dans un espace 3D. On doit en effet déterminer φ_1, κ_1, ω_2, φ_2, κ_2 qui sont les angles d'attitude des deux images, où ω_1 est omis parce qu'il est définit avec l'angle d'attitude globale pendant l'orientation absolue du modèle. La recherche exhaustive est possible parce qu'on travaille avec des groupes fermés (au un sens topologique) de valeurs comparées avec les rotations dans l'espace.

Toutes les valeurs trouvées avec un pas de $\pi/4$ sont enregistrées et utilisées pour résoudre un système linéarisé. Le pas de $\pi/4$ a été choisi selon le critère de valeurs acceptables pour la convergence de linéarisation des fonctions trigonométriques.

On veut faire remarquer, que dans la photogrammétrie non-conventionnelle, l'acquisition des images est effectuée sans mesures classiques de relief. Et aussi il n'est pas toujours possible de connaître les paramètres approximés de valeurs d'orientation relative de deux images ; dès lors une recherche exhaustive devient très utile et avantageuse.

Cette recherche exhaustive explore 12800 configurations possibles, et pour chaque cas, on résoud un système linéaire, en utilisant les valeurs de cette configuration comme paramètres approximés pour l'orientation relative symétrique. Des exemples ont été réalisés avec tous les points médians. Si on considère les cinq paramètres d'orientation relative symétrique, les angles κ_1, ω_2, κ_2 sont définis sur une rotation complète (huit configurations), en revanche φ_1, φ_2 sont définis parmi une demi-rotation (cinq configurations), qui nous amène aux 12800 configurations possibles d'un corps dans l'espace 3D.

Chaque système linéaire nous donne les estimations des paramètres d'orientation relative symétrique. La convergence est obtenue quand la valeur de σ_0 est suffisamment réduite. En considérant seulement les solutions distinctes on trouve quatre configurations analytiquement acceptables (Figure 1.4).

Ces configurations sont vraiment distinctes, et il n'est pas difficile d'avoir des informations sur la position initiale des images, pour chaque cas considéré. Si un opérateur sélectionne le cas approprié, il devient possible de calculer les estimations d'orientation relative symétrique attendues.

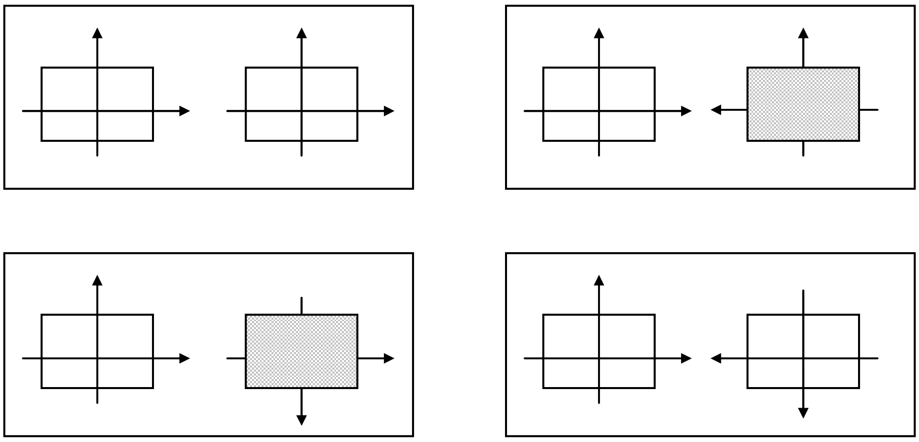


Figure 1.4. Les 4 configurations finales possibles

1.3.3. Formation du Modèle

La formation du modèle implique différentes stratégies pour calculer les cordonnées du modèle. Le parallaxe doit être la distance minimale à la place de la direction z de la photogrammétrie aérienne (ou de la direction y en photogrammétrie terrestre).

Ainsi le vecteur de parallaxe peut être exprimé comme combinaison linéaire de trois vecteurs :

$$\mathbf{p} = \lambda \mathbf{s} - (\mathbf{b} + \mu\, \mathbf{t}) \qquad (1.1)$$

Où λ et μ sont les coefficients d'échelle du vecteur unitaire $\mathbf{s}$ (1.2) et $\mathbf{t}$ (1.3), et $\mathbf{b}$ est la ligne de base entre les deux images (Figure 1.5).

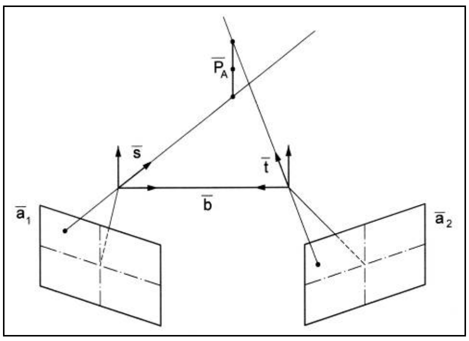


Figure 1.5. Schéma de Parallaxe

Si on fait une substitution des vecteurs unitaires suivants :

$$\mathbf{s} = -\frac{\mathbf{a}_1}{|\mathbf{a}_1|} \tag{1.2}$$

$$\mathbf{t} = \frac{\mathbf{a}_2}{|\mathbf{a}_2|} \tag{1.3}$$

Où:

$$\mathbf{a}_1 = \mathbf{R}_1^T \begin{vmatrix} x_1 - x_{PP} \\ y_1 - y_{PP} \\ -c \end{vmatrix} \qquad \mathbf{a}_2 = \mathbf{R}_2^T \begin{vmatrix} x_2 - x_{PP} \\ y_2 - y_{PP} \\ -c \end{vmatrix} \qquad (1.4, 1.5)$$

On obtient:

$$|\mathbf{p}|^2 = \mathbf{p}\,\mathbf{p} = \lambda^2 + b^2 + \mu^2 - 2\lambda\mathbf{sb} - 2\lambda\mu\mathbf{st} + 2\lambda\mu\mathbf{bt} \tag{1.6}$$

Pour réduire le parallaxe, on peut calculer les dérivées partielles des termes λ et μ (1.7 et 1.8) et les supposer égales à zéro.

$$\frac{\partial|\mathbf{p}|^2}{\partial\lambda} = 2\lambda - 2\mathbf{sb} - 2\mu\mathbf{st} = 0 \qquad \frac{\partial|\mathbf{p}|^2}{\partial\mu} = 2\mu - 2\lambda\mathbf{st} + 2\mathbf{bt} = 0 \qquad (1.7, 1.8)$$

En effet, avec cette approche on trouve les valeurs de λ (1.9) et μ (1.10) respectivement au minimum de la fonctionnelle p^2. Si on l'introduit dans la formule 1.1 on peut obtenir le minimum du parallaxe $\mathbf{p}_0$ (1.11).

$$\mu_0 = \frac{(\mathbf{s}\cdot\mathbf{b})(\mathbf{s}\cdot\mathbf{t}) - (\mathbf{b}\cdot\mathbf{t})}{1-(\mathbf{s}\cdot\mathbf{t})^2} \qquad \lambda_0 = \frac{(\mathbf{s}\cdot\mathbf{b}) - (\mathbf{b}\cdot\mathbf{t})(\mathbf{s}\cdot\mathbf{t})}{1-(\mathbf{s}\cdot\mathbf{t})^2} \qquad (1.9, 1.10)$$

$$\mathbf{p}_0 = \lambda_0\mathbf{s} - (\mathbf{b} + \mu_0\mathbf{t}) \tag{1.11}$$

Enfin les coordonnées du modèle sont obtenues en additionnant (ou soustrayant) ½ $\mathbf{p}_0$ à chaque coordonnée de la première ou deuxième image:

$$\mathbf{A}_1 = \lambda_0\mathbf{s} + \frac{1}{2}\mathbf{p}_0 \qquad \text{ou} \qquad \mathbf{A}_2 = \mu_0\mathbf{t} - \frac{1}{2}\mathbf{p}_0 \qquad (1.12, 1.13)$$

1.3.4. Procédure à trois images : Concaténation des Modèles

Dans notre approche on a décidé d'utiliser trois images pour pouvoir éliminer l'intervention humaine pendant l'exécution de la procédure globale. Avec deux images après l'orientation relative on doit choisir laquelle des quatre configurations obtenues est la plus adéquate. Avec l'introduction de la troisième image ce choix devient automatique.

Avec trois images stéréoscopiques on peut répéter la procédure d'orientation relative symétrique pour deux couples d'images, et obtenir pour chaque couple les quatre modèles (A, B, C et D) analytiquement acceptables.

Une transformation de rototranslation dans un espace 3D nous nous permet d'enchaîner les huit modèles dérivant des deux couples, et nous faire obtenir seize blocs (Table 1.1). La plupart de ces blocs sont complètement incohérents, en effet le σ_0 de la rototranslation dans l'espace 3D devient très grand. Cela est raisonnable seulement lorsque les deux modèles I et II sont congruents entre eux, et la concaténation est cohérent. L'ensemble de combinaisons cohérentes et incohérentes nous amène à seulement deux blocs avec un σ_0 acceptable. Ces deux blocs proviennent de deux différentes configurations admissibles en chaque couple. L'analyse de la géométrie des quatre solutions admissibles reconnaît un degré élevé de régularité des valeurs présentées. En conséquence, les deux blocs cohérents présentent les cordonnées dans les deux systèmes de référence spéculaires.

	IIA	IIB	IIC	IID
IA	IA-IIA	IA-IIB	IA-IIC	IA-IID
IB	IB-IIA	IB-IIB	IB-IIC	IB-IID
IC	IC-IIA	IC-IIB	IC-IIC	IC-IID
ID	ID-IIA	ID-IIB	ID-IIC	ID-IID

Table 1.1. Concaténation des Modèles

1.3.4.1. Reconstruction de l'objet : Orientation Absolue avec trois images

Une fois chaque modèle relatif enregistré, on peut réaliser l'orientation absolue en utilisant une paramétrisation linéaire du problème.

Si on part d'une roto-translation dans l'espace 3D, une alternative rationelle à la matrice classique de rotation est la matrice de Rodriguez :

$$\mathbf{R} = (\mathbf{I} - \mathbf{S})^{-1}(\mathbf{I} + \mathbf{S}) \tag{1.14}$$

Où **I** est la matrice identité de dimension 3x3, et **S** est la matrice antisymétrique définie ici :

$$\mathbf{S} = \begin{vmatrix} 0 & c & -b \\ -c & 0 & a \\ b & -a & 0 \end{vmatrix} \tag{1.15}$$

La matrice antisymétrique **S** permet de trouver l'exacte solution du problème d'orientation absolue, grâce à la solution d'un système linéaire, après une substitution adéquate de variables.

On part de l'équation de la conventionnelle roto-translation dans l'espace, avec une variation d'échelle λ, et on calcule l'espérance mathématique, pour pouvoir éliminer le vecteur de translation **t**:

$$\begin{array}{c} \mathbf{y}_i = \lambda \mathbf{R}\mathbf{x}_i + \mathbf{t} \\ \mathbf{y} = \lambda \mathbf{R}\overline{\mathbf{x}} + \mathbf{t} \\ \hline \mathbf{y}_i - \overline{\mathbf{y}} = \lambda \mathbf{R}(\mathbf{x}_i - \overline{\mathbf{x}}) \end{array} \tag{1.16}$$

De plus il est possible de calculer à la fin la valeur du vecteur **t** avec la expression suivante :

$$\mathbf{t} = \overline{\mathbf{y}} - \lambda \mathbf{R}\overline{\mathbf{x}} \tag{1.17}$$

On élève au carré la deuxième expression de l'équation 1.16, et on trouve une expression facile pour calculer le facteur d'échelle:

$$\mathbf{y}^T\mathbf{y} = \lambda^2 \mathbf{x}^T \mathbf{R}^T \mathbf{R}\mathbf{x} = \lambda^2 \mathbf{x}^T \mathbf{x} \quad \Rightarrow \quad \lambda = \sqrt{\frac{\mathbf{y}^T\mathbf{y}}{\mathbf{x}^T\mathbf{x}}} \tag{1.18}$$

Après une simple substitution, on obtient une solution linéaire, qui nous montre une proportion directe entre les coordonnées du modèle $\mathbf{x} = \mathbf{x}(u^0, \mathrm{v}^0, \mathrm{w}^0)$ et celles de l'objet $\mathbf{y} = \mathbf{y}(X, Y, Z)$:

$$\mathbf{y}_i = \mathbf{R}\mathbf{x}_i = (\mathbf{I} - \mathbf{S})^{-1}(\mathbf{I} + \mathbf{S})\mathbf{x}_i \quad \Rightarrow \quad (\mathbf{I} - \mathbf{S})\mathbf{y}_i = (\mathbf{I} + \mathbf{S})\mathbf{x}_i \tag{1.19}$$

$$\begin{vmatrix} 1 & -c_j & b_j \\ c_j & 1 & -a_j \\ -b_j & a_j & 1 \end{vmatrix} \begin{vmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{vmatrix}_i = \begin{vmatrix} 1 & c_j & -b_j \\ -c_j & 1 & a_j \\ b_j & -a_j & 1 \end{vmatrix} \begin{vmatrix} u^\circ \\ v^\circ \\ w^\circ \end{vmatrix}_{ij} \tag{1.20}$$

Si on réorganise les matrices et les vecteurs, pour obtenir dans un seul vecteur les paramètres inconnus de la matrice antisymétrique, on obtient l'équation finale suivante :

$$\begin{vmatrix} 0 & (\hat{Z}_i - w^\circ_{ij}) & -(\hat{Y}_i - v^\circ_{ij}) \\ -(\hat{Z}_i - w^\circ_{ij}) & 0 & -(\hat{X}_i - u^\circ_{ij}) \\ (\hat{Y}_i - v^\circ_{ij}) & -(\hat{X}_i - u^\circ_{ij}) & 0 \end{vmatrix} \begin{vmatrix} \hat{a}_j \\ \hat{b}_j \\ \hat{c}_j \end{vmatrix} + \begin{vmatrix} \hat{X}_i - u^\circ_{ij} \\ \hat{Y}_i - v^\circ_{ij} \\ \hat{Z}_i - w^\circ_{ij} \end{vmatrix} = 0 \tag{1.21}$$

Il faut noter que dans la procédure d'orientation absolue, la reconstruction de l'objet n'a pas besoin de valeurs approximées initiales, parce qu'on arrive à la solution exacte grâce à la résolution d'un système linéaire.

Si on travaille avec deux blocs en deux systèmes de référence spéculaires, une comparaison qualitative avec les coordonnés de l'objet sélectionne automatiquement la configuration congruente. Une transformation de roto-translation nous permet de comparer les coordonnées de l'objet avec celles du modèle, transforment les premières en les secondes. Cette transformation est calculable en manière linéaire et nous amène à une unique solution (Figure 1.6), qui nous permet de parcourir à l'envers le chemin suivi, enchaînant les choix corrects pendant les différentes étapes de la procédure et élimine les fausses alternatives possibles.

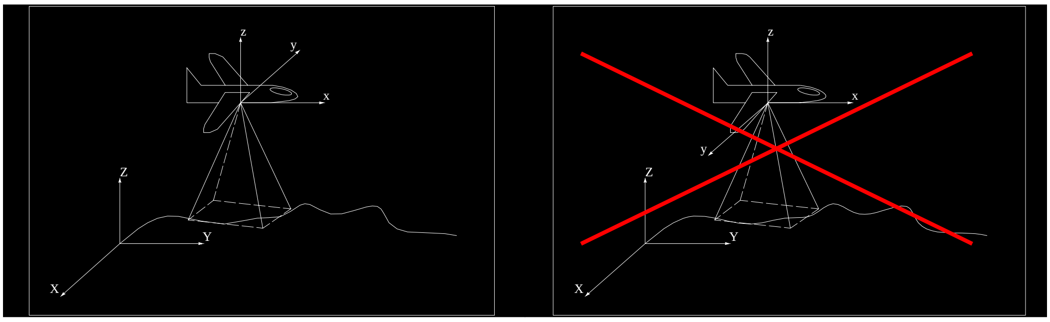


Figure 1.6. Le deux blocs obtenu après la concaténation des modèles (le deuxième est incohérent)

1.3.5. Simulation

L'entière procédure a été simulée pour vérifier son incertitude, précision et fiabilité. Nous avons développé un logiciel en langage Fortran 95. Les temps de calcul sont de 4-5 secondes pour la recherche exhaustive des paramètres d'orientation relative symétrique, et les calculs des autres procédures sont presque immédiats. Dans l'ensemble des simulations on a introduit une erreur de 20 μm, comme il est d'usage en photogrammétrie.

Evidemment, l'analyse avec de simples logiciels utilisant la procédure globale est plutôt lourde. On a besoin d'une longue accoutumance des outils qui nous ont permis d'acquérir les données, enregistrer et gérer les fichiers des données de sortie pour chaque pas de la procédure.

1.3.6. Conclusions de la Partie II

Cette méthodologie d'orientation présente de nombreux avantages pour les applications environnementales et de surveillance, et elle est un puissant instrument que l'on peut utiliser à côté de méthodologies plus traditionnelles. Cette méthodologie fonctionne automatiquement sans l'intervention interactive de l'utilisateur, qui doit seulement l'initialiser avec quelques paramètres, mais sans aucune valeur approchée des inconnues. Cette caractéristique fait que la procédure peut être utilisée également par des personnes non expertes en photogrammétrie. En conclusion on a développé une procédure originale pour l'orientation automatique de trois images.

PARTIE III. UN EXEMPLE EN PHOTOGRAMMETRIE ET DEVELOPPEMENTS FUTURS

1.4. UNE APPLICATION

Le système a été formé de trois webcams synchronisées disposées triangulairement ; il a permis de créer le relief sous différentes conditions de débit d'eau et de contraste de la surface d'eau (illumination transversale, morceaux de papier et de sciure). Nous avons modifié l'orientation des capteurs appliquant la procédure généralisée expliquée dans ma thèse, avons tracé le modèle numérique pour chaque séquence, et ensuite avons interprété la surface de l'eau avec une interpolation spatio-temporelle.

D'un point de vue informatique, nous avons proposé une description de données photogrammétriques basée sur le format XML pour les données géographiques. L'objectif est d'optimiser l'archivage et la gestion des données géomatiques. Le premier pas a été celui de faire un modèle conceptuel avec l'Editeur INTERLIS d'UML ; puis nous avons pu générer un Schéma GML du modèle tout entier. Avec ce modèle, il a été possible de décrire tout le processus photogrammétrique : acquisition d'images, représentation, et mosaïquage de données photogrammétriques. Ensuite nous avons développé un fichier XML/GML à partir du Schéma à l'aide d'un éditeur XML. XML m'a ainsi permis de construire un système interopérable pour les données qui proviennent d'un relief photogrammétrique. Grâce à la connaissance des métadonnées, il devient très facile d'obtenir des informations concernant les données et de les utiliser sans aucun contact ultérieur avec le producteur des données.

1.4.1. Le Model Hydraulique et ses problèmes

Le Laboratoire d'Hydraulique du Politecnico di Milano possède une variété de modèles hydrauliques 3D très intéressants. Pendant le développement de notre recherche photogrammétrique un modèle 3D d'une zone de confluence de trois torrents a été construit (Figure 1.9). Ce modèle-ci est très intéressant de par sa nature et ses dimensions ; la confluence de torrents Val Lunga et Val Corta qui confluent dans le torrent Tartano est très intéressante pour étudier un phénomène typique de la région alpine dans le nord d'Italie (Figure 1.7 et Figure 1.8).

Le relief de ce modèle a été effectué après une évaluation attentive de la confluence des torrents (Figure 1.10), considérant le lit de la confluence, la surface d'eau et les modifications du lit par le charriage dans les différentes conditions de débit d'eau. Les figures suivantes représentent le modèle de la confluence de trois torrents.

Figure 1.7. Confluence de torrents en une Région Alpine de la Valtellina

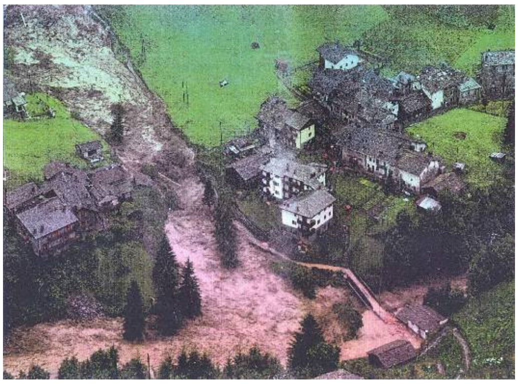


Figure 1.8. Zone de Confluence de torrents en une Région Alpine de la Valtellina (Exondation du 1987)

Figure 1.9. Vision d'ensable du modèle hydraulique 3D de la confluence des torrents

Figure 1.10. Modèle hydraulique de la zone de confluence

Notre but a été de produire un relief statique et un relief dynamique pour la réalisation des modèles numériques temporels de la surface de l'eau.

1.4.1.1. Modélisation

En 1987 la zone d'étude a été intéressée par une grande exondation (115 m^3/s, période de retour 100 ans), où un pont piéton a été complètement détruit et un autre situe après la confluence a été complètement submergé (Figure 1.11). Le but d'étude de ce modèle hydraulique est d'identifier les éléments critiques du système et d'évaluer le comportement hydraulique en conditions d'exondations, pour déterminer les zones vulnérables, leurs niveaux de risque et les mesures à adopter.

Figure 1.11. Exondation Critique du 1987

1.4.2. Le Relief

Le relief du modèle hydraulique a été exécuté en deux différentes étapes :

- relief du lit sans eau (relief statique) ;
- et relief de la surface d'eau (relief dynamique).

Le relief statique (Figure 1.12) a été déterminé avec une méthodologie classique de photogrammétrie terrestre, alors que dans une seconde étape nous avons réalisé le relief dynamique de la surface de l'eau (en mouvement) avec un système de trois vidéo-caméras numériques encadrent la zone de confluence.

Figure 1.12. Lit de la confluence des torrents.

Figure 1.13. Modèle hydraulique en condition de travail.

1.4.2.1. Relief Statique

Pour le relief statique sans débit d'eau on a utilisé une caméra numérique à haute résolution, une Nikon D100 du Politecnico di Milano. La caméra possède un objectif avec une longueur focale de 20 mm, une résolution de 3008x2000 pixels avec une dimension du pixel de 7.9 microns.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

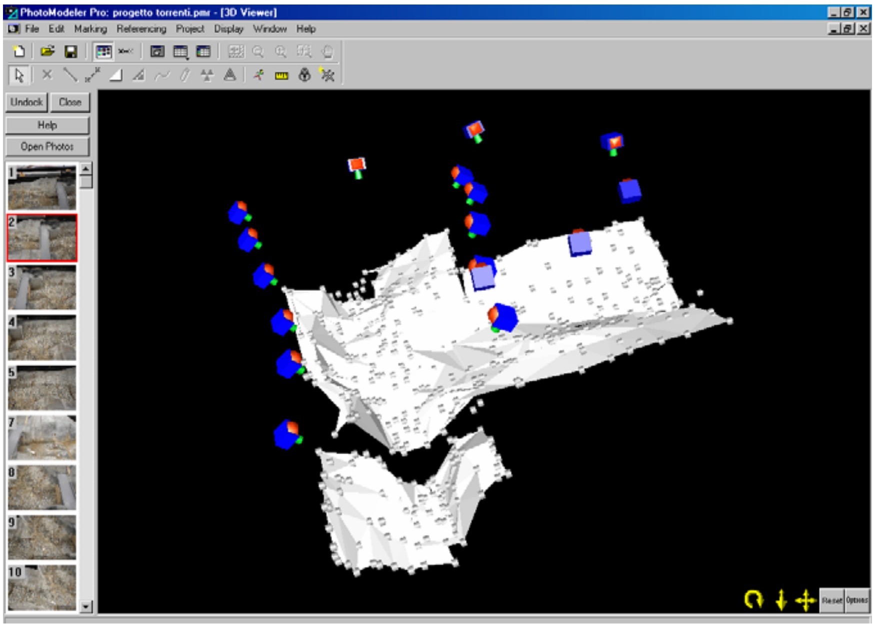


Figure 1.14. Modèle Numérique de la Surface du Modèle Hydraulique 3D (Relief Statique avec une Nikon D100)

Le relief a été déterminé comme un relief aérien avec toutes ses caractéristiques. Après l'acquisition des images, on a effectué l'orientation de point correspondant à l'aide d'un logiciel du commerce, obtenant une précision millimétrique en chaque direction (x=0.003 m, y=0.002 m, z=0.003 m). Ensuite on a construit le modèle numérique de la surface du modèlel hydraulique 3D sans débit d'eau. On a aussi relevé le réseau de contrôle, en géo-référentiant le modèle physique dans un cadre global.

1.4.2.2. Relief Dynamique

Le relief dynamique a été déterminé par l'intermédiaire d'un système de trois vidéo-cameras synchronisées à basse résolution. Ce système est la propriété du Homometrica Studio de Zurich (Ing. Nicola D'Apuzzo) et présente une configuration triangulaire (Figure 1.15). Les webcams ont une longueur focale de 4.8 mm et une résolution de 640x480 pixels avec une dimension du pixel de 5.6 microns. On a effectué le relief selon différentes conditions de débit d'eau. On a pris trois photos chaque seconde et on a filmé pendant 5 secondes, avec un total de 15 séquences (chacune étant composée par trois images synchronisées). Pour vérifier la stabilité du système de trois webcams on a effectué un relief de la zone de confluence sans débit d'eau avant et après la condition de travail du modèle hydraulique.

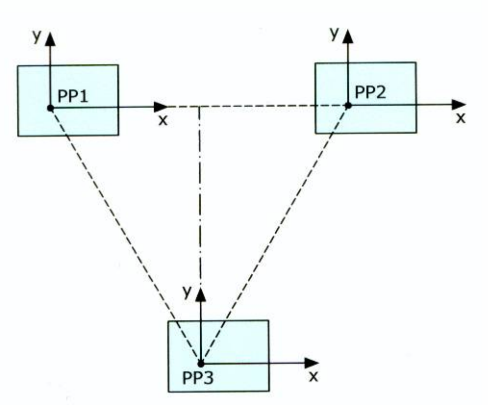


Figure 1.15. Configuration des les trois webcams

Pour améliorer le contraste de la surface d'eau on a utilisé des morceaux de papier et de la sciure (Figure 1.16 et Figure 1.17).

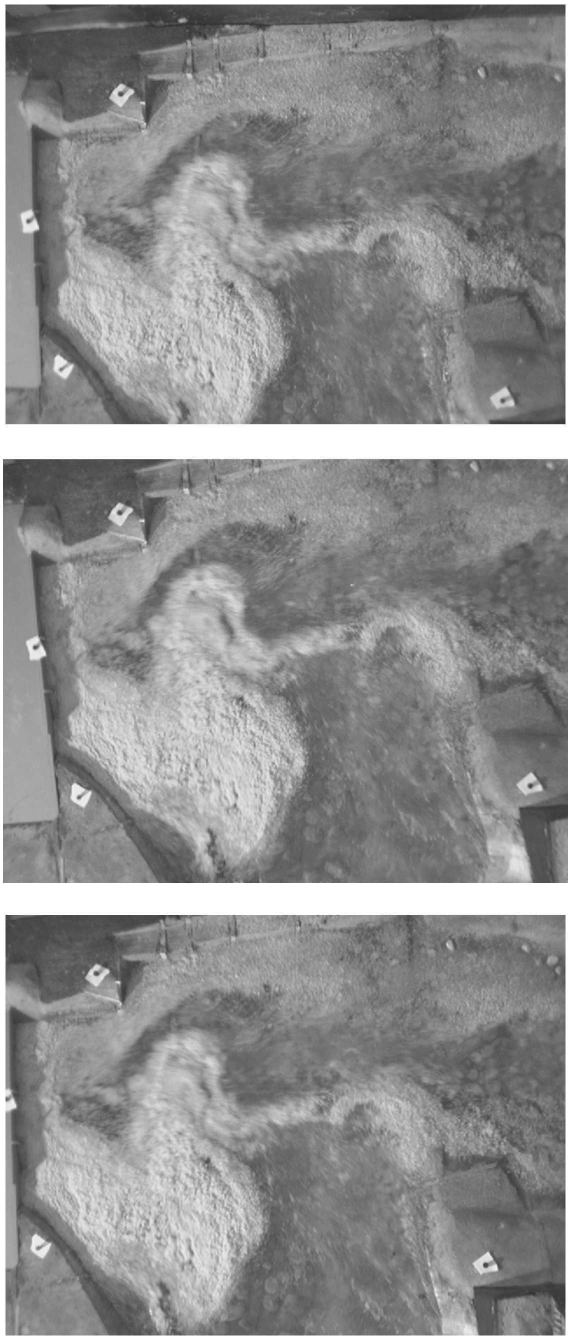


Figure 1.16. Séquences dynamique avec sciure

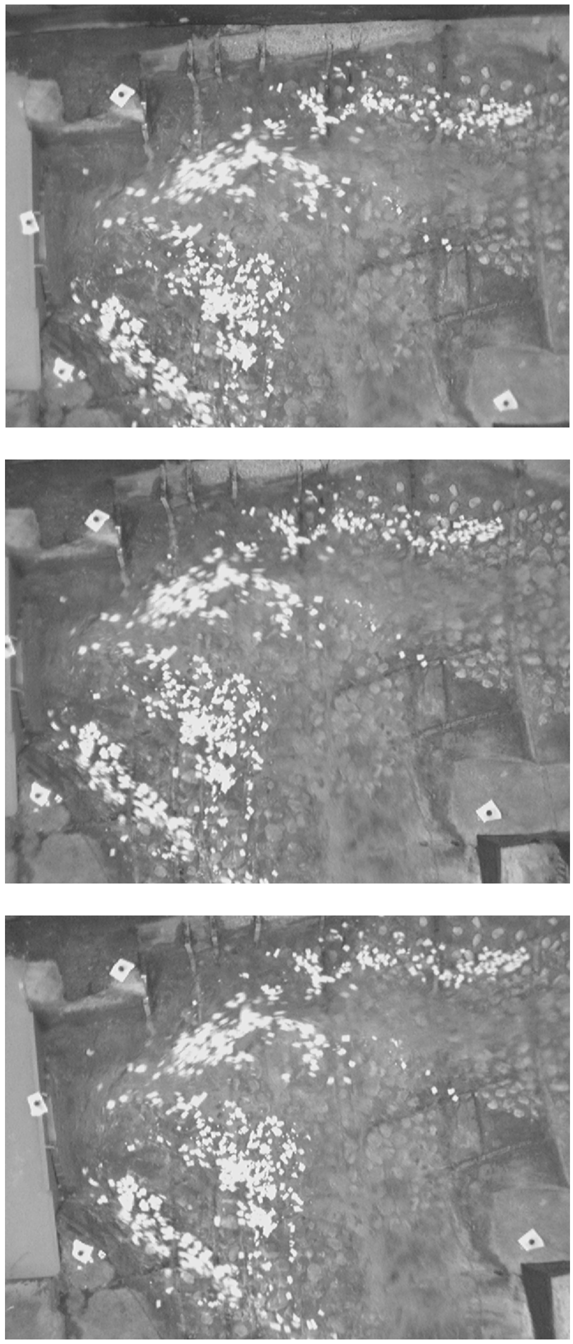


Figure 1.17. Séquences dynamique avec des morceaux de papier

1.4.2.3. Mise en Concordance et Compensation préliminaire

La mesure des coordonnées images des points (couple stéréoscopique) a été déterminée manuellement par un contrôle direct des mesures ; en fait le matching automatique fonctionne mieux avec les images avec la sciure mais les mêmes images sont trop homogènes par être distinguées par l'œil humain. Pour le développement futur de ce travail on recommande également une automatisation complète de cette étape de mesures des points sur le trois images.

Dans notre test on a choisi 8 séquences consécutives avec des morceaux de papier et en condition de crue. On a mesuré environ 400 points sur chaque image, avec un logiciel du commerce pour la photogrammétrie (Figure 1.18). Comme on peut le voir, les points mesurés ne sont pas distribués uniformément. Pour obtenir un plus résultat précis il faut faire appel à une stratégie différente afin d'opacifier la surface de l'eau. De toutes façons une mesure automatique de couples stéréoscopiques peut être une bonne solution. Avec les coordonnées des points images on a pu effectuer l'orientation des points correspondants avec la procédure développée pendant cette recherche et qui est décrite dans le paragraphe 1.3.

La calibration de la camera a été réalisée avec une méthodologie standard propriétaire du logiciel utilisé. Une calibration plus précise pourrait nous offrir de meilleurs résultats de compensation.

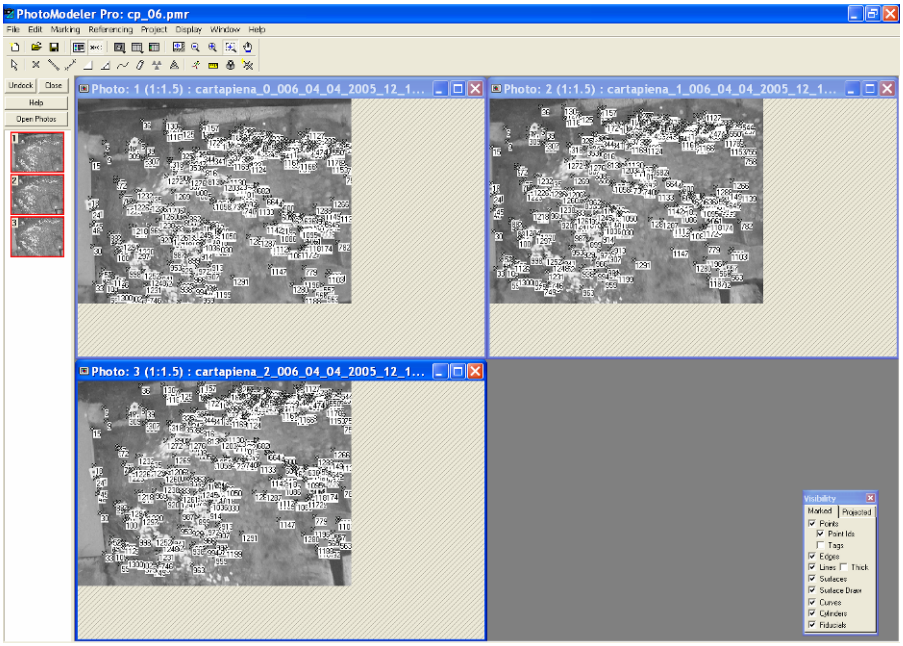


Figure 1.18. Match de points homologues avec un logiciel commercialisé d'orientation photogrammétrique

1.4.2.4. De la compensation à l'interpolation spatio-temporelle

Lors d'une deuxième étape on a exécuté la compensation qui nous calcule les paramètres non approximé pour obtenir les coordonnés compensés des points mesurés. Un logiciel, déjà existant CALGE, nous a permis aussi d'éliminer les erreurs dans les données.

Après la compensation on a un champ irrégulier de points (spot). La première chose qu'on a fait a été celle d'éliminer le point que n'appartient pas à la surface de l'eau (le point qu'on a utilisé préalablement pour la mise en concordance). Dans ce travail, à cause du petit nombre de points à éliminer on n'a pas automatisé la procédure, mais avec une simple intersection du modèle numérique de la surface avec le modèle statique effectué on pourrait automatiser et rendre plus rapide tout le processus.

Avec des techniques d'interpolation et approximation des données que l'on va expliquer plus loin, nous avons réalisé une grille régulière de points.

On a commencé par l'élévation de points en fonction de leur position sur le plan 2D (x, y). Nous avons considéré l'ensemble des données comme isotopiques, continues, normales et stationnaires d'ordre 2. Grâce à ces hypothèses initiales on a pu considérer la donnée avec une moyenne nulle, et calculer les fonctions de variance et covariance. On a opéré l'itération suivante :

- choisir un point, appelé pivot ;

- calculer la moyenne entre un certain nombre de points avec une distance prédéfinie (lag) ;
- calculer le produit entre cette moyenne et le pivot ;
- répéter la procédure pour tous les points et toutes les distances (lag).

Avec cette procédure on obtient la matrice de variance et covariance.

Les estimations empiriques n'ont pas la propriété d'être estimées positivement, car on doit interpoler avec un modèle approprié pour la propriété précédente. De cette façon, on applique un filtre, qui nous a permis de séparer le signal du bruit. Le filtre permet aussi de faire une prévision de l'élévation de points disposés selon une grille régulière, étape fondamentale pour une comparaison temporelle et les analyses statistiques relatives. Dans les Figures suivantes (Figure 1.19, Figure 1.20, Figure 1.21, Figure 1.22, Figure 1.23, Figure 1.24, Figure 1.25, Figure 1.26) il est possible voir les résultats de l'interpolation spatiale, on a fait le dessin de la surface 3D représentant l'eau selon les différentes séquences en grilles régulières. Il faut noter que dans les endroits où on n'a pas des informations le résultat sera pas fiable.

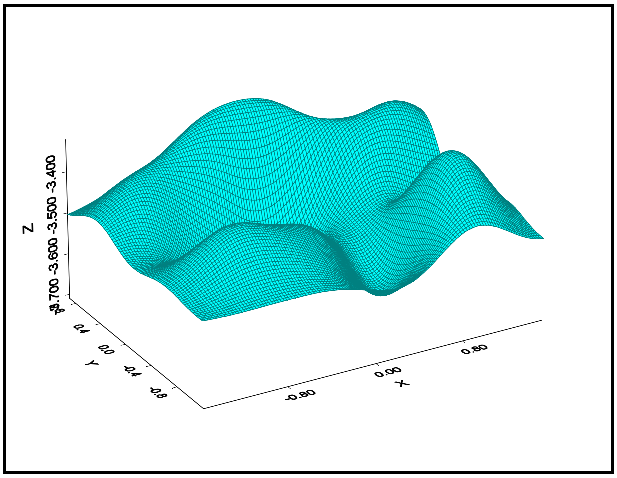


Figure 1.19. Données en grille – Séquence 06

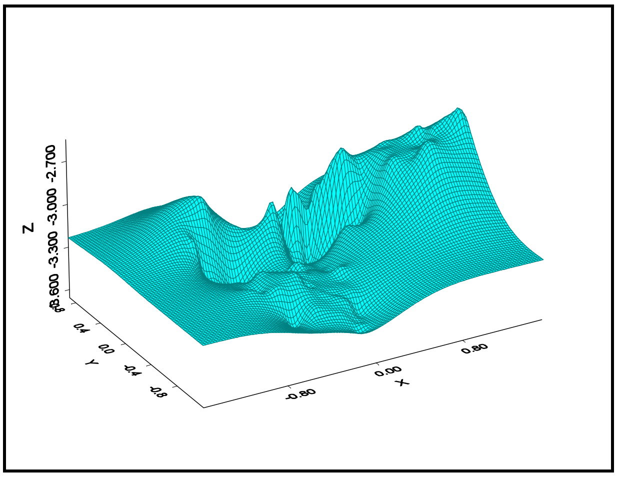


Figure 1.20. Données en grille – Séquence 07

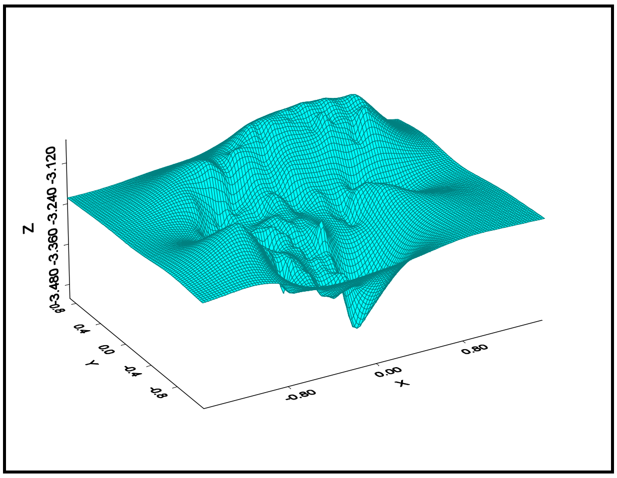


Figure 1.21. Données en grille – Séquence 08

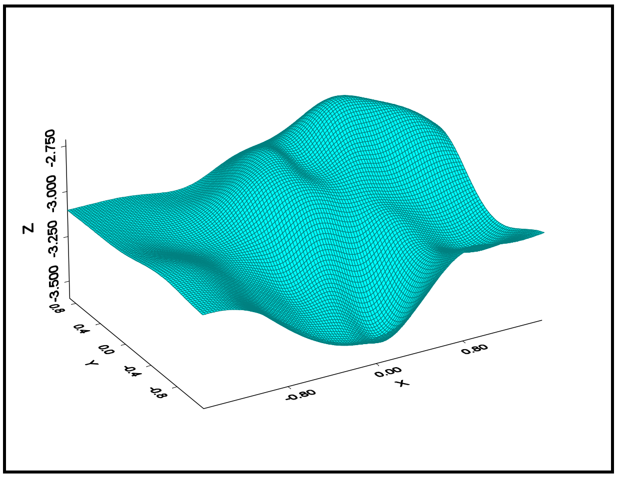


Figure 1.22. Données en grille – Séquence 09

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

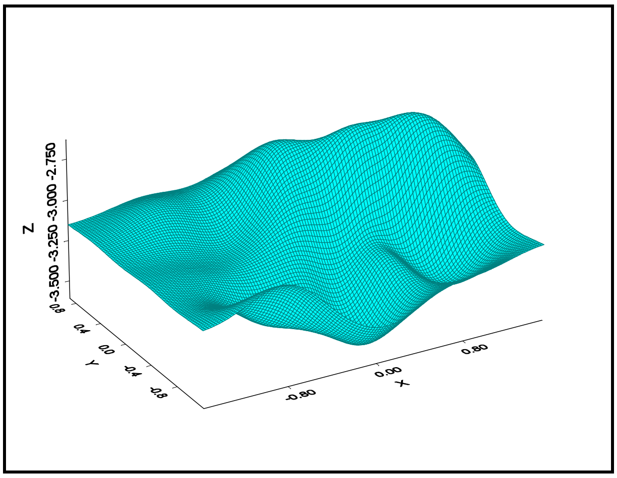


Figure 1.23. Données en grille – Séquence 10

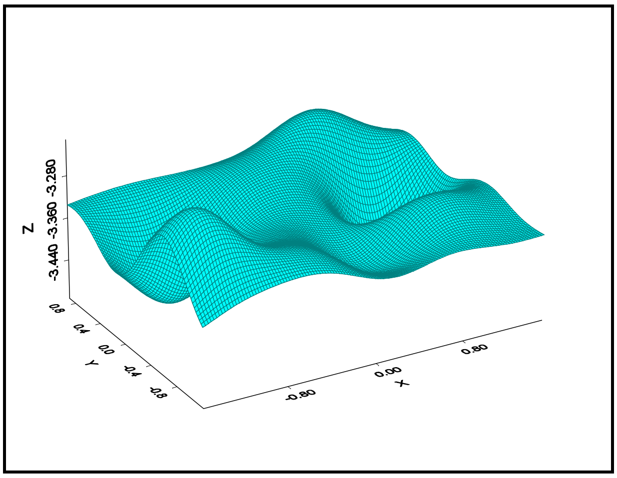


Figure 1.24. Données en grille – Séquence 11

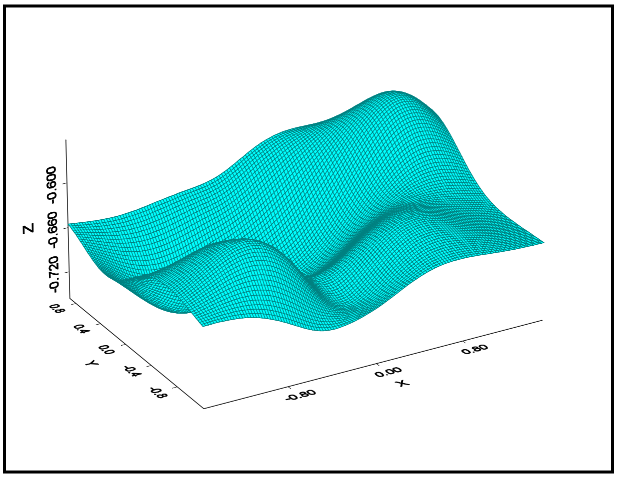


Figure 1.25. Données en grille – Séquence 12

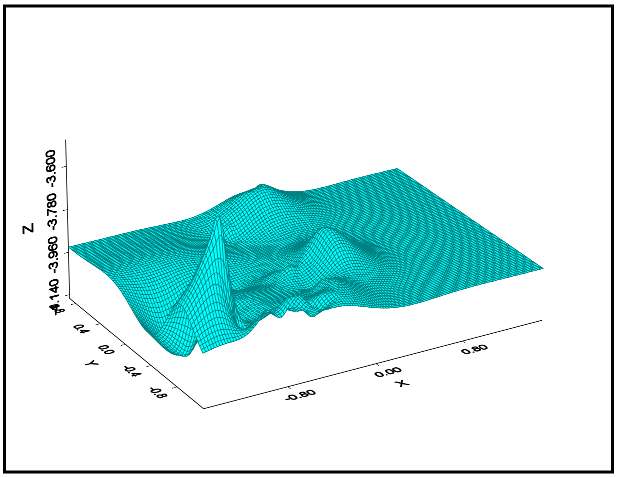
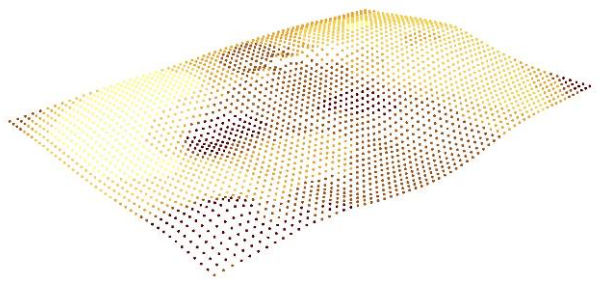


Figure 1.26. Données en grille – Séquence 13

En conséquence malgré le faible nombre des séquences analysées une comparaison temporelle n'est pas facile, en revanche on est capable de faire une analyse temporelle avec une régression linéaire pour détecter la dépendance temporelle.

En fait là où on trouve un coefficient de corrélation (en concordance avec les estimations de la régression linéaire) proche au zéro, une zone de turbulence est trouvée. En revanche là où le coefficient de corrélation est plutôt élevé, le comportement de l'eau est quasi-laminaire. Les données en grilles sont prises en considération séparément, considérant les huit séquences analysées. Dans la figure suivante on a représenté le modèle numérique de la surface de l'eau après une interpolation spatiale et une autre temporelle, on peut voir représenté les zones de turbulence en marron foncé et le zone de mouvement quasi-laminaire en jaune. Un clustérisation algébrique n'est pas présente.

On a remarqué une relation entre les zones de turbulence hydraulique, en correspondance de la confluence des torrents et les zones caractérisées par un bas coefficient de corrélation. Pour la même raison, on a trouvé une correspondance entre le zone de mouvement quasi-laminaire, à côté des bords des torrents, et un coefficient de corrélation plus élevé.



Légende:

-0.761000	-0.450000
-0.449999	-0.149999
-0.150000	0.150000
0.150001	0.450000
0.450001	0.716000

Figure 1.27. Interpolation spatio-temporelle de la Surface : Clusters du Coefficient de Corrélation

D'un point de vue hydraulique se pose la question de la manière comment le relief photogrammétrique et la surface numérique de l'eau correspondent au modèle hydraulique construit en laboratoire. Des mesures indépendantes et directes ont déterminé des différences en élévation entre 1 mètre et 1,2 mètre. On retrouve les mêmes mesures sur la surface numérique, la plus grande variation en hauteur rencontrée mesurant les huit séquences, est de 1.06 mètre, bien compris dans l'ordre de grandeur hydraulique.

1.4.3. Gestion des données photogramètriques

Aujourd'hui la quantité de données existant est très élevée, de même que les formats avec lesquels elles sont décrites. Car de nombreux comités, associations et consortia travaillent sur des projets de standardisation et sur les formats de transfert de données. Il existe de nombreuses solutions proposées selon des objectifs différents, mais durant les dernières années grâce à une stricte collaboration entre les différents sujets intéressés il semble qu'on va s'approcher d'une unique solution finale. L'organisation internationale de standards (ISO) [5] a opté pour un transfert basé sur les modèles, et elle propose comme formalisme graphique le langage unifié de modélisation (UML) [12]. Un langage associé qui peut être automatiquement interprété a été déjà prévu, mais ses caractéristiques ne sont pas encore définies. Une solution possible peut être le standard Suisse INTERLIS [4] ou une proposition similaire.

Pendant mon stage à l'ETH de Zurich, on a eu la possibilité d'étudier l'éditeur INTERLIS d'UML et on l'a utilisé pour la construction du modèle conceptuel des données photogrammètriques. XML [14] et GML [9] sont deux possibles standards utilisés par INTERLIS. Comme on travaille avec des données géographiques on a décidé d'utiliser le standard GML, qui possède des caractéristiques spécifiques pour ce type de données. Un autre caractéristique qui a nous fait décider pour INTERLIS 2 est la traduction automatique du modèle UML en Schéma GML, sans une traduction faite à la main qui a un grande probabilité d'être affectée par des erreurs. INTERLIS permet que les modèles de données soient écrits en différents langages. INTERLIS et UML sont donc deux langages complémentaires : les diagrammes en UML sont faciles pour une vision générale d'ensemble, et INTERLIS capture les détails pour une étude plus précise et plus appropriée. Les diagrammes des classes en UML, avec des outils spécifiques, peuvent être transformés automatiquement en langage INTERLIS (le contraire est aussi possible). INTERLIS nous offre les règles de conversion d'un modèle conceptuel en un format de transfert des données.

Le choix d'un format pour décrire les données devient dès lors d'intérêt secondaire : puisque les données à transférer sont basées sur le même modèle conceptuel leur conversion d'un format en un autre nécessite seulement un petit effort.

L'interopérabilité des données est très importante pour l'archivage et la gestion des données, car on a utilisé les techniques existantes pour la description de données géographiques. Lors notre recherche on a choisi une approche guidée par le modèle (MDA) qui nous a permis, après avoir modélisé les données avec le langage UML, de le traduire automatiquement en un schéma GML grâce à INTERLIS 2. Son automaticité permit la création des schémas avec la syntaxe XML également pour des personnes non expertes. Cette approche permet aussi un rapide processus de développement et permet de réutiliser le vocabulaire du modèle en différents langages ou environnements car le modèle n'est pas spécialisé au langage XML.

1.4.3.1. Modèle Conceptuel des Données

Comme dit précédemment, le premier pas d'une approche guidée par les modèles est la stabilité du modèle conceptuel qui soit le plus possible simple pour être compris et qui cache les détails d'implémentation. Avant que les données soient reformatées ou transférées ou traitées par un autre service, leur structure est décrite exactement à un niveau conceptuel d'indépendance du système et du format. Un langage graphique très diffusé pour la description de schéma conceptuel (CLS) est le langage de modélisation unifié (UML). Le modèle UML doit être définit comme un modèle des classes, où les classes sont les différents objets que l'on veut représenter.

Le premier passage de l'approche guidée par le modèle (qu'on a adoptée en cette phase de la recherche) est une description précise des données qu'on veut transférer selon un niveau conceptuel indépendant du système et du format. Le format de transfert peut être dérivé automatiquement du modèle conceptuel selon des règles par l'intermédiaire d'un compilateur. Après avoir vérifié la correction syntaxique du schéma conceptuel grâce à ce compilateur, avec ce dernier on peut déterminer le transfert des données correspondant (par exemple la description du format de transfert GML selon le langage du schéma GML). La codification d'un modèle UML en un schéma GML peut être effectuée de plusieurs façons, pour cette raison il est très important de fixer les règles de traduction et une stratégie de transformation, pour permettre le processus réversible et surtout l'unicité du schéma GML en partant du même modèle UML.

Un avantage fondamental de l'approche guidée par le modèle est la maintenance du modèle conceptuel de données ; ainsi si nous devons utiliser de nouvelles techniques d'implémentation, le modèle UML d'hier restera le même demain. Et aussi le même modèle UML peut être utilisé pour générer différents schémas XML et diverses représentations.

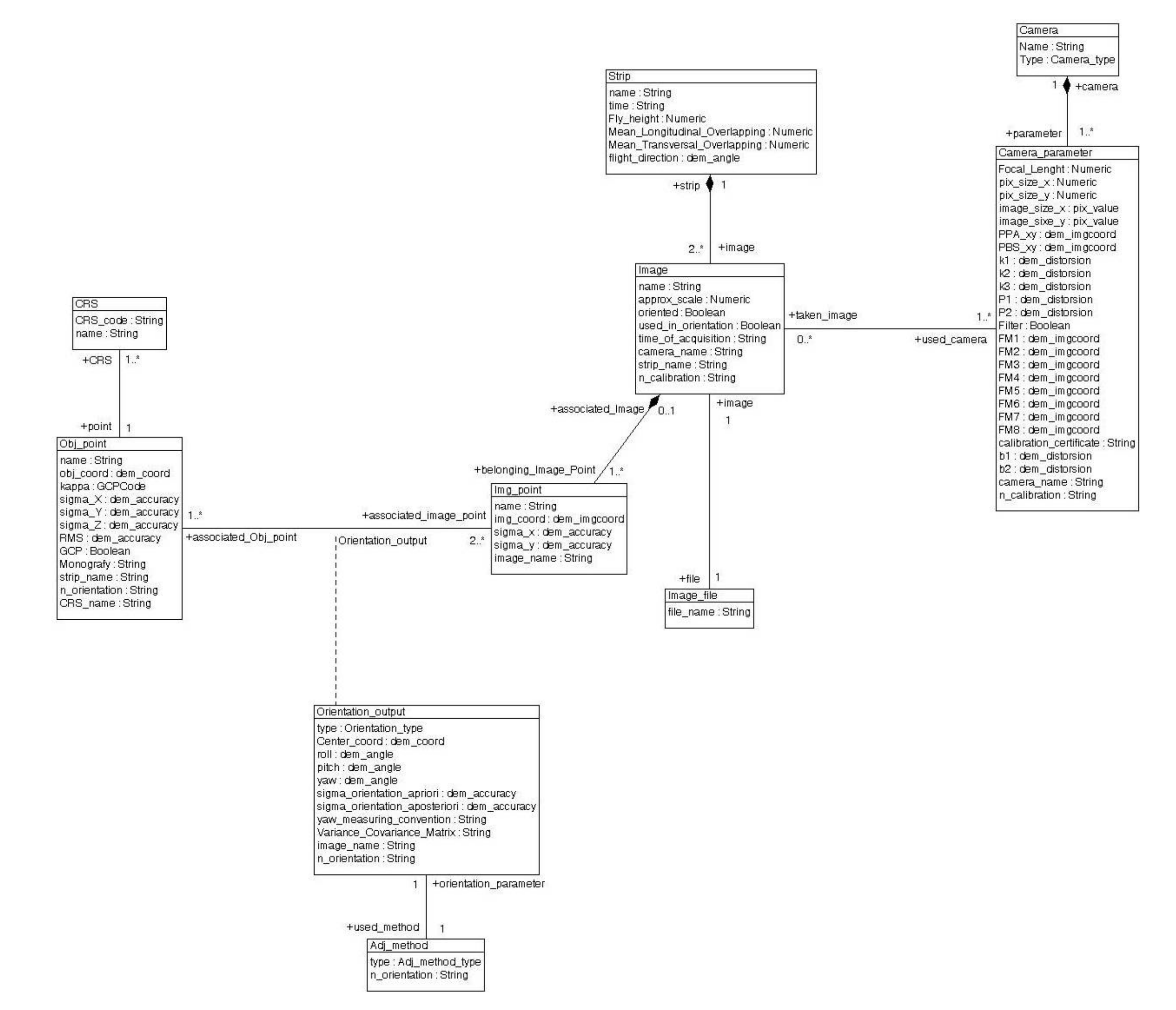


Figure 1.28. Modèle UML des données photogrammétriques

Nous avons construit le modèle conceptuel avec l'éditeur INTERLIS pour UML, où j'ai défini tous les objets de ma base de données comme des classes avec leurs attributs et les relations avec les autres objets (Figure 1.28).

Une description exacte des objets, des attributs et des contraintes permet une codification plus facile dans le format de transfert. Dans l'annexe C (en anglais) il est possible de visualiser la totalité du fichier INTERLIS correspondant au modèle UML de Figure 1.28.

1.4.3.2. Format de transmission généré automatiquement à partir du Modèle Conceptuel (GML Schéma et XML/GML fichier)

Comme il est possible de générer plusieurs schéma XML ou GML du même modèle UML, l'approche guidée par le modèle - ensemble à des règles de codification -, nous a permis de générer automatiquement le schéma GML correspondant, de pouvoir le régénérer plusieurs fois ou, plus simplement, de faire le parcours inverse. Le fichier qui décrit le schéma GML est visualisable dans l'annexe D (en anglais). Un schéma GML nécessite toujours un fichier correspondant GML (.xml) où sont contenues les données, pour pouvoir les visualiser. Le fichier GML (.xml) est un format de transfert et son interprétation n'est pas toujours immédiate. Ce passage d'écriture du fichier GML a été automatisé le plus possible grâce à de petits programmes en java qui nous ont aidée à l'écriture du fichier et le remplir avec nos données photogrammétriques. Cet effort a été très utile pour permettre des modifications futures ou pour développer la base de données. Ce fichier est consultable dans le CD qui accompagne ce travail.

1.4.4. Champs d'applications et applications futures

Cette recherche est inter-disciplinaire. Le relief photogrammétrique est très utilisé pour la surveillance de nombreux projets environnementaux. De plus une interopérabilité entre les données permet un échange et une communication plus faciles, ce qui nous offre de nouvelles frontières pour la gestion des données. Avec une base de données photogrammétriques exhaustive et interopérable, la procédure d'orientation de trois images peut être étendue pour être utilisée par des personnes non expertes en photogrammétrie.

1.4.5. Conclusions de la Partie III

Les stratégies les plus courantes souligne l'importance des modèles. Comment on l'a déjà présenté le long de ces chapitres le modèle conceptuel nous permet un développement et une mise à jour du système. Ces modèles conceptuells pouvant être interchangés pour faciliter l'interopérabilité des systèmes hétérogènes. De plus, l'approche guidée par le modèle favorise l'indépendance du modèle d'application entre la technologie et la plateforme d'implémentation.

Il est très important de mentionner que l'on n'a pas commencé à écrire la base de données directement en XML, ni on a écrit le fichier GML en partant des données géographiques, mais on a construit en premier le modèle conceptuel des données. Ce parcours nous nous a permis d'avoir une description des donnée cohérente et flexible devant les développements technologiques pour le transfert des données.

1.5. Conclusions

Après plus de trois années de recherche la réussite des objectifs qui nous ont été proposés, et les développements futurs sont très nombreux et variés.

L'automatisaton du processus photogrammétrique a été faite. Grâce à une procédure en deux pas pour l'orientation des images, à une recherche exhaustive des paramètres inconnus et à une linéarisation de la procédure d'orientation absolue, avec un triplet d'images on est capable d'exécuter l'orientation externe sans intervention humaine après l'introduction de quelques donnés d'entrée initiales. Le relief du modèle hydraulique est une application très importante. L'idée d'un relief dynamique nous a été suggèrée par des experts et l'intégration avec les résultats obtenus grâce à des méthodologies de relief de plus traditionnelles a nous permis de valider certains phénomènes hydrauliques attendus.

Encore un fois la modélisation des données photogrammétriques met en évidence beaucoup de questions liées à, la modélisation, au transfert et à l'interopérabilité des données. Un modèle pour la description des géo-données provenant d'un relief photogrammétrique a été fait.

Enfin :

- un logiciel original a été produit, qui permet de modéliser les terrains en utilisant la photogrammétrie à trois images ;
- une approche intégrée pour le traitement statistique des données qui va de la mise en concordance robuste à les techniques d'interpolation spatio-temporelles a été utilisé (on a utilisé des outils développés antérieurement dans le laboratoire de Milan)
- la description des géo-données dérivant du relief photogrammétrique ont été décrites avec le langage GML/XML pour une interopérabilité des donnés;
- le relief d'un modèle hydraulique a été effectué pour valider l'entière procédure.

Les possibles améliorations de cette thèse sont très variées, surtout pour l'ensemble des disciplines traitées. Très intéressants sont les problèmes de représentation et mosaïquage (étudié seulement d'un point de vue théorique) des géo-données, et des images, qui pourraient être inclus dans cette procédure et dans la description des données.

Concernent les géo-données, les développements possibles sont divers ; par exemple la création d'un outil pour le web pour le téléchargement des données en format XML est une très simple implémentation à la base des données déjà existante. Il est opportun de mentionner que l'importance de l'intégration de la base de données créée avec un SIG, où par exemple on peut obtenir des informations additionnelles sur le comportement hydraulique du modèle en étude ou aussi la chronologie des événements historiques. Une intégration avec une ontologie pourrait éviter les incohérences de langage et faciliter l'exploitation de cette base des données par diverses personnes.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

2. INTRODUCTION

This thesis deals with data processing in Geomatics. It ranges from data acquisition in Photogrammetry to data representation as well as done in Cartography. The natural frame of this thesis is a Ph. D. curriculum in the macro area Environment and Security, set up by the Interpolytechnic School among the TU's of Turin, Milan and Bari (Italy).

In this context, in my capacity of student of the XVIII cycle of the Ph. D. courses in Geodesy and Geomatics at the TU of Milan (by the Survey and Mapping Section of the DIIAR), I spent 18 months at INSA in Lyon (France), at LIRIS Laboratory (Laboratoire d'InfoRmatique en Image et Systèmes d'information) with the supervision of Professor Robert Laurini. This stage would have the aim to link two complementary disciplines (Geomatics and Computer Science) in a way that one takes advantage of the other and vice versa.

During the stage itself, Professor Laurini offered a chance to apply for a Ph. D. in France, by using some additional time, deeply going in the specifications, which link Geomatics and Computer Science.

After the conclusion of the Ph. D. Program both in Milan and Turin, a successive step will be a discussion in Lyon, where the referee team will be enlarged to a couple of French experts. Let me add, that an intermediate step was a stage at the IGP-ETHZ (in the Institut für Geodäsie und Photogrammetrie – Eidgenössische Technische Hochschule Zürich) with the supervision of Professor Alessandro Carosio.

On the other hand, the research itself is a stream, which began many years ago (before my arrival in the above mentioned section) which I had the honor to participate in and which will be surely continued by others after my departure. This is a modern conception of the scientific job, where common science and scientific revolution happen random.

Going back to the topics of this thesis, we studied an original procedure for the automatic orientation of three images. It is based on analytical photogrammetry and thanks to all the statistical techniques of data processing permits to create digital surface models starting from photogrammetric images.

According to the goals of the stage in Lyon, we worked to describe the data by the GML/XML format, with the aim to obtain a larger fruition of this procedure and to optimize the archiving and management of the continuous geo-data.

The application concerns the dynamic survey of a hydraulic model of stream confluence. In order to perform data analysis, specific software was written, implemented and tested according to the above mentioned procedures.

Notice that, according to a very long tradition in data analysis and processing at the Survey and Mapping section of the TU of Milan, a certain number of appendices, dealing with statistical data analysis and computational statistics, are added to this thesis. Their finalization is useful to complete the natural flow of the thesis' content, well characterizes the wish to treat data and quality metadata, using continuous fields (terrains and photogrammetry) as an example.

2.1. LITERATURE REVIEW

2.1.1. Photogrammetry

2.1.1.1. Orientation procedures in photogrammetry

Orientation procedures play a fundamental role in the object reconstruction process of photogrammetry. Traditionally, the call for stereo-vision leaded to setup a geometric solution based on interior and relative orientations, which are the pre-requisite for any further task to extract information from a pair of images. The former refers to the determination of 3 intrinsic parameters (principal distance and coordinates of principal point in the camera reference system), the latter to the computation of the baseline vector linking two perspective centers and relative rotation of one image with respect to the other; the number of unknown parameters adds up to 5, which usually follows one of two geometric model, namely the symmetric and asymmetric one. By introducing the knowledge of ground information (e.g. Ground Control Points) the absolute orientation can be computed and the model computed from relative orientation can be transformed into the real world, or to a scaled representation of topographic map. Research on this topic has been attracting the interest of photogrammetrists in the first mid of 20th century [122], [123], [124].

From the 50's to 70's, mathematical fundamentals of analytical photogrammetry were established. New formulations of two-image orientation were published [178], [186], [180], while the unexplored field of aerial triangulation began to be dealt with [167], [168], [80], [96].

Two topic aspects have to be focused concerning orientation procedures in photogrammetry up the so called "analytical era":

- the use of analogue imagery and of purely manual measurement for orientation purposes, resulting in the use of a small set of accurate points for computing relative and absolute orientation; this fact limits the problem of blunders to a small number of gross errors (due to wrong labelling, image content misunderstanding and the like) and to a low fraction of small errors.
- orientation problems such as formulated in photogrammetry are non-linear and they are usually solved by a Least Squares approach, after a linearization of equations. In this way, L.S. adjustments can run automatically and more refined treatments (e.g. robust procedures and re-weighted L.S.) can be performed, step by step, always solving linear systems. It is obvious that all methods can start only if the preliminary values of the unknown parameters are known. Aerial blocks feature regular shapes, so that approximations may be easily derived, because the project for data acquisition defines these parameters with a sufficient accuracy, or auxiliary measurements are available at the time of data acquisition. But also close-range blocks, up to 70's show configurations, which are very similar to those of aerial photogrammetry, offering the same possibility to solve for approximations.

These statements will result fundamental to comprehend the changes introduced in photogrammetric orientation approaches in the following decades.

Since the 80's a new challenge defied the community of photogrammetrists, given by the possibility of managing and processing digital images by computers. Whether the concept of a totally digital stereo-plotter [161] became in few years a reality, on the other hand automation of all analytical orientation procedures was the topic research issue up to the end of 1900 (for a review see [122]).

2.1.1.2. Photogrammetry meets Machine Vision

The development of *digital photogrammetry* is parallel to that of *machine* and *robot vision* techniques [123], [167]. Here the problem of object reconstruction is needed for specialized and real-time purposes, such as object recognition, production and quality control, vehicle and robot guidance an so on, not for deriving cartography of however a wider description of the space. This fact limits the number of digital sensors to be used to the minimum: in case of objects lying in a plane, a single image, in case of 3D object a two-image configuration will be adopted, tuning the interest on relative orientation procedure. For this reason, many algorithms have been developed to cope with this task, taking into account the possibility of solving for any geometric configuration (no approximation needed) and the use of uncalibrated sensors (cameras and video-cameras). Thus linear methods to solve for relative orientation[5] based on the *essential matrix* [96] and on the *fundamental matrix* [80], algorithms integrating self camera calibration [68], applications to motion vision [163] and estimation techniques different for classical L.S. have been introduced. A review on this subject can be found in [37].

The impact of these solutions to photogrammetry was twofold:

- solution to the problem of approximations, which are found by applying linear methods and then refined by standard photogrammetric equations; in this case derivation of geometry from algebraic parameters is needed [98], [123].
- preliminary gross outlier rejection, integrating high break-down robust techniques [188].

Several matching techniques were developed to find homologous points and features [80]. While in photogrammetry orientation equations are prevalently point-based, machine vision techniques also exploit other kinds of constraints, such as lines, surfaces and angles.

Nevertheless object reconstruction from a pair of images suffers from low redundancy, being the control on the extracting of homologous point by matching techniques limited to epipolar constraints. To overcome this drawback, a formulation of the relative orientation of a triplet of images has been established through the so called trifocal tensor (also referred to as trilinear tensor), introducing a higher redundancy [180],[124][6]. A review can be found in [161]. Application of trifocal tensor to solve approximations in standard orientation procedures (relative orientation, AT) is very useful, because it allows to deal effectively with large fraction of blunders, such those resulting from automatic extraction of tie points by matching techniques. However as in case of relative orientation, derivation of geometric parameters must be computed.

2.1.1.3. Image Triplets

Three images increase the reliability of the matching process. This idea was already used in photogrammertic community, knowing the camera orientation parameters [150]. If the camera parameters are not explicitly known, it is still possible to derive the epipolar

[5] In reality [184], coming from photogrammetry, already proposed a linear method for relative orientation which was similar to [150].

[6] Also in this case (see note 5), formulation of the dependency among three images was already published in photogrammetry [162].

geometry between three views using only point correspondences. A linear representation for the relative orientation of three views is represented by the trifocal tensor T.

The Trifocal Tensor was fully described in *Multiple View Geometry* by Hartley and Zisserman in 2000 [37] from an analytic point of view.

Another possible solution for the photogrammetric orientation of images is with quaternioni algebra [235], and for the absolute orientation it is also possible the application of the anblock method.

2.1.2. Geo-data

2.1.2.1. Geo-data Exchange: Transfer and Interoperability

In the last years one of the most significant needs is the exchange of geo-data, in fact nowadays an increasing number of organizations around the world works with geographic data, and the risk of inconsistencies and duplicated data is higher and higher. Furthermore the cost of data acquisition is the main investment in the creation of a database, so it would be advantageous to be able to use the existing collected data.

Often already existing data could not be used because they are incompatible with the required system or because a correct documentation is missing. While a proper description of collected data is easier to obtain, a solution for a global standard is really difficult to be found, because the requirements and the needs are so different from user to user.

To create interoperability among different systems there are different solutions:

- data transfer (data exchange among equal systems, data exchange with standard formats, based model data transfer method);
- interoperability (defined by the Open Geospatial Consortium [9], before known as Open GIS Consortium).

The complexity of communication among Geographic Information Systems obliges to integrate different solutions for the interoperability among them, furthermore for the multiplicity of the requests and of the already existing systems and database.

Moreover the on-line exchange of geographic information is widespread in every domain, requiring interoperability among data and a declaration of the data transfer method, more than a standard language. The use of model based method instead of fixed format is desired, working with different structures of data. The International Organization for Standardizations (ISO) research in this direction. ISO defines the following points:

- the data transfer method is adopted as a standard;
- UML must be the graphic formalism for the data structure description;
- a language, whose interpretation and reading could be automatic, is provided. Its properties are described and fixed, but any further decision was not done.

Another interesting solution for data exchange is the data communication without a real transfer of data. It became easier to standardize requests and answers than the database itself. With the foundation of the OGC (Open Geospatial Consortium) in 1994, the participation of some leader enterprises (ESRI, Intergraph, Siemens, Oracle, Microsoft, etc.), the collaboration with universities and research centers and a strictly collaboration with the International Organization for Standardizations (ISO), a research in that direction began.

Interoperability means right these concepts, and permits it contemporary use of different GIS without the need of data transfer. And also means the possibility of communication without the exchange of the original data.

The advantages of interoperability are:

- the communicating systems could be based on really different managing concepts;
- the system which makes the request doesn't need any information about the organization which gives the answer;
- the systems transfer only a part of the data, protecting the copyright of the whole database.

For these reasons system interoperability seems to be the right way to follow for data exchange.

Concerning the creation of a model for photogrammetric data, the work was a little bit difficult because there are not too many operative examples for this kind of data. At the moment all the councils and organization (ISO [5], CEN [1], OGC [8], etc) are working hard for giving specifications for this kind of data. Their main idea is to give instructions to all the users that need to generate a really interoperable database for the geographic data. The aim of these workgroups is to uniform, in a way, the description of the geodata that are becoming more and more widespread to all the different levels of use. In fact with the introduction of freeware and open source software for map navigation and GIS, every person could access to geo-data and use them.

In conclusion the communication among information systems is still a really various and complex task, and many different solutions are possible. The actual methods will develop in the further years and different methods will impose themselves as standards.

2.1.3. XML for Geographic Data

This research focuses its attention on the description of photogrammetric data. We looked for already existing languages for their description and their exchange. As already said the interest to archive photogrammetric data in a common format is more and more present. The aim is to reduce as much as possible the redundancy of information, and to give a fast and easy access to photogrammetric data also for not experts in photogrammetry. A common standard seems to be the direction to follow for the specification of a structured document in photogrammetry to use over the web. During these years many working groups investigated and developed XML formats and extended it for different applications for data coming from photogrammetry. Among different projects and interesting one is the ARPENTEUR [73] web based tool. ARPENTEUR is a simple photogrammetric tool devoted to architectural report; it is a software for education and research. Being a web tool, it has the main advantage to be the same for all the clients that access to the website and use it for the photogrammetric orientation. In this way it is able to collect all the concerned and useful photogrammetric data in the common standard XML.

Another interesting project is SensorML [10]. It is an Open Geospatial Consortium standard markup language (using XML schema) for providing descriptions of sensor systems. By design it supports a wide range of sensors, including both dynamic and stationary platforms and both in-situ and remote sensors. It provides standard models and an XML encoding for describing any process, including the process of measurement by sensors and instructions for deriving higher-level information from observations. This standard enables to have much information about the used sensors. All the collected data and metadata about them could be shared among the users. This is obviously a great advantage and a useful plug in for many photogrammetric applications.

With our research we investigated in the direction of the automatic orientation of three images, and taking into account all the existing possibilities we stored our data with a standard language for geographic data (the Geographic Markup Language [9]). It is also possible and wishable to integrate of our data with other existing data models such as the sensor model (described with SensorML) and also to integrate with the existing reference system databases.

2.2. Objective and Contribution

One of the major goals in photogrammetry research and development is the automation of the modeling process. The purpose of this work is to give an accurate, automatic and low cost procedure to survey and model dynamic surfaces in space and time evolution. A software has been developed for the automatic orientation of three simultaneous images without a priori knowledge of preliminary values of the unknown parameters. Thanks to the independence from these a priori data the process could be easily adapted to images coming from untraditional or unknown sources.

In literature already some analogous procedures exist (see paragraph 2.1.1.3), but this one has the main advantage to be completely automatic after some initial input.

This feature, combined with the automatic orientation process, allows this method to be easily employed also by users not skilled in photogrammetry.

Our contribution was also the test of this process with the survey of a hydraulic model of stream confluence. This application permitted the better emphasis the procedure advantages.

Sensor orientation has been performed by using the generalized procedure proposed along the thesis. The successive step has been the physical plotting of DSM (Digital Surface Model) for every sequence, and the spatio-temporal interpretation of the water surface dynamics. In this way we gave a really powerful tool to hydraulic experts and to all the researchers interested in surveying using photogrammetry techniques. Hydraulic experts could study the behavior of the water surface in critical zones as stream confluence areas are with this accurate technique.

Thanks to a co-tutoring agreement with LIRIS Laboratory at INSA de Lyon, this work has been enriched with a database model in GML/XML language for the description of geo-data. The aim was the creation of an interoperable mean for geo-data coming from photogrammetric survey, answering to the actual needs of interoperability among data coming from different sources. Thanks to the knowledge of all the concerned metadata it becomes really easy to have information about the data and use them without a further contact with the data producers.

The main goal was to unify and merge the knowledge of two disciplines, so different but so complementary. The interoperable geo-data modeling is still in evolution, especially concerning the object relations, for that reason photogrammetrists do not use yet all the advantages of interoperable database, such as GML/XML language. Our aim in that field was the creation of a photogrammetric data model that could be taken as starting point for further and more sophisticated models.

Our personal contributions to goal achievement were:

- The development of a new software product for the automatic orientation of three simultaneous images for non–conventional photogrammetry;
- The creation of an integrated approach for the dynamic scene modelling and the spatio-temporal analysis of the geo-data;
- The construction of a post-analysis process for a quality solution studying;
- The investigation of the existing model for geo-data description and formulate a specific one for continuous data coming from photogrammetric survey;
- The survey of a hydraulic model to test the whole procedure.

Concerning the scientific progress, our main contribution is to have given an easy and quality tool for photogrammetric survey. Environmental surveying and monitoring were always based on photogrammetric techniques, but they were always used by photogrammetric experts. Our contribution was to have created an easy and accurate procedure for time depending survey.

We also gave an improvement in the description, archive and management of geo-data, with the creation of a model in GML/XML language, useful as starting point for more sophisticated and accurate photogrammetric database.

2.3. Overview and Organization

After this introduction the thesis is subdivided in three main parts. Part I deals with the description of the geo-data and included the chapter 3 which briefly reports standardization of the geographic information and the problems of interoperability among data. It also points out some important problems in the metadata definition for a quality database.

Part II presents the data acquisition, and more specifically in chapter 4 reports some fundaments of projective geometry and analytic photogrammetry, as necessary for the dissertation. The same chapter explains the automatic model formation and object reconstruction process, on which the developed software was based. In the end of the chapter the whole description of the orientation procedure was presented.

Part III deals with a photogrammetric example done to test the presented procedure. Chapter 5 well explains both the photogrammetric method applied and the geo-data description for a database creation.

Chapter 6 reports the conclusion and a possible further development of this work.

Some appendixes conclude the dissertation. The first two appendixes illustrate the INTERLIS file and the GML Schema. An enclosed CD contains twelve additional Appendixes, which help the reader to follow the whole path of this thesis, explaining several details, skipped in the main text, because the author focuses on her personal contributions. On the other hand the whole path is quite important in order to understand how the personal contribution is relevant in the scientific and technological knowledge growth of survey and mapping disciplines.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

Part I. The Geo-Data

3. GEO-INFORMATION CONCEPTS

This chapter presents an overview of the stat-of-the-art in geo-information systems and motivates and introduces the concept of interoperability for the geo-information. We start by introducing the possible standards for the geographic data and some criteria for an appropriate choice, then we describe the model-driven approach (MDA) as a good solution to geographic information transfer, and finally we pass to a short description of metadata and their standards.

3.1. GEOGRAPHIC DATA AND INTEROPERABILITY

In our work we started from geographic data coming from photogrammetric survey and to generate digital surface models either static or dynamic. Some geographic data are continuous ones, and their codification has to consider all the process that brings to the reconstruction of their continuity. Geographic data are also very different among them; in fact nowadays there are a large amount of devices for surveying the territory that make more difficult having data standard formats. For these reasons it is very important to pay attention in the storage process, in the model transfer and in the standard used for that purpose. Moreover it is necessary to know and define quality data and metadata (see paragraph 3.5.1).

Many times there is the problem of using existing data, and these ones are incompatible with the required system. Anyway a solution for a global standard is really difficult to be found, primarily because each user has its own requirements and needs.

In ISO 2382-1 (International Organization for Standardizations) we found the following definition for interoperability:

"Interoperability is the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units".

A data transfer method has to be adaptable for a real interoperability. A model based transfer could be useful for the exchange between different software, local or regional extensions and for the mutations through the time (products and technology). For a model based transfer we need:

- a standard language for conceptual description of data, defining univocally and consistently the data structure to transfer;
- a procedure to obtain the transfer standard of data structure.

A widespread standard for geographic data structure is GML, based on XML grammar [22].

For that reason in the following paragraphs we will briefly describe the XML language as a support for the comprehension of its GML extension, and a quick overview on the standardization processes and organizations.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

3.2. Standardization of Geographic Information

3.2.1. Committees, Organizations and Consortia

In 1992 CEN TC 287 (Comité Européen de Normalisation) for the standardization of geographic information was born. This Technical Committee in 1999 finishes the draft of some "experimental standards" for geographic information (ENV).

The International Organization for Standardization (ISO) was born in 1994 from a strict collaboration among different partners who use standards in data exchange. At that moment ISO/TC 211 and CEN/TC 287 reached an agreement: CEN/TC 287 would have finished its work and would have helped define the work planning for ISO/TC211. The ENV standards have been recently substituted by the corresponding EN ISO.

In 1994 also another committee was born, the Open GIS Consortium (actually Open Geospatial Consortium). This Consortium is an association of enterprises, organizations and universities with the consensual goal of developing public interface specifications. OGC is principally financed by its adherents and by the rights and shares. OpenGIS® is a protected mark of OGC, Inc. and it is used as a name for specifications and documents published by OGC.

OGC and ISO/TC 211 have an agreement to sustain the technical alignment of their respective developments. This is accomplished through mutual review and development of draft documents. OGC adopt ISO standards and implements them. When OGC specification meets certain requirements, ISO will adopt it as an ISO specification [22].

3.2.2. ISO norms for Data Transfer: actual status

Standards are strictly needed for a real interoperability among a data infrastructure. In the following table we try to resume all the norms related to interoperability and geo-data description. Some of them are still a working draft, this is due to their complexity.

Norm	Title	Status	Description
OMG UML	Unified Modeling Language	Different versions. 191xxx are based on UML 1.3	Class diagrams
ISO 19103	Conceptual Schema Language	DTS	UML restrictions + basic data type (text, numbers, etc.)
ISO 19109	Rules for application schema	DIS	Metamodel (=modeling language). Confused because UML and 19103 define the model language
ISO 19107	Spatial Schema	IS	Geometric data type (topology included)
ISO 19108	Temporal Schema	IS	Temporal data type (topology included)
ISO 19111	Spatial Referencing by coordinates	IS	Data model for spatial reference system for coordinates
ISO 19112	Spatial referencing by geographic identifiers	IS	Data model for geographic names
ISO 19123	Schema for coverage	DIS	Data model - Coverage

	geometry and functions		
ISO 19115	Metadata	IS	Data model for Metadata
ISO 19118	Encoding	DIS	Codification rules for data transfer. Must be univoque and complete for interoperability
W3C XML	XML	1.0 (rarely 1.1)	Flexible text format
W3C XML-Schema	XML-Schema	1.0	Description language for XML data
ISO 19136	Geography Markup Language	IS (GML 3.2)	Common specification of OGC and ISO for data transfer

Table 3.1. ISO Norms (WD: Working Daft; CD: Committee Draft; DIS/DTS: Draft International Standard/Drat; Technical Specification; FDIS: Final Draft International Standards; IS: International Standard) from [22]

3.2.3. XML (eXtensible Markup Language) and its Extensions[7]

The Extensible Markup Language (XML) is a subset of SGML that is completely described in the recommendation document of the World Wide Web Consortium (W3C) [14]. Its goal is to enable generic SGML to be served, received, and processed on the Web in the way that is now possible with HTML. XML has been designed for ease of implementation and for interoperability with both SGML and HTML.

The design goals for XML are:

- XML shall be straightforwardly usable over the Internet;
- XML shall support a wide variety of applications;
- XML shall be compatible with SGML;
- it shall be easy to write programs which process XML documents;
- the number of optional features in XML is to be kept to the absolute minimum, ideally zero;
- XML documents should be human-legible and reasonably clear;
- the XML design should be prepared quickly;
- the design of XML shall be formal and concise;
- XML documents shall be easy to create;
- terseness in XML markup is of minimal importance.

XML has many advantages:

- it enable the independence of data from software and platforms;
- it is a modular language and it can be easily adapted;

[7] This paragraph is part of the XML specifications of the W3C and could be found at [14].

- it permits definition of new entities and attributes;
- it is the syntactic and grammatical base of other formats and it is very spread for the geographic data;
- it is associated to a robust protocol like http.

For these reasons XML is a powerful standard for geographic data. Even if it is not conceived for that purpose, it is a really good starting point for other more specific languages with more utilities for the geo-data. XML can be extended to territorial data, and needs to be extended for more complex applications. The main goal of these extensions is the on-line managing for vectorial data. The focal interests are:

- to lighten the server load;
- to reduce the client-server exchanges;
- to allow client queries;
- to install locally at a client level some data management tools.

The most known extensions are:

- Scalable Vector Data (SVG)[10] [12]: for drawings as maps, raster, etc…;
- Geography Markup Language (GML) [9]: for geographic data;
- LandXML [4]: for civil engineering application.

During the last year many other extensions are in continuous development, one of the last most interesting one is CityGML [1]. It is a common information model for the representation of 3D urban objects. It defines the classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantical and appearance properties. Included are generalization hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. This thematic information go beyond graphic exchange formats and allow to employ virtual 3D city models for sophisticated analysis tasks in different application domains like simulations, urban data mining, facility management, and thematic inquiries. CityGML is realised as an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is implemented as an application schema for the Geography Markup Language 3 (GML3) [9], the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211. CityGML is intended to become an open standard and therefore can be used free of charge. In our comparison we didn't take it into account, because only in July 2007 it has been approved as a standard by OGC, and also because it seems more appropriate for 3D city models than for terrain models.

We try to give a short description of the most spread wide extensions:

SVG (Scalable Vector Data) is a XML extension where the object is the vectorial graphic object description in 2D. In 1998 a working group with interest in graphics (Sun, HP, and Adoboe) began to developed SVG format. Actually it is supported by the main enterprises and groups working with informatics graphics. It had been developed to increase HTML graphics functions, with the aim to create a vectorial standard for web representation. Thanks to its high quality in graphics it is very suitable for on-line GIS. It is an open standard, thanks to its DOM (Document Object Model) it permits the definition, or suppression of objects, attributes and properties.

GML (Geography Markup Language) is an XML extension developed by the OGC, with the task to define a language for geographic data exchange on the Web. This extension is specific for geo-data transport and storage, preserving geometry and properties of geographic elements. GML has been drawn up for:

- encoding spatial information, exchange and store it;
- being extensible in a way to support a large variety of applications;
- establishing modular and incremental GIS fundaments on the Web;
- encoding effectively geometry (data compression);
- separating the spatial and non-spatial contents;
- integrating easily spatial and non-spatial data;
- creating common geographic object groups to permit interoperability among applications developed independently.

LandXML is a project of Autodesk and EAS-E (Engineering and Surveying-Exchange) began in 1999. In 2002 LandXML.org announce the 1.0 version of the standard and "Land Development and Transportation Industry Consortium accepted it as exchange standard. Before LandXML, the used software to build up a project required its standard format. In that way for all the project/product life it had been necessary the use of the same software and format or in some cases translates it, when possible. Often the software able to read the project was not the best application for it. LandXML avoids this problem by separating:

- software (for each project it is possible choosing the more suitable application able to manage it);
- data standard (LandXML).

This approach permits to develop a standard easy to read and understand independent from the used software. The main goal of LandXML was to create a standard for civil engineering and surveying applications to make easier the exchange of data among different actors during all the lifetime of a product and to give a standard for long term data archiving. The implementation of Land XML is already in evolution.

3.2.4. How to choose a Language for Geo-data

The advantages and the disadvantages of each language are strictly connected to the data structure and above all to the objectives one has to reach. In fact every language, among the described above, could be suitable for some purposes but not for others. Therefore it would be auspicious make a deep cost/benefit analysis before choosing the language to work with.

Afterwards we will try to give a short comparison among these languages and we will resume in a table some of the aspect that could help the user in its decision. These three

XML extensions are conceived for different purposes and application. The code of all of them is XML based. The used format for all the languages is ASCII following XML specification, and particularly SVG is a standardized dialect of XML. SVG is completely independent from the platform and permits also to work directly on the format sharing the code. LandXML has many markups (tags) and this feature makes that this language is not easy to code in text editor; while a file in Geography Markup Language could be exported directly with some software. For all the three languages the norms are free but only GML doesn't need commercial software to use it.

All the languages have not a proprietary format, they are an open standard being in that way easily comprehensible by the users. GML and SVG could be internationalized (SVG already preview different languages versions for the same visual file). They also preview metadata associated to the data (SVG has metadata in an extern file).

Concerning their use as a norm, GML is submitted to ISO who is reviewing the 3.2 version, while SVG is recommended by the Wide Web Consortium (W3C) in 2000.

An important difference between the three languages is the managing of the third dimension: SVG is not able to manage it, because it is conceived for the description of 2D representation, particularly for drawings (maps and so on). GML and LandXML could work with 3D data. This is one of the important characteristic that makes choose for one or another language. In our case, working with point coordinates in the space, GML or LandXML are more suitable to archive our geo-data.

GML is a really flexible language compared to the other two, and this makes it a very powerful language for the geo-data description. Being interested more in the archiving than in the visualization of the photogrammetric data GML seems to be the more opportune choice. For our purposes we decided to use GML, in fact it has many advantages for the description of georefereced data.

In the following table there are reported some criteria for each language and a note for efficacy from 1 (low efficacy) to 5 (high efficacy) is assigned.

Criteria	GML	SVG	LandXML
Meaningful tag names	5	5	3
Extensibility (possibility to define new attributes...)	5	0	3
Standardization (OGC, ISO, W3C…)	4	5	3
Free format	5	5	4
Temporal representation	5	5	2
3D	3	0	5
2D Elements	5	3	5
3D Elements	4	0	5
Possibility of creating complex elements	5	5	5
Capacity to visualize the DB/Possibility of visualization (PC, browser, PDA…)	1	5	5
Possibility of representation/restitution	1	5	3
Navigation into the image	proper of the visualizer	5	3
Possibility of stocking data associated to geo-data	5	5	5

Interactivity of elements (responses to events)	0	4	5
For professional use/Applicable by professionals	5	5	---
Able to associate/Possibility of associating external scripts	1	5	5

Table 3.2. Comparison table among the XML extensions for geographic data[8]

In the following chapter we will describe in details GML standard and its benefits for our purposes.

3.3. ISO STANDARDS AND GML[9]

The Geography Markup Language (GML) is an XML encoding for the modeling, transport and storage of geographic information including both spatial and non-spatial properties of geographic features. It was originally developed within the Open Geospatial Consortium Inc. (OGC). ISO 19136 was prepared by the Technical Committee ISO/TC 211, *Geographic information/Geomatics*, in close cooperation with OGC. The OGC try to adapt their conceptions to the ones of ISO. For that reason with ISO 19136 norm they want to harmonize the specifications of the two different organizations. Actually the version 3.2 of ISO 19136 is reviewed and rules the encoding for the geographic data.

The key concepts used by GML to model the world are drawn from the Open Geospatial Consortium (OGC) Abstract Specification [9] and they are well documented in the version 3.2 of GML specifications, shortly resumed in the above paragraph 3.2.4. The universal use of GML as a standard for many geo-referenced data is one of its principal goal. The application domains are:

- base for GIS internet applications;
- data exchange between different GIS;
- base for Location Based Service.

In the following lines we report some concepts of the GML specification that clarifies the principal idea of this language.

A feature is an "abstraction of real world phenomena" (ISO 19101); it is a geographic feature if it is associated with a location relative to the Earth. So a digital representation of the real world may be thought of as a set of features. The state of a feature is defined by a set of properties, where each property may be thought of as a {name, type, value} triple. GML provides a variety of kinds of objects for describing geography including features, coordinates reference systems, geometry, topology, time, units of measure and generalized values.

[8] Translated from [78]

[9] Parts of this chapter are taken from [9].

Implementers may decide to store geographic application schemas and information in GML, or they may decide to convert from some other storage format on demand and use GML only for schema and data transport.

The International Standard defines the XML Schema syntax, mechanisms, and conventions that:

- provide an open, vendor-neutral framework for the description of geospatial application schemas for the transport and storage of geographic information in XML;
- allow profiles that support proper subsets of GML framework descriptive capabilities;
- support the description of geospatial application schemas for specialized domains and information communities;
- enable the creation and maintenance of linked geographic application schemas and datasets;
- support the storage and transport of application schemas and data sets;
- increase the ability of organizations to share geographic application schemas and the information they describe.

3.4. ORGANIZATION OF GEOGRAPHIC DATA

The most optimal way to organize a large amount of data, either geographic or of any other type, so that it can be accessed, managed, retrieved and updated is in a database, Databases are organized around data models, which represent people's perception of reality in an abstract way. Data models are used to describe the architecture of a database (by architecture we mean the data contents, relationships and constraints, the data structure and the physical storage or data format).

Since 1995 the two main standardization organizations for Geographic Information, ISO/TC211 and OGC (Open Geodata Consortium) have worked on the specification of standards for geographic data and services. Unified model language (UML) has been selected as the normative specification language within ISO/TC211 since 1998, while OGC is currently using UML in a non-normative way. ISO/TC211 focuses on platform independent models expressed in UML, and on a model-driven approach for mapping these to XML, while OGC is addressing implementation specifications for multiple technologies. Currently it has not been possible to fully realize the model-driven approach to standard specifications across ISO/TC211 and OGC.

The principal difference between OGC and ISO is the method they decided to use for exchanging information: ISO wants to transfer data, and a model-driven approach is strictly needed for an interoperable data transfer; while OGC doesn't need a model-driven approach, because it transfers only queries and answers. For sure this different point of view makes that the two organizations follow a different strategy.

In this work one of our aims is data transfer, so the model-driven approach adopted by ISO is very suitable to our purposes. Furthermore in the last years the research on that field goes on, and now the model-driven approach is complete and it could be easily used for many different applications in geo-information field.

3.4.1. Conceptual Schema

ISO/TC211 experience shows that geographic information standardization is only possible at the system-independent conceptual level. In fact if we want to exchange data between systems with different data structures the solution is to map data models on a conceptual level and let perform the corresponding transformation of data by an appropriate model-driven approach (MDA)-tool (see paragraph 3.4.2).

The conceptual level describes what kind of information is stored in the database. At this level we define accurately what the data contents are, the relationships among the data, and the constraints they should hold on this data. This description of the database is called conceptual database schema. Conceptual schema can be expressed using different techniques. One of the most commons is the Unified Model Language (UML), which is also the standard for data modeling adopted by ISO (ISO19103), as already mentioned.

3.4.1.1. UML and INTERLIS[10]

UML is an easy language, widespread and really general for many applications. UML is officially defined at the Object Management Group (OMG). OMG™ is an international, open membership, not-for-profit computer industry consortium. UML is not restricted to modeling software. UML has been a catalyst for the evolution of model-driven technologies, which include the Model-driven approach (MDA). By establishing an industry consensus on a graphic notation to represent common concepts like classes, components, generalization, aggregation, and behaviors, UML has allowed software developers to concentrate more on design and architecture.

UML allows a graphic description of data. In our work we used a *class diagrams approach*. This approach maps the data in classes correspondent to the real object we want to store, and each class has different attributes corresponding to the different attributes of an object.

The UML model description in ISO 19115/2003 is too general for a real application. For that reason Switzerland detailed the UML model creation in a standard language INTERLIS2[11] (Swiss standard for modeling an exchanging data, in UML notation). In that way the exchange of data become more tangible and possible, in fact INTERLIS2 contains encoding rules for the automatic generation of XML and GML Schema. This schema could be read from any computer and could be used for the generation of a database and its applications. Thanks to these rules, and to the UML model, we are not obliged anymore to design "by hand" the GML/XML Schema as the ISO actually does applying the 19139 norm, avoiding in that way many errors occurred before. For example with the INTERLIS Editor for UML it is possible to define the type and the unit measure of an attribute, its minimum and maximum possible value, and other useful properties.

INTERLIS consists of a conceptual description language and a transfer format which in particular takes into account spatially related data (shortly geodata), thus permitting compatibility among various systems and long-term availability, i.e. depositing in archives and documentation of data. Making use of INTERLIS when deciding, planning or administering processes may yield great profit. Very often (e.g. through multiple applications and uniform output of documented and verified data) major economies can be achieved. Five years after its publication INTERLIS, in retrospect called version 1, has come out of its "Sleeping Beauty existence". In the meantime a considerable range of software tools has become available to the user, making it possible to process geodata

[10] Part of [4].

[11] Switzerland is part of CEN (Comité Européen de Normalisation). CEN is the European representative for ISO, the International Organization for Standardizations. Switzerland as part of CEN considered ISO standard (as ISO 19115/2003) in the creation of a national standard rules (INTERLIS2).

described and encoded in INTERLIS. INTERLIS has been created out of the requirements of official survey, but its range of applications is considerably wider, as proved by more than a hundred data models and projects which nowadays work with INTERLIS.

INTERLIS is the only available and operative solution with all the necessary tools that permits the realization of the model-driven approach. It is a textual form of UML, very similar to a programming language and easy to improve and integrate with different utilities.

INTERLIS allows co-operation between information systems, especially geographic information systems or land information systems. As its name suggests, INTERLIS stands between (inter) land information systems. It is crucial that all systems involved have a very clear notion of these concepts that are of major importance to their co-operation:

INTERLIS is a standard which has been especially composed in order to fulfill the requirements of modeling and the integration of geodata into contemporary and future geographic information systems. The current version is INTERLIS version 2 (English). INTERLIS version 1 remains a Swiss standard. With the usage of unified, documented geodata and the flexible exchange possibilities the following advantage may occur:

- the standardized documentation;
- the compatible data exchange;
- the comprehensive integration of geodata e.g. from different data owners;
- the quality proofing;
- the long term data storage;
- the contract-proof security and the availability of the software.

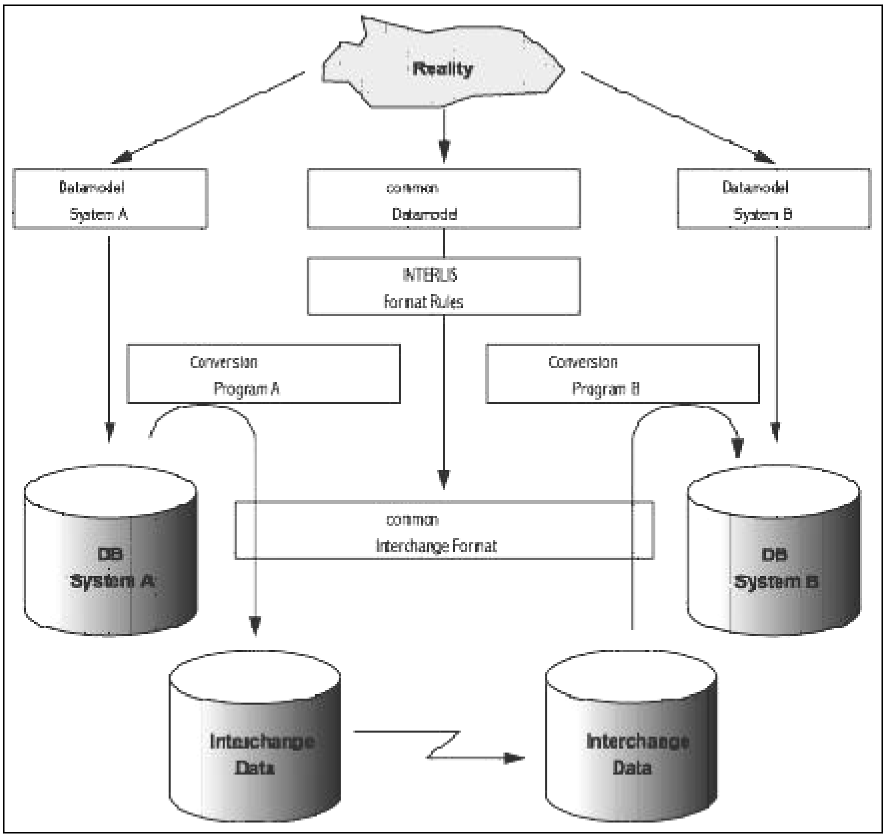


Figure 3.1. From Reality to a Database Exchange with INTERLIS

A very useful INTERLIS Tool is the UML Editor. It helps in building the conceptual schema, defines the semantic mapping from the original to the final model by providing the necessary parameters for the INTERLIS conversion system (ICS). Then ICS automatically calculates the final data from the original data in the standard format.

Thanks to Swiss experience, INTERLIS:

- solution steps using UML-INTERLIS-Tools:
  - provide the conceptual schemas:
    - of the start data structure (original data model);
    - of the final data structure (pedestrian navigation);
  - define the semantic mapping from the original to the final model by providing the necessary parameters for the INTERLIS conversion system (ICS);
  - ICS automatically calculates the final data (reduced data set for pedestrian navigation in the standard format corresponding to the final model) from the original data in the standard format (e.g. TeleAtlas).

Thanks to the INTERLIS/UML Editor it is possible to derive automatically from the UML model also the corresponding GML schema. As in the last years geographic information became more and more spread wide, this tool was necessary. INTERLIS provides unique rules for the automatic codification of the GML schema starting from the UML model. This is a very fundamental step which permits to related different models among them. In fact from a UML model it is possible to derive infinite GML schemas, and thanks to INTERLIS constraint, once a GML schema is generated with its rules, it is possible to reverse the process, and derives once again the source UML model of the corresponding GML schema. In the following paragraph this step of the data modeling procedure is explained more in details.

3.4.2. Model-driven Approach (MDA)

The model-driven approach (MDA) is a really useful strategy for data transfer independent from the used format or system. It is based on a first exact description of the structure of the data to be transferred. This description is called conceptual data model or conceptual schema. The transfer format can then automatically be derived from the conceptual schema according to rules (once fixed a standard) by a piece of software called compiler. The model-driven approach (MDA) is a four shell modeling process as it is shown in the following figure.

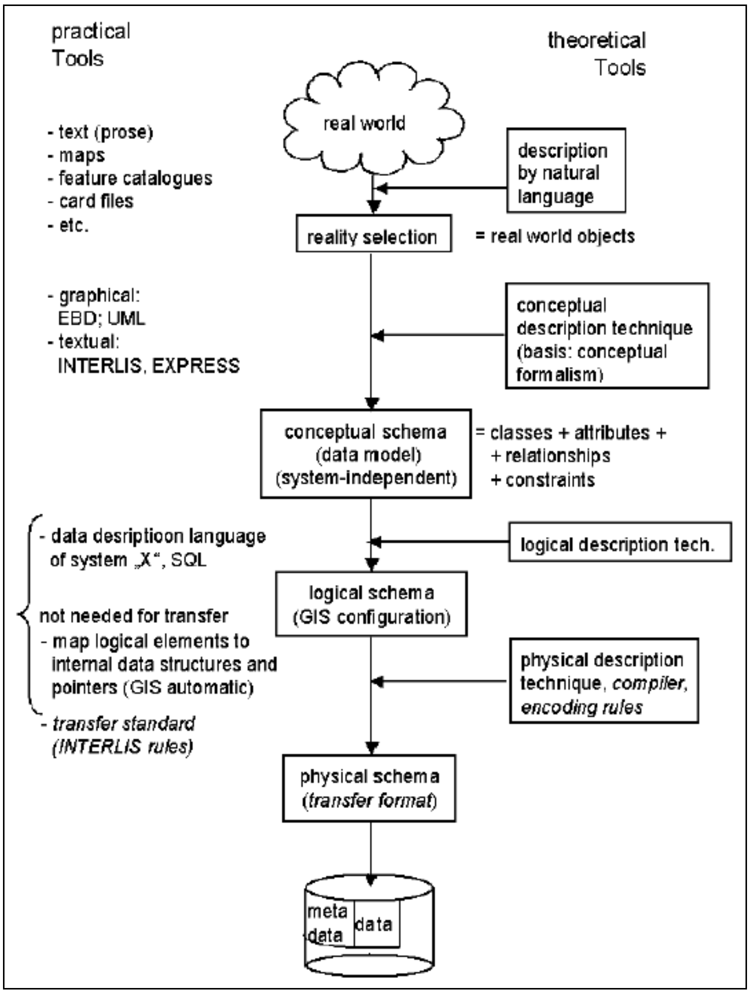


Figure 3.2. Data modeling procedure[73]

Model-driven approach (MDA) could be resumed in two phases, a first one in which, before any data are reformatted or exchanged or treated by any other service, the structure of these data is exactly described on the system- and format-independent conceptual level. This description by a conceptual schema language is called data model or conceptual schema. A widely used graphical conceptual schema language (CSL) is the unified modeling language (UML); and a second phase where from this conceptual schema, once tested for syntactical correctness by a compiler, in which the description of the corresponding standard transfer format according to fixed rules can then automatically be calculated by the same compiler [73].

This two phases are part of the core of the model-driven approach (MDA) corresponding to the classical four shell modeling procedure of the data base design as you can see in Figure 3.2.

3.4.2.1. Different Approaches to Data Modeling

In our work we define the UML data model following the GML restrictions and specifications (also ISO 19103), and we use the data type defined by GML (ISO 19103 and ISO 19107). Successively we could apply the rules of model codification characterized by GML, to obtain the transfer format. We do not need any further agreement for data transfer.

As mentioned in paragraph 3.3, and as we could read in the standard [9], GML for data modeling could be used in two different ways:

- as storage application: information are stored directly in GML;
- only for schema and data transport: information are converted from some other storage format on demand and GML is used only for schema and data transport.

With the introduction of GML, we have two different approaches for data modeling:

- UML model as visualization tool; GML Schema as reference standard;
- UML model as reference standard; GML Schema as transfer format.

In this work we decided to start from the UML model of our photogrammetric data, and use it as a reference standard. In fact when a model is defined, decisive choices are taken. For that reason using UML as a reference standard we take these choices. With this approach the UML model is decisive and the GML Schema is automatically derived from it (having in its structure all the important constraints defined with the definition of the model), and it is needed only for the data transfer. The advantages of this approach are:

- other transfer formats could be generated from the same UML model;
- the UML model describes only the data structure, while the format used is created automatically from the encoding rules.

For sure there are also some disadvantages in this approach:

- some GML functionalities could not be used because in the ISO 19136 (Annex E) some encoding rules from UML to GML are missing;
- a UML model translation is needed for the real format transformation. While the user has only to click a button, the software developers need to know quite well the UML model, the transfer format and the translation rules.

3.5. Describing Geographic Data

With the large diffusion of Internet, General Packet Radio Service (GPRS) devices and mobile Global Positioning System (GPS), there is an increasing quantity of data coming from different and non-conventional sources. GPS networks are more and more widespread and we could suppose that in a near future a wide sensor's network will control and exchange geographic data for different and non-homogeneous applications. GIS became the basic support for many decisions in social fields and there is the risk that they could be based on non-quality data. Additionally the acquisition of quality data is the main investment in a GIS. To reduce the risk of redundancies and waste (of time and money) a standard definition and evaluation of data and metadata quality become necessary.

In 1992 CEN TC 287 (Comité Européen de Normalisation) for the standardization of geographic information was born. This Technical Committee in 1999 finishes the draft of some "experimental standards" for geographic information (ENV).

CEN number	Name	Year
ENV 12009	Geographic Information – Reference Model	1997
ENV 12160	Geographic Information – Spatial schema	1997
ENV 12656	Geographic Information – Data descriptor - Quality	1998
ENV 12657	Geographic Information – Data descriptor - Metadata	1998
ENV 12658	Geographic Information – Data descriptor - Transfer	1998
ENV 12661	Geographic Information – Referencing – Geographic identifiers	1998
ENV 12762	Geographic Information – Referencing – Position	1998
ENV 13376	Geographic Information – Data descriptor – Rules for application schema	1999

Table 3.1. ENV Standards (CEN/TC 287)

The International Organization for Standardization was born in 1994 from a strict collaboration among different partners who use standards in data exchange. At that moment ISO/TC 211 and CEN/TC 287 reached to an agreement: CEN/TC 287 would have finished its work and would have helped to define the work planning for ISO/TC211. The ENV standards have been recently substituted by the corresponding EN ISO.

ISO number	Name	Year	EN ISO
ISO 19113	Geographic Information – Quality principles	2002	EN ISO 19113:2005
ISO 19114	Geographic Information – Quality evaluation procedures	2003	EN ISO 19114:2005
ISO 19115	Geographic Information - Metadata	2003	EN ISO 19116:2005

Table 3.2. Some of ISO Standards for Data Quality (ISO/TC211)

3.5.1. Quality of Data and Metadata

ISO Committee has defined some standards ISO 19113 (Geographic Information – Quality principles) and ISO 19114 (Geographic Information – Quality evaluation procedures) right for this purpose.

ISO 19113 - Geographic Information – Quality principles: This standard establishes the principles for describing the quality of geographic data and specifies components for reporting quality information. It also provides an approach to organizing information about data quality. The standard is applicable to data producers providing quality information to describe and assess how well dataset meets its mapping of the universe of discourse as specified in the product specification. It is also applicable to data users attempting to determine whether or not specific geographic data has sufficient quality for their particular application.

ISO 19114 - Geographic Information – Quality evaluation procedures: This standard provides a framework of procedures for determining and evaluating quality that is applicable to digital geographic datasets, consistent with the data quality principles defined in ISO 19113. It also establishes a framework for evaluating and reporting data quality results, either as part of data quality metadata only, or as an evaluation report.

It is very important to define what quality means for data. We can define some quality elements:

- **Lineage**: material sources of data and used methods to get them, and also all the transformations they get through.
- **Thematic accuracy**: (non-spatial attributes) difference between attribute values and their real values. It is the inverse of error, and it could be determined only by comparison with the most accurate measures that could ever be obtained.
- **Temporal accuracy**: origin date, update frequency and validity.
- **Positional accuracy**: conformity degree of data related to the reality or to the nominal terrain. Shifting between their respective/relative positions.
- **Completeness**: information about characteristics, definitions and selection criteria. It points out if a database is free of slip errors. We could have information about model or object completeness.
- **Logic consistency**: reliability of stored relations, related to the constraints defined in the specifications/standards. To evaluate it there are tests on mathematical/logic constraints or topological ones.
- **Thematic coherence**: object, relation and attribute number correctly encoded in relation to the general norms and standard specifications.

The evaluation of data quality could be done by:

- data producer: using conformity test strategies;
- final user: thanks to metadata furnished by the data producers, users would be able to evaluate the quality of data (unluckily data producers do not have a feedback from users to adjust data errors);
- users: thanks to standard specifications information about data quality is bidirectional, so data producers have a feedback from users and could identify significant problems and intervene on data.

3.5.2. Metadata Specifications

ISO Committee has defined the standard ISO 19113 (Geographic Information – Metadata), and an XML implementation of that standard has been developed (ISO 19139).

ISO 19115 – Metadata: This standard defines the schema required for describing geographic information and services. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of geographic data.

For better understanding what we mean for metadata in geographical information we can add those other definitions:

- metadata are structured data and permit to describe a resource of information that, thanks to them, becomes easily identifiable.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

- metadata are information that could be read by electronic resources or by other devices.

Metadata give an exact description of the contents of geo-data. They also help the users know more about the accuracy, the model, the formats and other additional information to understand if the geo-data fulfill the requested criteria.

Actually metadata are available for visual consulting; in a near future they would be automatically used by interoperable systems.

3.6. PART I CONCLUSIONS

In this chapter there are all the motivations of our choice. In conclusion we can say that the model-driven approach is a good option for the description and the transfer of geo-data, it is the only operative solution for an interoperable data transfer. Moreover using INTERLIS there are many advantages about the consistency of the model description and it became easier to pass from the conceptual model (in UML) to a GML schema and if it is necessary go back. Thanks to all the norms and specification about geo-data the procedure for data transfer is well documented and has a high control even for the quality of the data, including a large amount of metadata.

Part II. Data Acquisition and Processing

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

4. STEREO MULTIPLE SCENE SEQUENCES BY PHOTOGRAMMETRY

In this chapter an automatic procedure for the external orientation of three images is presented. Two images are not sufficient to automate the orientation procedure. Introducing a third image we are able to skip the manual assessment after the step of relative orientation. In this chapter we describe the procedure to obtain the adjusted point coordinates starting from a photogrammetric survey based on a trifocal sensor.

4.1. MODEL FORMATION AND OBJECT RECONSTRUCTION

The main function of photogrammetry is the transformation of data coming from the image space to the object space. We chose a two-steps procedure for this transformation that pass through the model formation before reconstructingf the object.

This two-step procedure permits the definition of the problem of absolute orientation, separately from the relative orientation one. Usually the solution for this task can be obtained after a linearization of a non-linear functional model, in which the preliminary values of the unknown parameters are strictly required. In this new solution, we use an exhaustive research of preliminary values (of parameters) for relative orientation, while for the absolute orientation a linear parameterization of the problem is used.

4.1.1. *Three-image orientation through exhaustive research*

In this work, we tried to solve the non-linear problem of three-image orientation based on the classical background of photogrammetry. Solution such as those based on the trifocal tensor could be very useful for stand alone problems such as those of machine vision. When approximate values of geometric orientation parameters of a standard photogrammetric block have to be found, a solution giving this parameterization (or a similar one, e.g. requiring only 3D transform) would be better.

In [231] and [233] a solution of relative orientation problem based on exhaustive research of the preliminary values of parameters has been proposed.

Exploring the 3D space with a step of $\pi/4$ is possible for finding all the preliminary values of the unknown orientation parameters. This idea wants to avoid the linearization of the orientation functions supplying the lack of information about the position and the attitude of an image.

4.2. FROM IMAGES TO OBJECT VIA MODEL

The main function of photogrammetry is the transformation of data from the image space to the object space. We can make this transformation in a direct way, with collinearity equations, or in two steps, with the formation of a model and, only in a second time, reconstructing the original object [46]. First of all, we have to take into consideration that:

- an image is not a map;
- at least two images are needed for reconstructing an object.

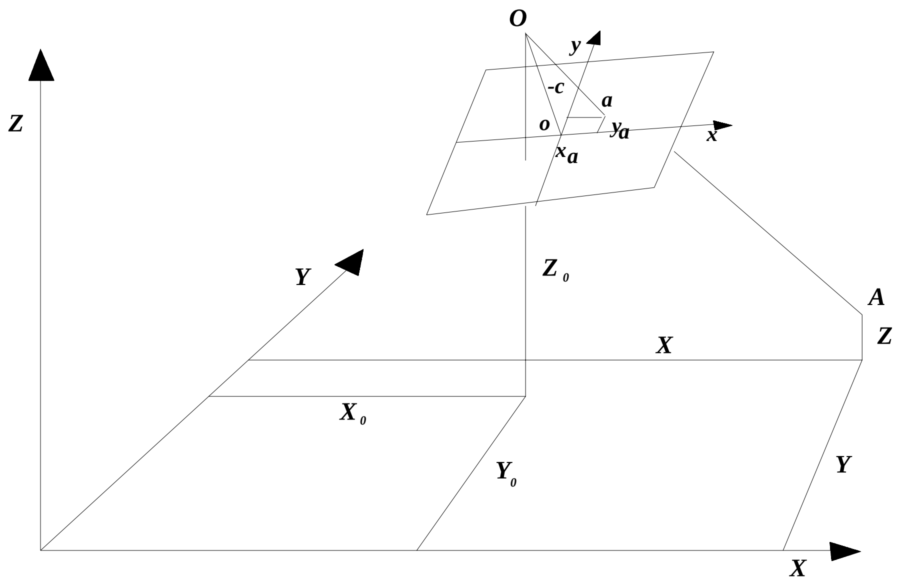


Figure 4.1. Reference Photogrammetric Systems

A relation of roto-translation with scale variation constitutes the link between the coordinates of the point *Q (x, y, z)* in an image, and the coordinates of the corresponding point *P (X, Y, Z)* in the object space (Figure 4.1). Both reference systems are traditionally Cartesian reference systems, but the same is true, with minor changes, using a different reference system, suitable linked to the previous ones. Let us show the above mentioned relation:

$$\begin{vmatrix} x^\circ \\ y^\circ \\ -c \end{vmatrix}_{ij} = \hat{\lambda}_{ij}\hat{R}_j \left(\begin{vmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{vmatrix}_i - \begin{vmatrix} \hat{X}_0 \\ \hat{Y}_0 \\ \hat{Z}_0 \end{vmatrix}_j \right) \quad (4.1)$$

where x_0, y_0, c = image coordinates and principal distance

$\hat{X}_0, \hat{Y}_0, \hat{Z}_0$ = coordinates of projection center

$\hat{X}, \hat{Y}, \hat{Z}$ = object coordinates

λ = scale factor, variable point by point.

4.2.1. Projection transformation

The photogrammetric technique is based on a transformation of a perspective (or a couple of perspectives) in a dimensioned orthogonal projection. In this transformation, we have non-linear equations and, before starting the plotting, we need information about the preliminary value of unknown parameters. Our main aim is to find expressions working with parameters easy to be obtained. We choose a '*two steps*' procedure to orient two images in the 3D space. This procedure does not use the classical collinearity equations (12 parameters: X_1, Y_1, Z_1, X_2, Y_2, Z_2 -coordinates of the two projection centers, and ω_1, φ_1, κ_1, ω_2, φ_2, κ_2 attitude angles of the two sensors), but separates the model formation (Relative Orientation) from the object reconstruction (Absolute Orientation). In this procedure, we define the problem of Absolute Orientation by means of 7 parameters: t_x, t_y, t_z (shift vector), λ (scale factor), Ω, Φ, K (Cardanic angles). In contrast, to define the problem of Relative Orientation, we need 5 parameters: φ_1, κ_1, ω_2, φ_2, κ_2 (Symmetric Relative Orientation), or b_y, b_z, ω_2, φ_2, κ_2 (Asymmetric Relative Orientation).

4.3. MODEL FORMATION

4.3.1. Relative Orientation Parameters

Regarding the Relative Orientation, we make an exhaustive research of the preliminary values, solving a linearized problem in all its possible cases. Notice that an exact solution has been found (see paragraph 2.1.1.1), but it leads to a four ordered equation, which supplies four plausible solutions, as we can easily achieve by repeating a linearized problem via an exhaustive research. In case of Asymmetric Relative Orientation, we have to define b_y, b_z, ω_2, φ_2, κ_2, which are the parameters of position and attitude of the second image, compared to those of the first image. Notice that b_x is already defined in the Absolute Orientation, as the scale factor λ. In case of Symmetric Relative Orientation, we have to define φ_1, κ_1, ω_2, φ_2, κ_2, parameters which represent position and attitude of the two images. Notice that ω_1 is missed because it is already defined in the Absolute Orientation, as the global attitude angle Ω.

4.3.1.1. Inghilleri Proposal [145]

In the Relative Orientation Professor Giuseppe Inghilleri suggested estimating even a scale factor λ. It is possible to estimate this term by measuring some distances on the object, leaving unknown the b_x component of the baseline. In this case the equation system contains also observation equations for the measured distances, suitable linked by the scale factor λ to the model coordinates.

4.3.2. Exhaustive Research

For the Relative Orientation, we should have previous information about the preliminary values of the parameters. It is not always possible to know them, before the plotting. Let us point out that non-conventional photogrammetry implies often camera acquisition without classical surveying measurement. If we consider the classical Symmetric procedure of Relative Orientation, we can make an exhaustive research of all possible preliminary parameters, because we work in a closed group (in the topological sense) of values compared to the rotations in the space.

The convergence of linearization of trigonometric functions is acceptable as far as values lower or near $\pi/4$. Therefore we decided to explore all the admissible values for rotation angles with a step of $\pi/4$, as shown in the Table 4.1 below:

	φ_1	κ_1	ω_2	φ_2	κ_2
$\pi/2$	°			°	
$\pi/4$	•			•	
0	•	•	•	•	•
$\pi/4$	•	•	•	•	•
$\pi/2$	°	•	•	°	•
$3\ \pi/4$		•	•		•
π		•	•		•
$5\ \pi/4$		•	•		•
$3\ \pi/2$		•	•		•
$7\ \pi/4$		•	•		•

Table 4.1. Exhaustive Research for Symmetric Relative Orientation parameters

where ° $\kappa_1 \equiv 0$ if $\varphi_1 \equiv \pm\pi/2$ and/or $\kappa_2 \equiv 0$ if $\varphi_2 \equiv \pm\pi/2$

As known, if the φ angle is around $\pm\pi/2$, we cannot individuate the k rotation, which is fixed equal to zero. Indeed in the polar zones (we assumed their range in a circle of one degree), the two angles are identical or quasi identical, and this fact produced singularity or ill-conditioning.

The exhaustive research explored 5x8x8x5x8=12800 possible configurations. For each case, a linear system was solved, using the values of this configuration (case), as preliminary values of the parameters of the Symmetric Relative Orientation.

Examples were carried out in all the middle points of the possible configuration. Considering the 5 parameters of the Symmetric Relative Orientation, the angles κ_1, ω_2, κ_2 are defined in a complete rotation (8 configurations), whilst φ_1, φ_2 are defined in a half rotation (5 configurations), which led to the above mentioned 12800 cases.

Each linear system solution gave us the estimate parameters for the Symmetric Relative Orientation. The convergence to admissible values is when σ_0 is small enough. Considering only the distinct solutions, we found four analytical acceptable configurations (Figure 4.2).

These configurations are really different, so it is not so difficult to have information about the initial position of the images, in every specific case. If an operator would select the proper case, it is possible to calculate the estimate parameters for the expected Symmetric Relative Orientation.

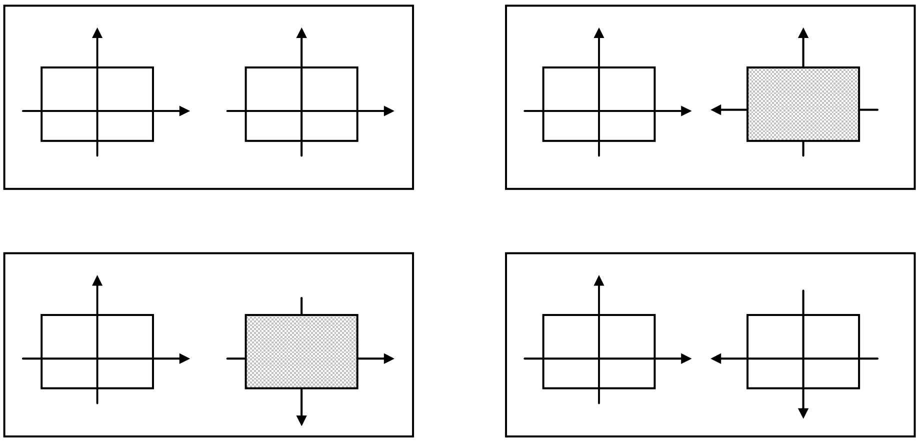


Figure 4.2. The 4 final possible configurations

Notice that in the Asymmetric procedure of Relative Orientation, we have two shift parameters to be searched, but the group of shifting is not a closed one, so we had to use a different way to find the preliminary values. However with the following relations is possible to transform the Symmetric Relative Orientation parameters in the Asymmetric ones, and vice versa:

$$\begin{aligned} b_x &= \cos\varphi_1 \cos k_1 \\ b_y &= \cos\varphi_1 \sin k_1 \\ b_z &= \sin\varphi_1 \end{aligned} \qquad \begin{aligned} \varphi_1 &= \arcsin b_z \\ k_1 &= \arctan\frac{b_y}{b_x} \end{aligned} \qquad (4.2, 4.3, 4.4, 4.5, 4.6)$$

$$\mathbf{R}_2^T(\omega_2\varphi_2k_2 \,|\, b_x b_z) = \mathbf{R}_2^T(\omega_2\varphi_2k_2)\mathbf{R}_1(\omega_1\varphi_1k_1) \qquad (4.7)$$

$$\mathbf{R}_2^T(\omega_2\varphi_2k_2) = \mathbf{R}_2^T(\omega_2\varphi_2k_2 \,|\, b_x b_z)\mathbf{R}_1^T(\omega_1\varphi_1k_1) \qquad (4.8)$$

4.3.3. Model Coordinates

The model formation in a general way implies a different strategy to compute the model coordinates. In fact the parallaxes must indicate the minimum distance, instead of the z direction for the aerial photogrammetry (or the y direction for the classical terrestrial case).

Thus the parallax vector could be expressed as a spatial combination of 3 vectors, as you can see in the following:

$$\mathbf{p} = \lambda\mathbf{s} - (\mathbf{b} + \mu\,\mathbf{t}) \qquad (4.9)$$

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

Where λ and μ are scale coefficients of the unit vectors $\mathbf{s}$ (4.10) and $\mathbf{t}$ (4.11), and $\mathbf{b}$ is the baseline between the 2 images (Figure 4.3).

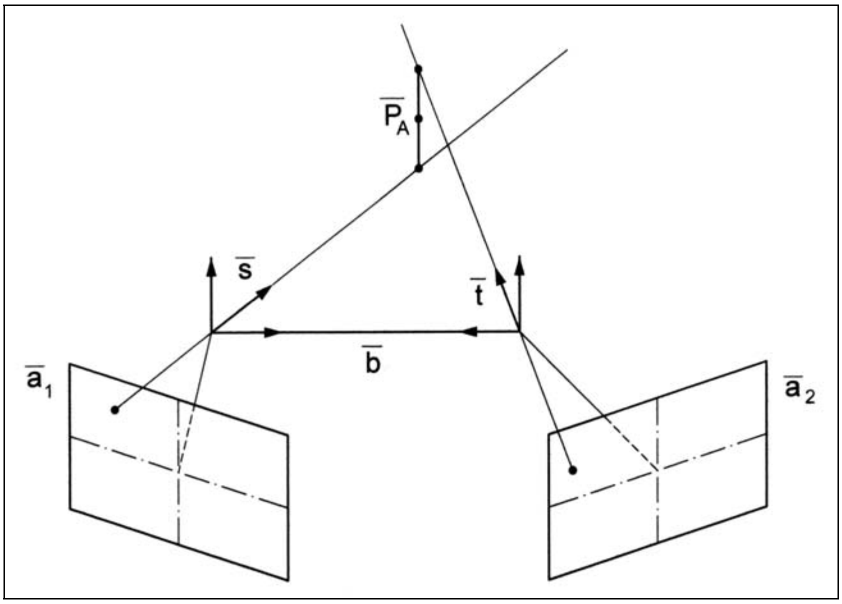


Figure 4.3. Parallax Schema

Indeed being the above mentioned unit vectors:

$$\mathbf{s} = -\frac{\mathbf{a}_1}{|\mathbf{a}_1|} \tag{4.10}$$

$$\mathbf{t} = \frac{\mathbf{a}_2}{|\mathbf{a}_2|} \tag{4.11}$$

Where:

$$\mathbf{a}_1 = \mathbf{R}_1^T \begin{vmatrix} x_1 - x_{PP} \\ y_1 - y_{PP} \\ -c \end{vmatrix} \qquad \mathbf{a}_2 = \mathbf{R}_2^T \begin{vmatrix} x_2 - x_{PP} \\ y_2 - y_{PP} \\ -c \end{vmatrix} \tag{4.12, 4.13}$$

We obtain:

$$|\mathbf{p}|^2 = \mathbf{p}\,\mathbf{p} = \lambda^2 + b^2 + \mu^2 - 2\lambda\mathbf{sb} - 2\lambda\mu\mathbf{st} + 2\lambda\mu\mathbf{bt} \tag{4.14}$$

In order to minimize the parallax, we can compute the partial derivates both for the terms λ and μ (4.15, 4.16) and set them to zero.

$$\frac{\partial|\mathbf{p}|^2}{\partial\lambda} = 2\lambda - 2\mathbf{sb} - 2\mu\mathbf{st} = 0 \qquad \frac{\partial|\mathbf{p}|^2}{\partial\mu} = 2\mu - 2\lambda\mathbf{st} + 2\mathbf{bt} = 0 \qquad (4.15, 4.16)$$

In that way we find the values of λ (4.17) and μ (4.18) respect to which the functional p^2 has got a minimum. Introducing it in the formula 4.9 we get the minimum parallax $\mathbf{p}_0$ (4.19).

$$\mu_0 = \frac{(\mathbf{s}\cdot\mathbf{b})(\mathbf{s}\cdot\mathbf{t}) - (\mathbf{b}\cdot\mathbf{t})}{1-(\mathbf{s}\cdot\mathbf{t})^2} \qquad \lambda_0 = \frac{(\mathbf{s}\cdot\mathbf{b}) - (\mathbf{b}\cdot\mathbf{t})(\mathbf{s}\cdot\mathbf{t})}{1-(\mathbf{s}\cdot\mathbf{t})^2} \qquad (4.17, 4.18)$$

$$\mathbf{p}_0 = \lambda_0\mathbf{s} - (\mathbf{b} + \mu_0\mathbf{t}) \qquad (4.19)$$

Finally the model coordinates are obtained adding (or subtracting) ½ $\mathbf{p}_0$ to each coordinates of the first image (of the second image):

$$\mathbf{A}_1 = \lambda_0\mathbf{s} + \frac{1}{2}\mathbf{p}_0 \quad \text{or} \quad \mathbf{A}_2 = \mu_0\mathbf{t} - \frac{1}{2}\mathbf{p}_0 \qquad (4.20, 4.21)$$

4.3.4. Critical Cylinder[12]

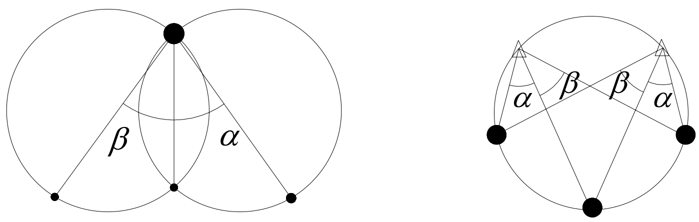


Figure 4.4. Inverse intersection and Critical configuration

It is possible to determine a point position with an inverse intersection, knowing three point coordinates and measuring α and β angles stationing in the unknown point. We consider the two circumference equations that pass from the two known points and the unknown one, and we intersect them. If the 4 points lie in a unique circumference, we are in a critical case, and the unknown point position is indeterminable.

[12] The arguments of this paragraph start from an idea of Professor Battista Benciolini, TU of Trento (Italy), formalized in an internal report (see the enclosed CD).

This unfavorable configuration could happen also in photogrammetry; in fact if we are surveying a cylindrical object (e.g. a U valley) and we suppose the baseline view on the generating line of the cylinder, we are in this critical case. We have to reconfigure the entire problem, higher than the circumference connecting the three points with a consequent reduction of scale factor, or lower with a reduction of the observed object.

4.4. 3-IMAGE PROCEDURE

In our approach, we choose to use three images to operate the global procedure, in order to eliminate the human decision. Actually to start the Absolute Orientation, we have to select manually one among the founded four configurations. Introducing the third image, we want to bypass the human decision, turning it automatically.

The step of the Model Construction furnishes four admissible solutions, as above said, and produces four distinct models (called A, B, C, and D). In case of three partially overlapped images, this step can be repeated two times. Indeed the model I can be formed by the images 1 and 2, and the model II can be formed by the images 1 and 3.

4.4.1. Bridging the models

A 3D S-transformation allows to make the bridging of these models, taking into account all the four models obtained according to the admissible solutions founded in the Relative Orientation. The procedure leads to sixteen different small blocks (Table 4.2).

The majority of these blocks are completely unlikely; indeed the sigma naught of the 3D S-transformation adjustment is enormous. This fact is reasonable because if and only if both models (1 and 2) are congruent between themselves, the bridging can be carried out successfully.

The set of congruent and incongruent combinations supplies only two small blocks whose sigma naught is satisfying. The two small blocks are originated from two different admissible solutions in each four couple; (this means that) putting in a square table all the sixteen solid structures, the two congruent ones belong always to different rows and columns.

	IIA	IIB	IIC	IID
IA	IA-IIA	IA-IIB	IA-IIC	IA-IID
IB	IB-IIA	IB-IIB	IB-IIC	IB-IID
IC	IC-IIA	IC-IIB	IC-IIC	IC-IID
ID	ID-IIA	ID-IIB	ID-IIC	ID-IID

Table 4.2. Models Bridging

The analysis of the geometry of four admissible solutions recognizes the high regularity of the presented values. As a consequence, the two congruent small blocks present 3D coordinates in two mirror reference frames.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

4.5. OBJECT RECONSTRUCTION

4.5.1. A Linear Solution by Rodriguez Matrix[13]

Starting from a roto-translation in the space, a rational alternative to classical Rotation Matrix is the Rodriguez Matrix.

$$\mathbf{R} = (\mathbf{I} - \mathbf{S})^{-1}(\mathbf{I} + \mathbf{S}) \tag{4.22}$$

where **I** is the *identity matrix* of 3x3 dimensions, and **S** is an skew-symmetric matrix defined as follows:

$$\mathbf{S} = \begin{vmatrix} 0 & c & -b \\ -c & 0 & a \\ b & -a & 0 \end{vmatrix} \tag{4.23}$$

This *skew-symmetric matrix* **S** permits to find the exact solution of the absolute orientation problem, thanks to the solution of a linear system, after a suitable substitution of variables.

We start from the conventional roto-translation in the space, with a global scale variation λ, and we computed the expected value in a way to eliminate the shift vector **t**:

$$\begin{array}{c} \mathbf{y}_i = \lambda \mathbf{R} \mathbf{x}_i + \mathbf{t} \\ \mathbf{y} = \lambda \mathbf{R} \overline{\mathbf{x}} + \mathbf{t} \\ \hline \mathbf{y}_i - \overline{\mathbf{y}} = \lambda \mathbf{R}(\mathbf{x}_i - \overline{\mathbf{x}}) \end{array} \tag{4.24}$$

Indeed it is possible to calculate **t** lately with the following expression:

$$\mathbf{t} = \overline{\mathbf{y}} - \lambda \mathbf{R} \overline{\mathbf{x}} \tag{4.25}$$

Making the square of the second expression in the formula number (3.24), we also find an easy expression to calculate the scale factor:

[13] See [235].

$$\mathbf{y}^T\mathbf{y} = \lambda^2\mathbf{x}^T\mathbf{R}^T\mathbf{R}\mathbf{x} = \lambda^2\mathbf{x}^T\mathbf{x} \quad \Rightarrow \quad \lambda = \sqrt{\frac{\mathbf{y}^T\mathbf{y}}{\mathbf{x}^T\mathbf{x}}} \tag{4.26}$$

After simple substitutions, we obtain a linear solution, showing the direct proportion between the model coordinates $\mathbf{x} = \mathbf{x}(u^0, \mathrm{v}^0, \mathrm{w}^0)$ and the object ones $\mathbf{y} = \mathbf{y}(X, Y, Z)$:

$$\mathbf{y}_i = \mathbf{R}\mathbf{x}_i = (\mathbf{I}-\mathbf{S})^{-1}(\mathbf{I}+\mathbf{S})\mathbf{x}_i \quad \Rightarrow \quad (\mathbf{I}-\mathbf{S})\mathbf{y}_i = (\mathbf{I}+\mathbf{S})\mathbf{x}_i \tag{4.27}$$

$$\begin{vmatrix} 1 & -c_j & b_j \\ c_j & 1 & -a_j \\ -b_j & a_j & 1 \end{vmatrix} \begin{vmatrix} \hat{X} \\ \hat{Y} \\ \hat{Z} \end{vmatrix}_i = \begin{vmatrix} 1 & c_j & -b_j \\ -c_j & 1 & a_j \\ b_j & -a_j & 1 \end{vmatrix} \begin{vmatrix} u^\circ \\ v^\circ \\ w^\circ \end{vmatrix}_{ij} \tag{4.28}$$

Reorganizing matrices and vectors, in a way which collects in a unique vector the three unknown parameters, coming from the above mentioned skew-symmetric matrix, we obtain the following final equation:

$$\begin{vmatrix} 0 & (\hat{Z}_i - w^\circ_{ij}) & -(\hat{Y}_i - v^\circ_{ij}) \\ -(\hat{Z}_i - w^\circ_{ij}) & 0 & -(\hat{X}_i - u^\circ_{ij}) \\ (\hat{Y}_i - v^\circ_{ij}) & -(\hat{X}_i - u^\circ_{ij}) & 0 \end{vmatrix} \begin{vmatrix} \hat{a}_j \\ \hat{b}_j \\ \hat{c}_j \end{vmatrix} + \begin{vmatrix} \hat{X}_i - u^\circ_{ij} \\ \hat{Y}_i - v^\circ_{ij} \\ \hat{Z}_i - w^\circ_{ij} \end{vmatrix} = 0 \tag{4.29}$$

Notice that in our procedure for the Absolute Orientation, the object reconstruction does not need preliminary parameters, because we can reach the exact solution, by solving the linear system, as mentioned above.

4.5.2. Absolute Orientation with 3-image procedure

If we have to manage two different small blocks in two mirror reference frames, the qualitative comparison with the object coordinates select automatically the congruent configuration. As well-known, a 3D S-transformation permits to compare model and object coordinates, transforming the first coordinates in the second ones. The 3D S-transformation can be done in a linear way, in fact the whole procedure terminates with a unique solution (Figure 4.5), which traces back the entire path followed, enhancing the correct choices at the different steps and eliminating the wrong possible alternatives.

After all the orientation procedure we obtain different data:

- the preliminary coordinates of point (X, Y, Z) and a K code to indicate if is a 1D, 2D or 3D ground control point;
- the projection centers of the cameras (X_0, Y_0, Z_0);
- the attitude angles of each image.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

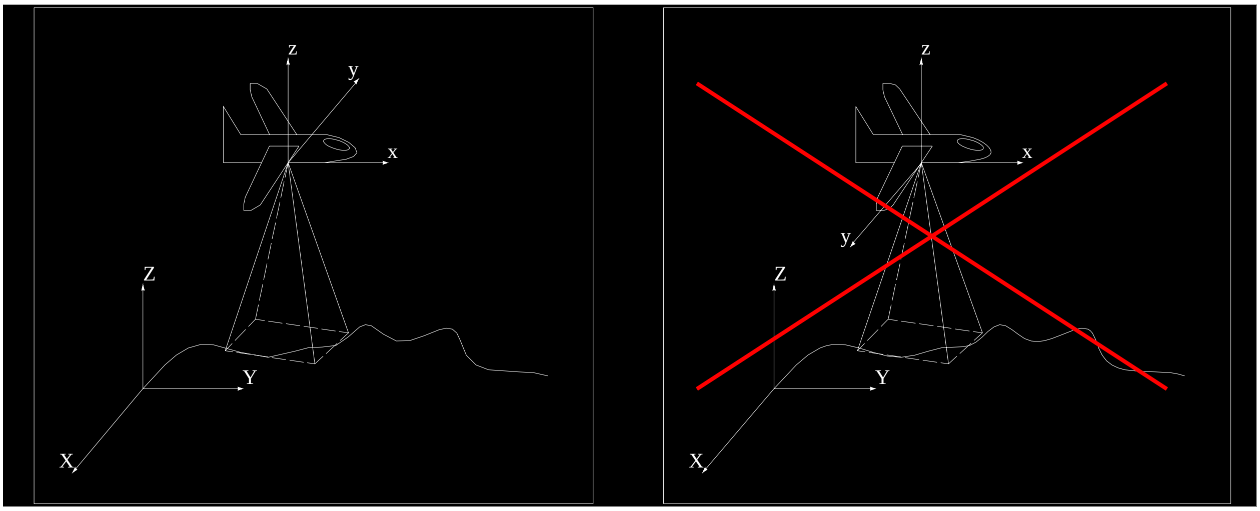


Figure 4.5. The 2 small blocks obtained after the model bridging (the second one is incongruent)

4.6. SIMULATION

To verify precision, accuracy and reliability of these techniques, a program in FORTRAN 95 has been implemented and tested. It runs on a Pentium 3 PC, with 933 MHz–262 Mb/RAM–30GB/Hard Disk. The exhaustive research for the Symmetric Relative Orientation works in 4-5 seconds, while all others procedures are immediate. In all the examples, we introduced random errors, with standard deviation of 20 μm, as usual in photogrammetry. Here we present an explanation of these programs:

ORPHO_ it converts Cardanic angles in Eulerian angles and vice versa. This is a very large used transformation in close range photogrammetry, because it is essential for the image orientation, when the rotation angles are acquired by surveying measurements.

ORSYM_ it calculates the preliminary values for the Symmetric Relative Orientation. It solves 12800 linear problems, exploring all possible configurations in the space, with a step of Π/4. The same program, choosing one of the four distinct solutions, permits to calculate the preliminary parameters for the Asymmetric Relative Orientation.

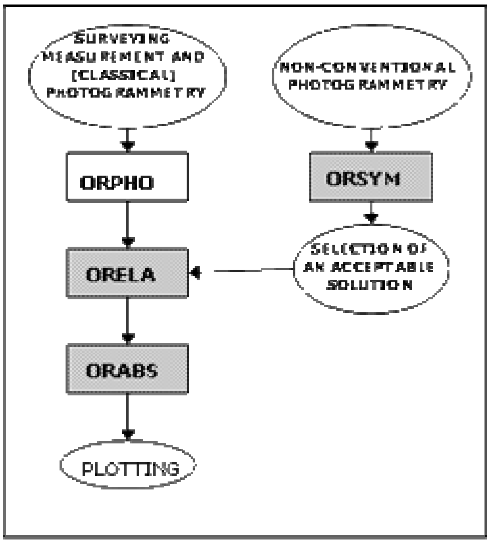
ORELA_ it calculates the adjusted parameters of the Asymmetric Relative Orientation, starting from its preliminary ones. If these preliminary values are unknown at the data acquisition, it is possible to get them from the results of the previous program. On the contrary, if they are already known, it is possible to transform the Eulerian angles, more frequently and easily acquired, into the Cardanic ones, by means of ORPHO program.

ORABS_ it calculates the adjusted Absolute Orientation parameters. They are calculated with a simple substitution of variables, which is able to transform the non-linear problem of the Absolute Orientation in a linear one.

Let us summarize the global procedure for the orientation of two images, viewing the flowchart (Figure 4.6).

With the new procedure, we eliminate any human intervention after the starting inputs. For that reason we unify all the Orientation programs in one called ORTRE. This program can run automatically and is able to find the adjusted parameters of the Absolute Orientation. In the follow flowchart (Figure 4.7) we want to show how all the global procedure run after the starting inputs of three images.

As evident, the analysis of the performance of the single programs and of the global procedure was quite heavy. Indeed it needed a long preparation of tools, which permitted to manage files of commands. Furthermore many different levels were prepared in order to collect, save and store the output files for the different steps.



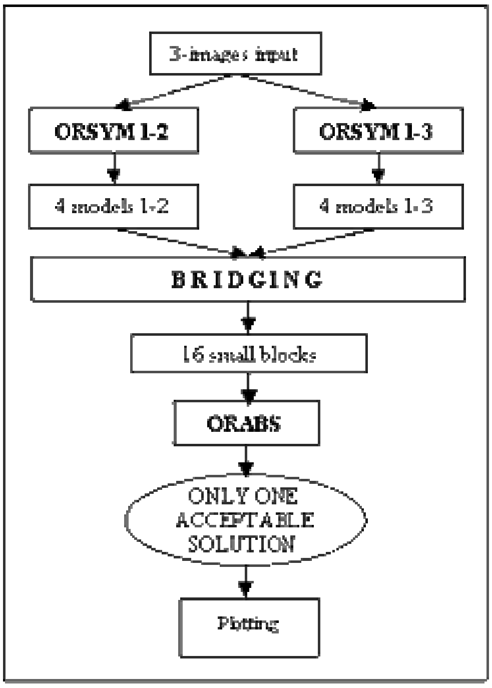


Figure 4.6. 2-image Orientation :Global Procedure

Figure 4.7. 3-image Orientation: Global Procedure (ORTRE Program)

4.7. PART II CONCLUSIONS

The procedure described in the previous paragraphs surely is one among other existing ones. This methodology has some relevant advantages for environmental and security surveying, and make it a very powerful tool next to more traditional methodologies.

The advantages of this method are:

- it runs automatically without requiring the interactive control of the user, who has only to setup some initial parameters (mean object scale, rough distance between cameras and the others);
- it doesn't need any preliminary values of the unknown parameters.

These features allow that this method could be easily used by users not skilled in photogrammetry.

Therefore an original procedure for automatic three image orientation was described and a software that computes all the steps was developed. Notice that this procedure, even if necessary in order to obtain the preliminary values of unknown parameters, is usually completed by a rigorous adjustment, such as the least square method.

Let add that a procedure for the rigorous adjustment and the outliers detection is supplied by CALGE[14], which is a program developed at Dept. IIAR of TU of Milan in 1990. It is able to adjust with least squares geodetic and photogrammetric networks. It works with linearized equations and need preliminary values of the External Orientation to compute the adjustment (in our case, coming from the preliminary adjustment at chapter 4). By repeating the adjustment, it does a robust detection of outliers, assigning null-weight (or quasi) to the suspected observations.

The program is also able to do a control on reliability and conditioning. A refinement of the stochastic model implies to find a reproduction point for suitably chosen reweighted groups of observations. CALGE is based on graph theory, with the aim of easily managing the data and quickly performing the solution of the system. Anyway, CALGE produces a field of spot data, where is quite impossible to determine a dynamic behavior and morphological scenes. On the other hand, methodology and procedure of data interpolation and approximation permit to pass from spot data to raster data.

To analyze and study the dynamic behavior of topographic scenes we have to use an integrated approach, able to compute together a multi-level procedure. Firstly low-level polynomial interpolation removes a general trend; then finite element method (e.g. spline) follows to match local variations. The last step is performed assuming the topography and/or dynamic to be a realization of a continuous, linear, normal, stationary and isotropic (or orthogonal factorized) stochastic process. Thus a filtering technique, based on covariance estimation and collocation, is applied. Finally the whole procedure can be repeated using the contribution of the integrated geodesy in its broadest sense.

The aim of geodesy and geomatics is the determination of the position of points, together with their variation in time and the representation of them, in various suitable forms.

The geometric observables in geodesy and related sciences, which can be determined by satellite geodesy, surveying, photogrammetry, space photogrammetry and remote sensing, are all simple, or more complex functions of the relative position of two points. They are influenced by various physical fields, like the earth's gravitational field and the field of atmospheric refraction. Geodetic networks, in their various forms, like leveling networks, triangulation and trilateration networks or photogrammetric blocks, allow for the transition from geometric observables to the determination of the (relative) position of the network points. When measurements are repeated in time, variations in (relative) position can be determined. The imposition of an arbitrarily chosen reference system is needed to remove the indetermination of origin, orientation and scale.

The relation between the observables and the geometric parameters, which describes the position of the network points, is expressed in functional models. These are often non-linear; therefore have to be linearized (using preliminary values for the unknown parameters) to provide a linear system of observation equations. The rank defect of this system is removed by the introduction of a reference system. The relation between the geodetic observables and the physical field(s) can conveniently be expressed in stochastic models. These models, linearized and interpreted stochastically, provide covariance functions (invariant with respect to suitable groups of parameter transformations), with which one can obtain the stochastic signal present in the observables. In integrated geodesy (in its broadest sense), after the formulation of the functional and stochastic models, which tie the observables to the stochastic and not-

[14] CALGE, see [30].

stochastic parameters, the complete set of equations and unknowns is solved simultaneously in one single adjustment. The computation of the solution is nowadays realistic. However, because of its complexity it has to be regarded as a final analysis, following both the traditional network adjustment and the digital modeling of the physical fields and/or the geometric parameters treated like fields. In appendix A the mathematical aspects of the integrated approach is stressed starting from covariance estimation and arriving to generalized least square, where finite element interpolation is presented as a parallel and/or alternative tool.

The School of Data Processing at the TU of Milan has a long history starting at least a century ago. Cassinis, Cunietti, Inghilleri and Togliatti were important people in this role. In this frame, the post-calibration proposed by Inghilleri [145] indicates a goal: it is not so important to remove all the errors, but we have to understand why they appear and learn from them. On the other hand, Cunietti [24] observed that additional means transform noise into signal, however we should always take care if this passage has a physical explanation.

Generalizing the problem, after the rigorous network adjustment, as well as after a space-time modeling, residuals and/or noise remain in the data. A post-analysis proceed to the study of the solution quality, trying to learn from residuals and/or noise a better knowledge of the phenomena. A program of post-analysis is able to study errors charts (1D, 2D, 3D+t or not and 1, 2 or 3 components). It is an easy adaptative analysis, to be used a posteriori.

A first treatment analyzes the data (or the metadata), considering their domain in 1D, 2D, 3D+t or not and their 1, 2 or 3 components, and performs the statistical summary. This means to describe the data using the one-dimensional indices (i.e. the classical statistics, like: the average value, the variance, the Gini's delta, the skewness and curtosis indices, etc, as well as the robust statistics, like: the median, the median absolute value, the Shannon's entropy, etc.) and the two-dimensional indices (i.e. the classical statistics, like: the Pearson's indices, the linear correlation coefficient, etc, as well as the robust statistics, like: the Bonferroni indices, the Spearman rank correlation coefficient, etc.).

Notice that the most interesting zones for the post-analysis are where the data present the maximum or minimum points and the saddle points in 2D or 3D (on the contrary, the inflection point in 1D is quite instable to be defined, because of the roughness of the discrete data). The successive analysis of these data proceeds to test them using classical or distribution free inference. Indeed if the data are normally distributed and independent among themselves, classical tests supply very powerful decisions. On the contrary, if the data are not normally distributed or they are not independent among themselves, distribution free tests furnish very general answers.

In conclusion after the rigorous network adjustment, as well as after a space time modeling, residuals and/or noise remain in the data. A post-analysis proceed to the study of the solution quality, trying to learn from residuals and/or noise a better knowledge of the phenomena. To analyze and study the dynamic behavior of topographic scenes we have to use an integrated approach, able to compute together a multi-level procedure. Firstly low-level polynomial interpolation removes a general trend; then finite element method (e.g. spline) follows to match local variations. The last step is performed assuming the topography and/or dynamic to be a realization of a continuous, linear, normal, stationary and isotropic (or orthogonal factorized) stochastic process. Thus a filtering technique, based on covariance estimation and collocation, is applied. In this part of the thesis there are explained all the data processing procedures for outliers detection, an integrated approach able to model spatio-temporally scene sequences and a post-analysis procedure to validate the data and the model. In this part there are some fundamental concepts that take us from the rigorous adjustment of the designed network to the creation of digital surface models of the observed object. On the other hand, spatial-temporal data analysis and validation is a very broad field, as documented in a large part of statistic literature (e.g. [24]).

Part III. A Photogrammetric Example and Further Development

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

5. AN APPLICATION

In this part a dynamic survey show the direct application of the presented procedure, which has been developed in this thesis. Let add that the acquisition of a sequence of three images of a scene in movement is not too easy; therefore satisfying examples are not too frequent and a fruitful search had to be done.

During the development of this research, in the same Department (DIIAR) a hydraulic model was installed. The idea of a collaboration for testing the procedure was really immediate. It is to be noticed that the analyzed problem is really complex both from a photogrammetric point of view and also from a geo-information one.

In this chapter we will presents the experimental application we have done and the results we have obtained, outlining the reached goals.

The XML format for geographic data (Geographic Markup Language) optimizes the archiving and management of the geo-data. Starting from the creation of a conceptual model for the photogrammetric data, a GML Schema was automatically generated. Then a XML/GML file has been developed from the Schema with a common XML editor for an interoperable data management.

The wide field of this research implies many different knowledges and mainly for that reason it was necessary a lot of time for achieve satisfying results. We want also to add that many improvement and different applications could be adjoint, and we hope that our efforts could be a solid starting point for other researches.

5.1. THE HYDRAULIC MODEL AND ITS PROBLEMS

The Fantoli Laboratory of the Hydraulics and Water Infrastructure Sections of the DIIAR at the TU of Milan (Italy) have got a certain number of interesting hydraulic 3D models, among which a stream confluence in the mountain area is one of the most important.

Figure 5.1. Stream Confluence in the Alpine Region of Valtellina

Figure 5.2. Stream Confluence Zone in the Alpine Region of Valtellina (Flood in 1987)

Indeed because of its size and nature, the confluence of two streams, named Val Lunga and Val Corta, which after their confluence forms the stream, named Tartano, is quite important to study a typical phenomenon in the Alpine region of Valtellina in the North part of Italy (Figure 5.1 and Figure 5.2).

A model of the confluence area of these streams has been built up in the Fantoli Laboratory; a picture of it can be seen in Figure 5.3.

The survey of this model will be carried out, after an accurate project and the judgment formulated by the expertise in Hydraulics and Water Infrastructures, taking into account the survey of the floor of the three streams and the confluence, the water surface presented by the hydraulic 3D model and the modification of the floor, when the water flows during its performance.

The Figure 5.4 shows a photo of the three streams in their confluence point, which is the most interesting point to be surveyed.

Figure 5.3. A global view of the hydraulic 3D stream confluence model

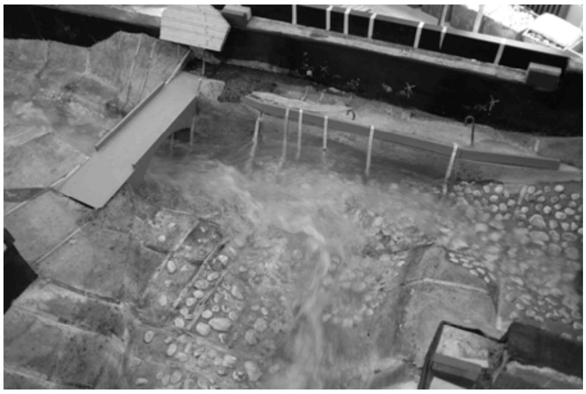


Figure 5.4. The confluence area of the hydraulic model

Our purpose is to perform a static and a dynamic survey, for the realization of temporal digital surface models. This application has geotechnics and hydrological interests. In fact Geotechnics have the task to choose a suitable factor of safety for the studied case, defined as "the factor by which the strength has to be reduced to bring the mechanism to equilibrium" (Chandler). The factor of safety depends on:

- the method of analysis;
- the choice of the strength parameters;
- uncertainties regarding the processing (failure).

Hydrological interest is to interpret correctly the results coming from the photogrammetric survey of the model suitably built. An experiment on a physical model has also the task to verify the existing situation and to detect the critical elements of the system.

5.1.1. Modeling

Looking at the history of floods of the basin, it is recalled that in 1987 the area was subjected to a critical flood (115 m^3/s, period of return of 100 years) in which a pedestrian bridge was totally destroyed and another bridge located downstream the confluence completely overflowed (Figure 5.5).

The purpose of this project was therefore to detect the critical elements of the system, to identify the hydraulic behavior under flood conditions and to define the vulnerable areas and eventually countermeasures to adopt under extreme events.

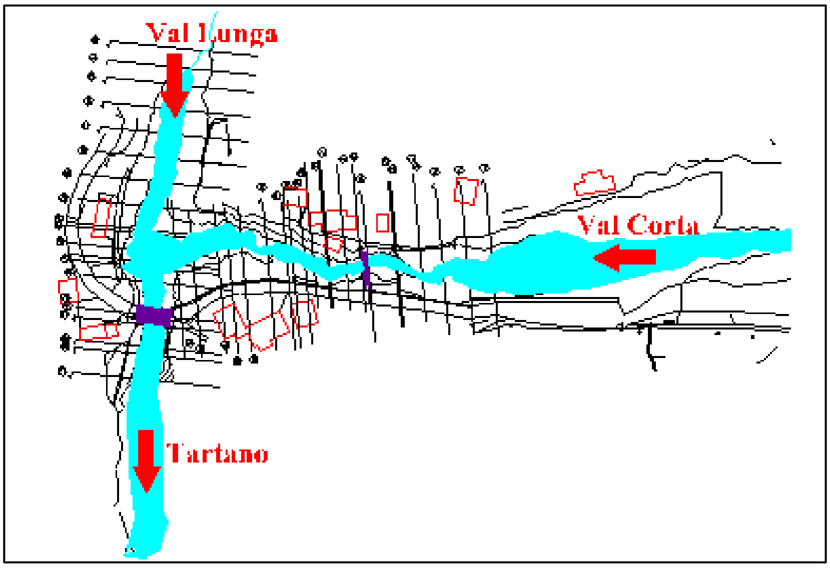
Figure 5.5. Critical Flood of 1987

The physical model was built considering a geometric 1:30 non-distorted downscale, (with a different depth, length and wide downscale), in which the sections and the river topography were obtained through consecutive survey campaigns. The hydraulic characteristics of the streams were evaluated for each tributary, considering the channel geometry and the slope conditions.

Besides, the roughness was estimated considering the bed features, such as vegetation and size materials on the prototype.

5.1.2. Characteristics and Simulation Modeling

The physical model was built considering a non–distorted down-scale of 1:30, which ensures wide hydraulic sections. Due to the specific typology of the problem under analysis, a dynamic simulation of Froude was applied: the value of the geometric scale ensures high values for the Reynolds and Weber's number, associated with negligible distortions effects of viscosity and superficial tension.



unbiased geom. scale 1:30

length	λl=1:30
volume	λW=1:27000
speed	λV=1:5.5
time	λt=1:5.5
flow rate	λQ=1:4930

Figure 5.6. Physical Model Design

In the physical model, the linear downscaling of 1:30 implies a volumetric downscaling of 1:27000, a velocity downscaling of 1:5.5, a time downscaling of 1:5.5 and a discharge downscaling of 1:4930. Besides the hydrogram of the model was estimated by using a 100 year discharge return period for both the Val Lunga and the Val Corta streams.

5.1.3. Results

The experimental campaigns, for different discharge conditions, show a good agreement with the prototype. In particular, three special conditions were analyzed:

- uniform flow;
- rapidly varied unsteady flow;
- sediment transportation.

5.1.3.1. Uniform Flow

The uniform flow was modeled by using a 100-year period of return discharge. Under uniform flow condition, different flow reigns were detected; particularly, critical, transition and subcritical zones as well as a hydraulic jump were found. Comparing those results with the documented water levels during the 1987 flood (prototype), it was found a good agreement between the prototype and the model results.

5.1.3.2. Rapidly Varied Unsteady Flow

The rapidly varied unsteady flow was modeled for each channel separately. The water wave celerity, in the model, was calculated by using the trial-and-error method until convergence of the water level in the model to the water level in the prototype (the 1987 flood). For instance, wave celerity of 2.2 m/s in the model ("Val Corta" channel) corresponds to a value of 12.0 m/s in the prototype.

5.1.3.3. Sediment Transportation

Under different uniform flow conditions, the sediment transport was modeled for each channel separately. The highest amount of solids used in the models was equivalent to 8.600 m^3 for each prototype channel. In the Val Corta channel, the results exhibit a good solid transportation process, for almost the whole watercourse. In the case of the Val Lunga channel the results show a sediment deposition in join section with the main channel (Tartano stream). For both channels, no local erosion process was observed. Finally, the sediment transport in the channels did not present any significant change in the hydraulic sections.

5.2. The Survey

The survey of the hydraulic model will be carried out in two different steps:

- survey of the floor without water (static survey);
- survey of the water flooding surface (dynamic survey).

The static survey (Figure 5.7) will be carried out by close range photogrammetry, while in a second step, the dynamic survey (Figure 5.8) of the water flooding surface will be carried out by using three digital video-cameras, focusing on the confluence area.

Figure 5.7. Hydraulic Model in non-working conditions

Figure 5.8. Hydraulic Model in working conditions

5.2.1. Static Survey

For the static survey, without water, we used a high resolution camera, a Nikon D100 of the TU of Milano (Lecco campus). The camera has a focal Length of 20mm, a resolution of 3008x2000 pixels and a pixel size of 7.9 microns.

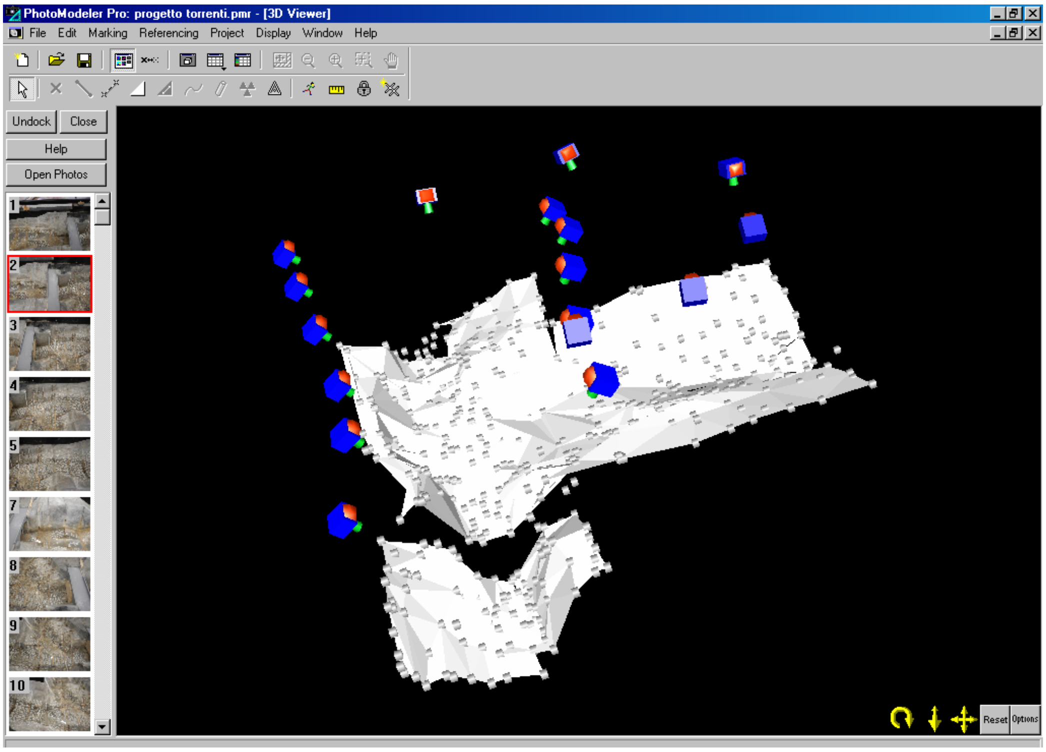


Figure 5.9. Digital Surface Model of the Hydraulic 3D model (Static survey with Nikon D100)

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

The photogrammetric survey was designed as an airborne one with all the suitable technical characteristics. After the image acquisition we execute the orientation of corresponding points with a commercial software, obtaining millimetric accuracy in every direction (x=0,003 m, y=0,002 m and z=0,003 m). Successively we built the Digital Surface Model starting from the adjusted points. We also survey the control network, georeferencing the physical model in a global frame.

5.2.2. Dynamic Survey

The dynamic survey was done with a system of three synchronized webcams. We would like to remind that this thesis is not especially on Photogrammetry, in fact we didn't care about high calibration of the webcams, or about the use of high cameras. The three webcams system is property of Homometrica Studio of Zurich (Ing. Nicola D'Apuzzo) and it has a triangular configuration (**Errore. L'origine riferimento non è stata trovata.**). Webcams have a focal length of 4.8 mm, a resolution of 640x480 pixels and a pixel size of 5.6 microns. We performed the survey in different conditions of flow. We take 3 pictures every second, during 5 seconds of videoing, reaching a total of 15 sequences (each one composed by three synchronized images).

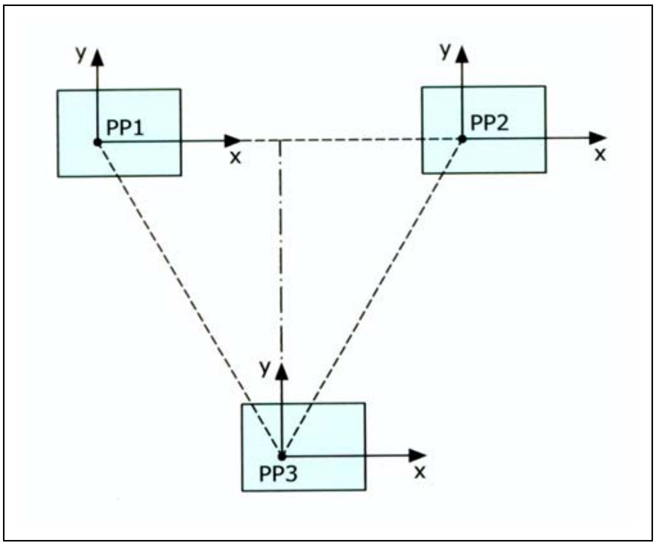


Figure 5.10. Three webcam configurations

To improve the contrast on the water surface we used sawdust and pieces of paper (Figure 5.11 and Figure 5.12).

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

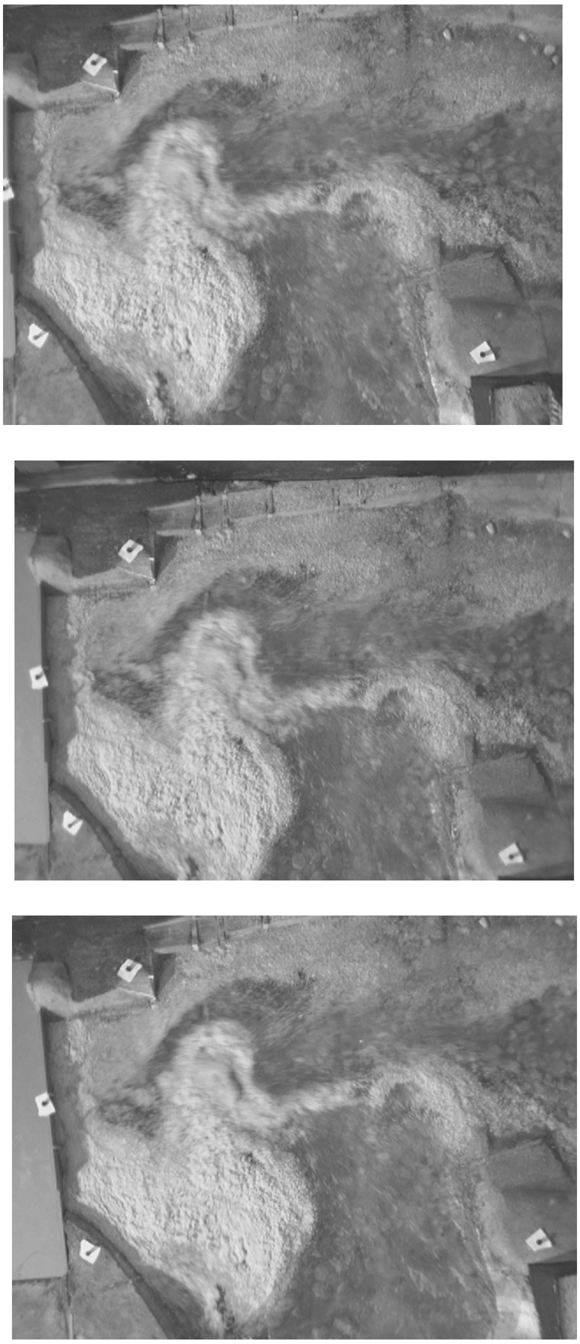


Figure 5.11. Dynamic Sequence with Sawdust

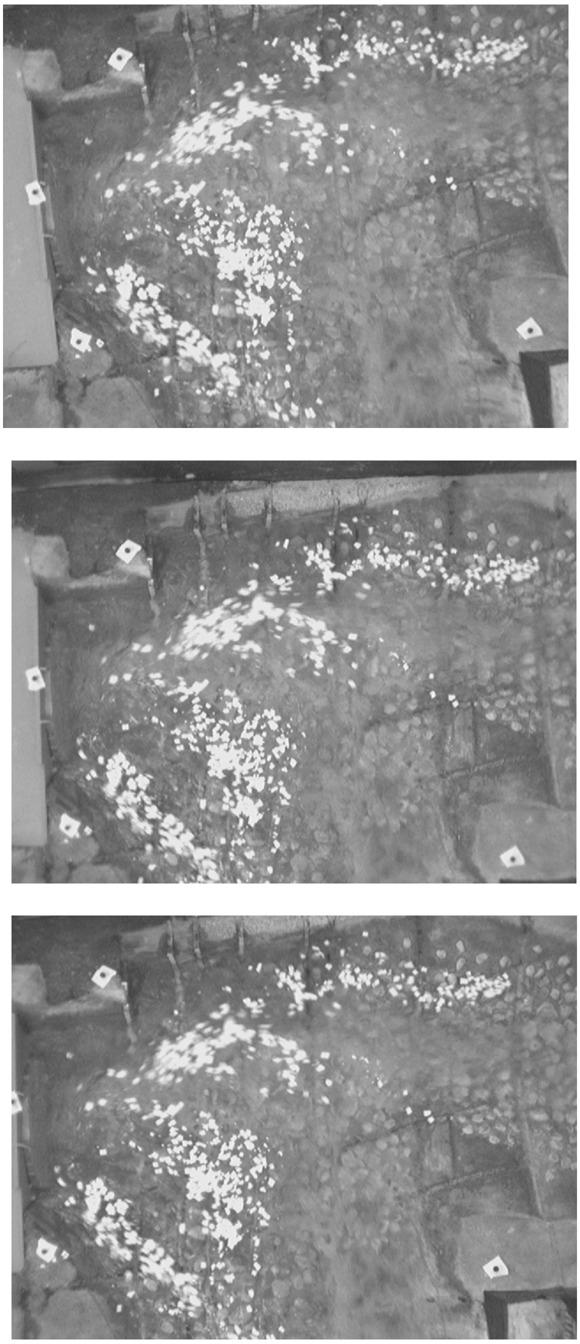


Figure 5.12. Dynamic Sequence with Paper

5.2.2.1. Matching and Adjustment

In our survey, the matching of the homologous point was made manually. We decided for this way to avoid a long calibration of the automatic matching procedure and to have a direct control of the measures. In fact the automatic matching works better in the images with sawdust, which are quite homogeneous to be distinguished by hand. Anyway in further works it is recommended to automate totally the procedure and use an automatic matching software. In our test we chose for eight consecutive sequences with pieces of paper on the water surface and in flood condition, for easy pattern recognition by hand. We measured the image coordinates of 400 points, for each image, using a commercial software for photogrammetry orientation (Figure 5.13 and Figure 5.14). As you could surely see the matched points are not homogeneously distributed. For more accurate results another strategy has to be found to opacify homogeneously the water surface. Anyway an automatic matching could help in that direction, working on a grey scale of the image pixels. This commercial software helped us to collect the image point coordinates with useful tools. With the image point coordinates we were able to execute the orientation of corresponding points with the generalized procedure described along this thesis chapter Part II.

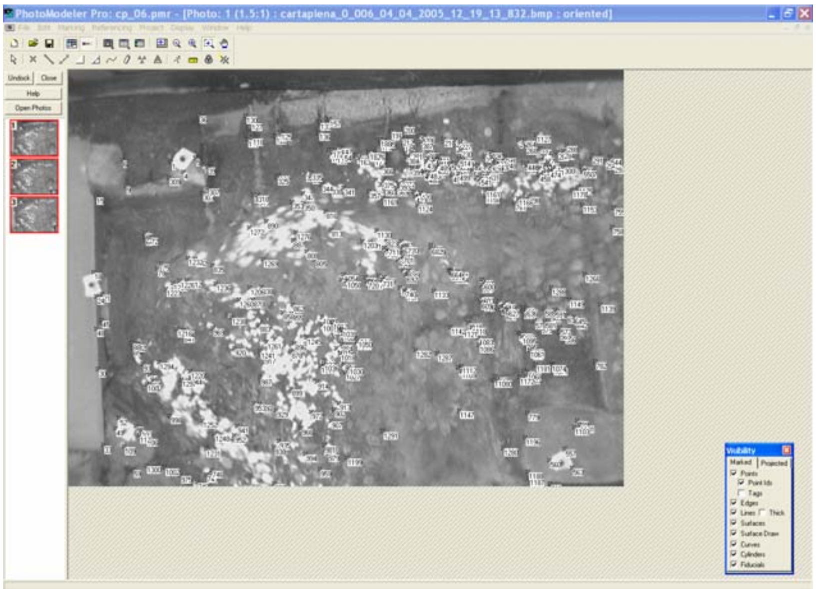


Figure 5.13. Manual Matching of 400 image points (for each image)

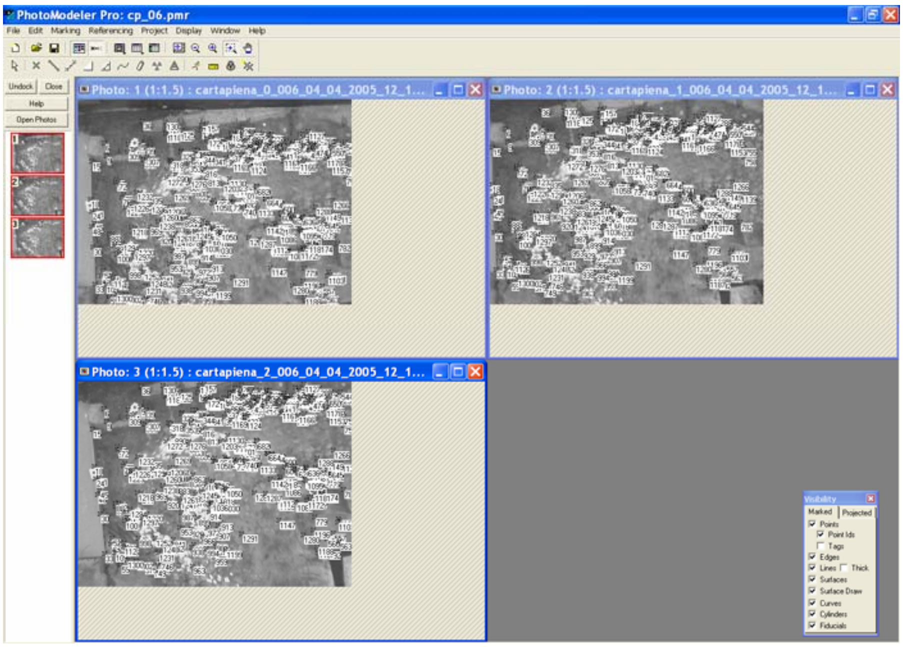


Figure 5.14. Matching of Homologous Points with a Commercial Software for Photogrammetric Orientation

Camera calibration was computed with a standard method, proper of the same commercial software used for the point matching (Table 5.1). Obviously a higher accurate camera calibration could help us for better adjustment results.

Photo #	Camera	Focal Length (mm)	Format Width (mm)	Format Height (mm)
1	web_00	4.637100	3.584000	2.688000
2	web_01	4.876914	3.584000	2.687650
3	web_02	5.004184	3.622600	2.688000

Camera	Principal Point X (mm)	Principal Point Y (mm)	K1	K2	P1	P2
web_00	1.779700	1.335500	0.002052	0.000455	0.002488	-0.002195
web_01	1.781745	1.336895	0.002086	0.000433	-0.000163	0.000799
web_02	1.777600	1.210300	-0.000364	0.000386	-0.000277	0.000204

Table 5.1. Calibrated Camera Parameters.

Sensor orientation was performed by using the generalized procedure proposed along this thesis. For each image 400 points were to be adjusted, automatic matching could be an easy solution (and a good option) for the quick acquisition of many data.

5.2.2.2. Rigorous Adjustment

In a second time we executed the rigorous adjustment with CALGE software. In the same step we are able to detect outliers. In the output files of CALGE we could find all the useful information we need for the physical plotting of DSM for every sequence, and the spatio-temporal interpretation of the water surface dynamics.

5.2.2.3. Spatio-temporal Interpolation (collocation filter – Crippa [217])

After the rigorous adjustment we obtain an irregular field of points (spot). The first thing we had to do was to eliminate the points not belonging to the water surface (e.g. the target on the banks used for the adjustment). This kind of procedure was made manually because of the small number of points. As already said, also this process could be automated for a faster procedure. For example an intersection between the water surface DEM and the empty hydraulic model could be a good way for operating automatically.

Thanks to interpolation and approximation techniques, better explained afterward in this paragraph, we were able to generate a regular grid of points.

We start from the elevation points in function of their 2D position (x, y). We consider the set of data as isotropic, continuous, normal, and stationary of 2-order. Thank to this initial hypothesis we can set all the data with null mean, and then compute the variances and the covariance functions. We operate an iterative computation:

- we chose a reference point, called pivot;
- we compute the mean among a certain number of points with a chosen distance (lag);
- we compute the product between this means and the pivot;
- we repeat the procedure for all the points and all the distances (lag).

With this procedure we are able to obtain the covariance functions.

The empiric estimates do not have the property to be positive definite, we have to interpolate with a suitable model functions with the above mentioned property. In that way, we apply a filter, which permits us to separate the signal form the noise. Obviously we are looking for a large signal and a small noise. This filter permits us also to predict elevations in a regular grid. This step is fundamental for temporal comparison and the related statistical analysis.

In the following graphics (Figure 5.15, Figure 5.16, Figure 5.17, Figure 5.18, Figure 5.19, Figure 5.20, Figure 5.21 and Figure 5.22) you could see the results of these interpolation process. Obviously before the interpolation process, outlier detection was done. In the graphics you can see the plotting of (x, y, z) of the analyzed sequences. Notice that where we do not have information, the interpolation process could not give a reliable result.

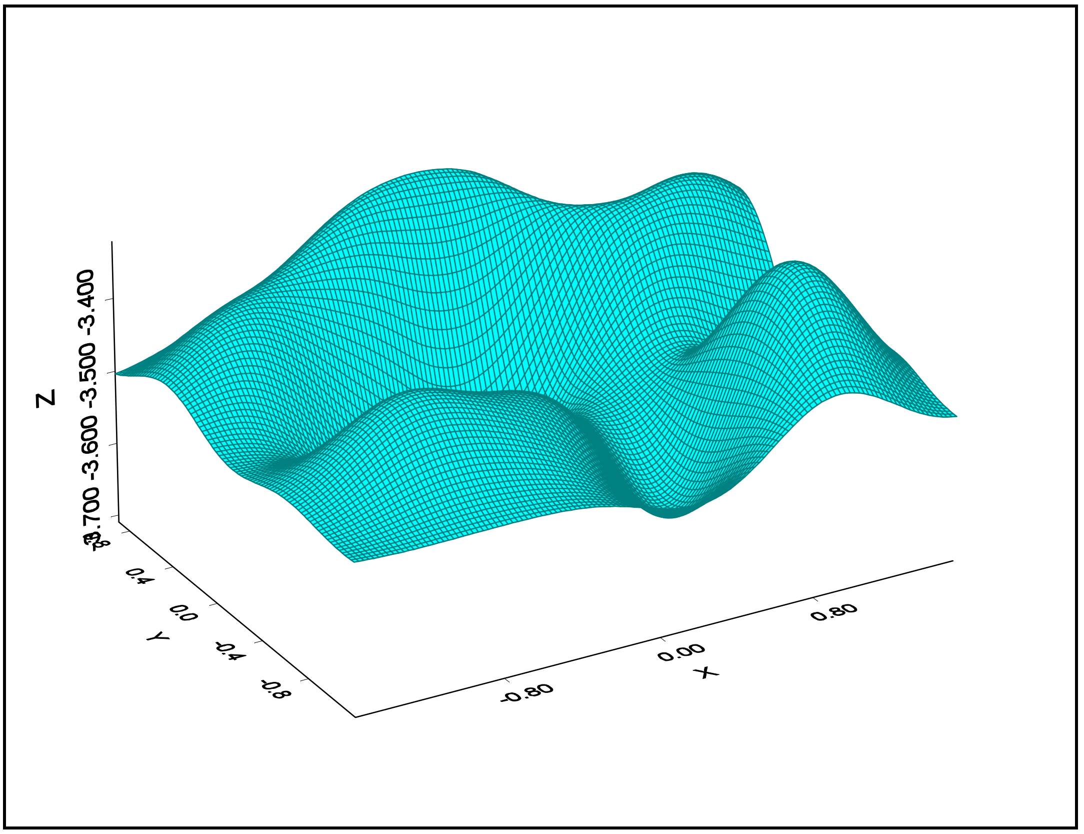


Figure 5.15. Grid Data – Sequence 06

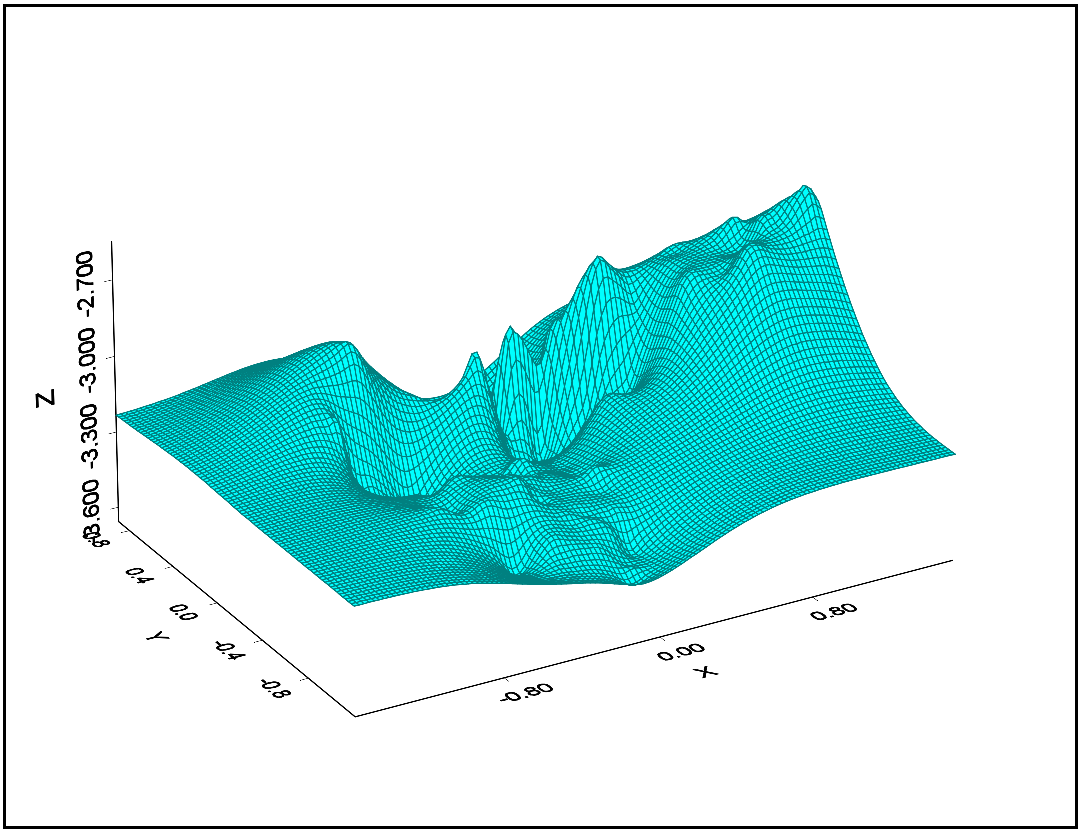


Figure 5.16. Grid Data – Sequence 07

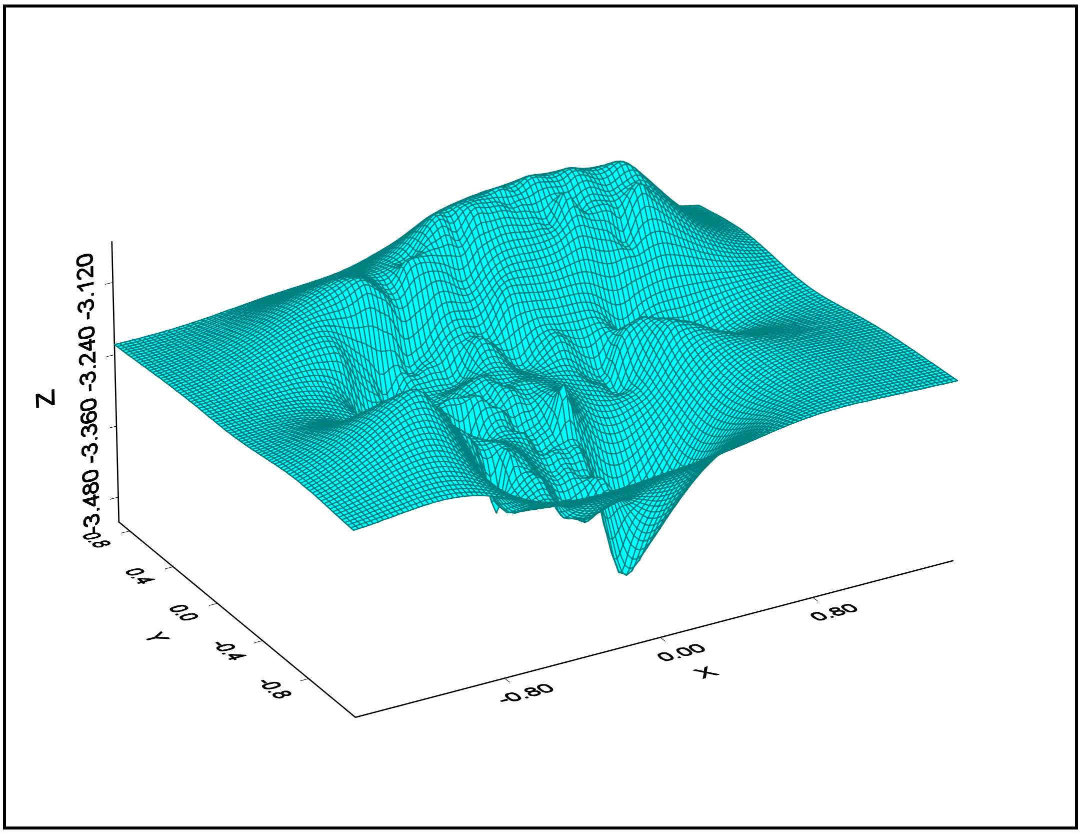


Figure 5.17. Grid Data – Sequence 08

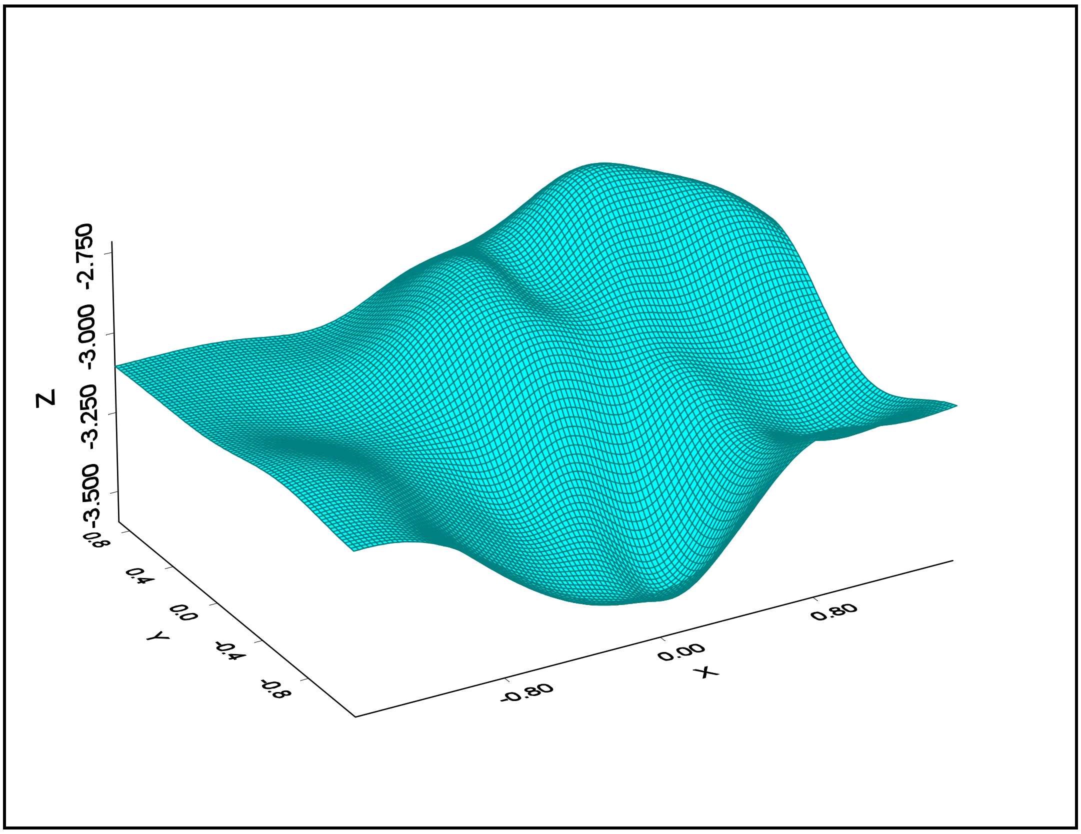


Figure 5.18. Grid Data – Sequence 09

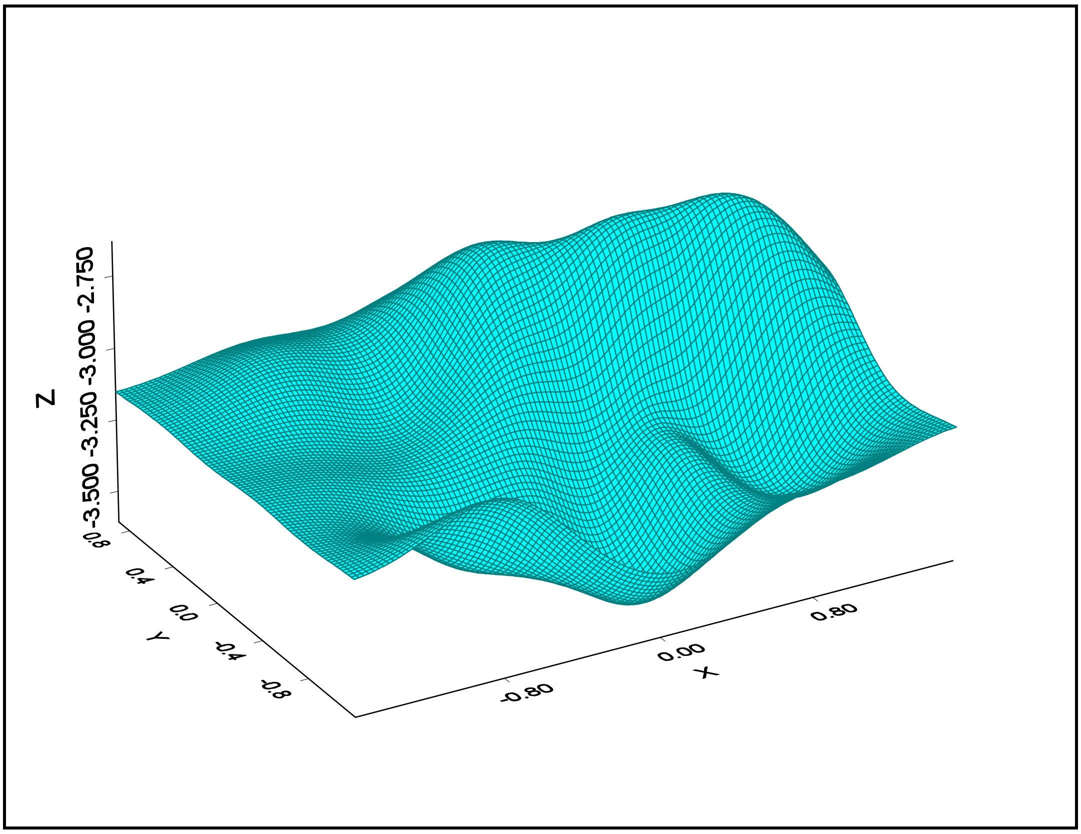


Figure 5.19. Grid Data – Sequence 10

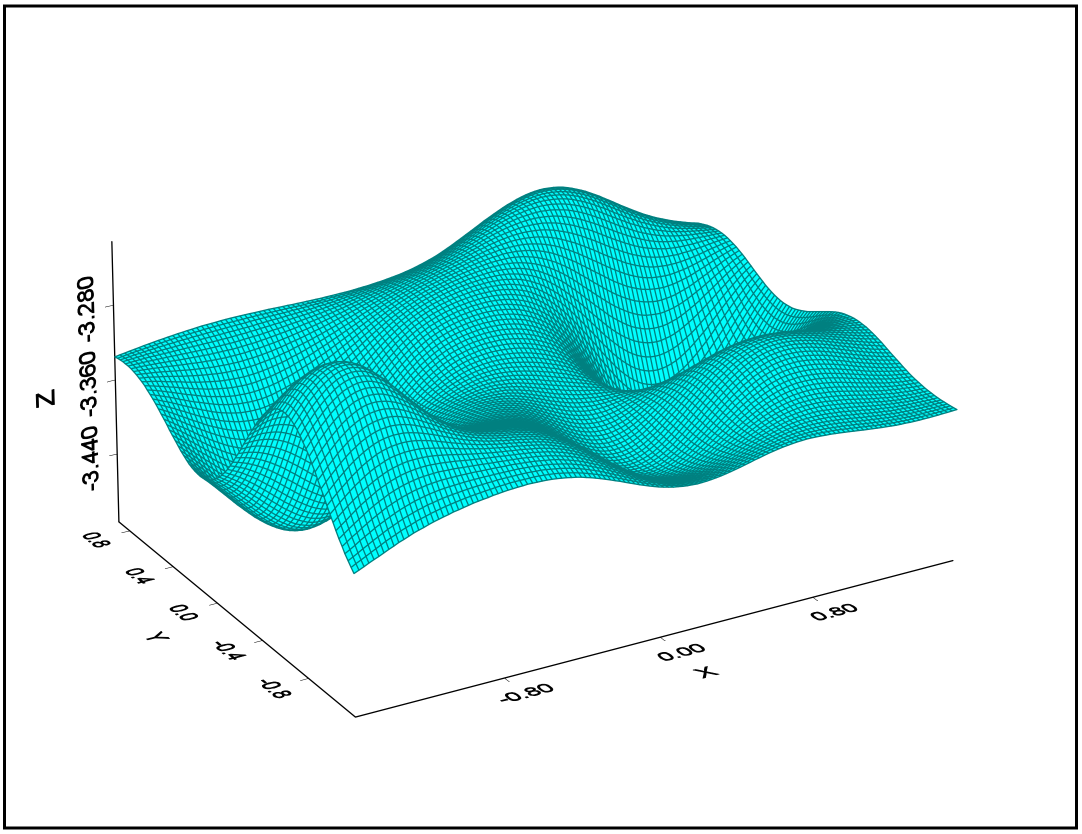


Figure 5.20. *Grid Data – Sequence 11*

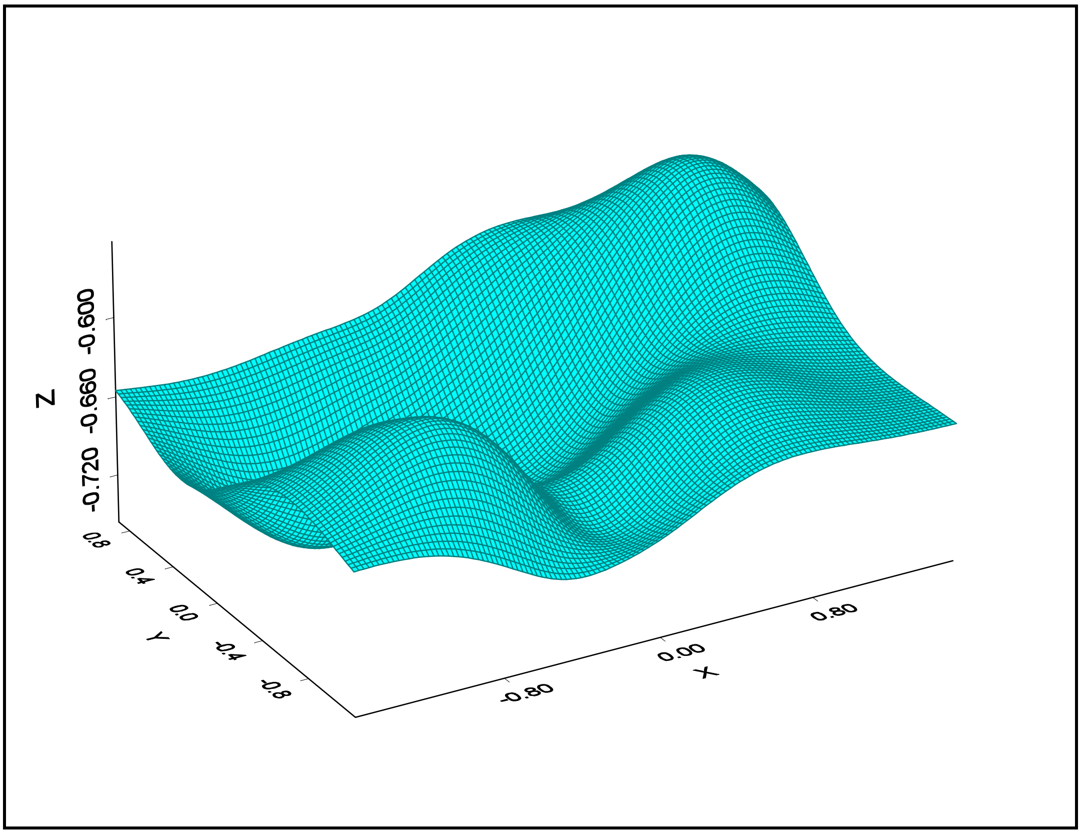


Figure 5.21. *Grid Data – Sequence 12*

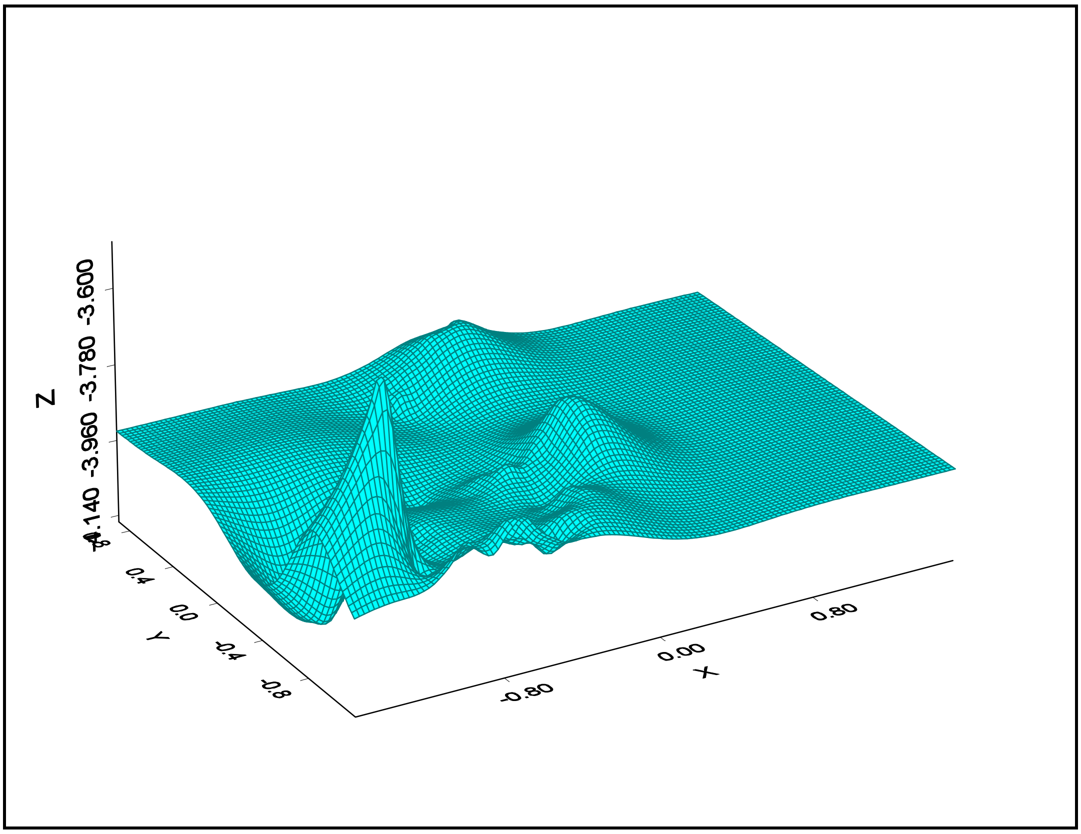
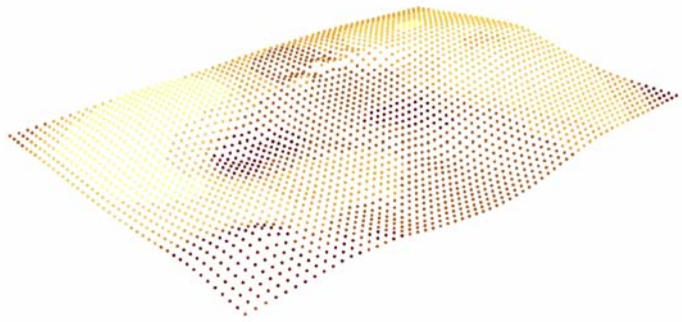


Figure 5.22. Grid Data – Sequence 13

Because of the small number of analyzed sequences a temporal confrontation is not so easy. Anyway we were able to make a temporal analysis with a linear regression to identify the temporal dependency.

Indeed, where the linear correlation coefficient (according to the linear regression estimates) is near to zero, a turbulence zone is found. On the contrary where the same correlation coefficient is quite high, the water behavior is quasi-laminar. This means that the girded points are analyzed separately, taking into account the sequence of eight scenes. However a similar behavior, in term of correlation coefficients, determinates the visualization of turbulence zones and quite-laminar zones, which are represented in a chart with brown and yellow colors respectively.

In the following plots (Figure 5.23) we represent the temporal interpolation. You can see the DSM of the temporal interpolated surface, and the clusters of the correlation index. Notice that algebraic clusters of the correlation index are not present, anyway we decided to represent the cluster graphically, for a better visualization of the areas with different values of ρ.



Caption:

-0.761000	-0.450000
-0.449999	-0.149999
-0.150000	0.150000
0.150001	0.450000
0.450001	0.716000

Figure 5.23. Spatio-temporal interpolation surface: Correlation coefficient clusters

A hydraulic judgment recognizes a concordance between the hydraulic turbulent areas, put in the zone of the confluence, and the above mentioned zones characterized by a low correlation coefficient. For the same reason, a concordance is found between the hydraulic quasi-laminar areas, put in the zone near the borders, and the zones characterized by a relatively high correlation coefficient.

On the other hand, a hydraulic judgment responds the question how the photogrammetric model and the digital surfaces constitute a true representation of the physical hydraulic model, built in the laboratory. Independent direct measurements determined a maximum in the height differences ranged from 1 meter to 1,2 meter. The same measure in the digital surface (i.e. the largest height variation, analyzing all girded points in the sequence of 8 scenes) is 1.06 meter, very well included in the range 1-1,2 meters.

5.3. Photogrammetric Data Management

In chapter 3 we tried to show the actual panorama of data transfer and interoperability for geographic data. Because of the large amount of already existing data and formats many organizations, consortia and committees are involved in standardization projects and data transfer solutions. The purposed solutions are still various, depending on the different aims and goals, but in the last few years thanks to various collaborations and agreements they seem to converge to a unique final one. ISO decided for a model-based transfer, and the graphic formalism used for this purpose is UML. An associated language that could automatically be interpreted is already previewed, but its characteristics are not defined yet. A possible solution could be the Swiss standard INTERLIS (see chapter 3.4.1.1) or a similar one.

During my Ph. D. I had the possibility to spent eight months at ETH of Zurich, and thanks to this stage I managed to learn more about the INTERLIS2 Editor for UML, and we used it to build the conceptual model of a part of our data. XML and GML are two possible formats used by INTERLIS. Working with geographic data we opted for GML, which is more specific for geographic data description. INTERLIS 2 is able to translate automatically the UML model in a GML Schema, avoiding in that way many errors that could occur writing it “by hand”.

INTERLIS is a standard language used since more than 10 years, many compilers could automatically generate transfer model exchange. Its purposes and scopes are presented in chapter 3.4.1.1. INTERLIS permits that models and data can be drawn up in different languages. INTERLIS and UML complement one another: UML diagrams are easy to drawn and ideal for providing a rough overview. By using INTERLIS details may be captured in a precise and nevertheless easy to comprehend form. There are tools that permit automatic conversion of UML class diagrams into INTERLIS descriptions. The reverse is also possible: the representation of an INTERLIS model in UML notation may take place automatically. It is easy to see that this automatic conversion in both senses between UML and INTERLIS is a fundamental advantage of this language and procedure. Moreover INTERLIS does not prescribe any specific XML dialect but supplies rules that allow the automatic derivation of an exchange format from the respective data model. All things considered the question of the data format is secondary: as long as data to be transmitted are based upon similar models their conversion from one format into another requires little effort.

As already said UML is the standard used for the data management adopted by ISO. UML is able to manage relations among object which is a fundamental tool a language has to have for geographic data archiving.

Interoperability among data is really important, even if we don't exchange data. Interoperability is necessary to manage and archive data, even without any transfer. We used already existing techniques for the data description, and in this specific work we used a model driven approach, starting from a conceptual model in UML of our geo-data, that could be automatically be translated in a GML Schema thanks to INTERLIS2 utilities and properties.

A related goal is to allow a valid XML schema to be automatically generated from any UML class diagram, even if the modeler has no familiarity with the XML schema syntax. Having this ability enables a rapid development process and supports reuse of the model vocabularies in several different deployment languages or environments because the core model is not overly specialized to XML.

5.3.1. Conceptual Data Model

The first step of the model-driven approach (MDA) methodology is to specify a UML model. This model should ideally be a conceptual model that hides implementation details so that the model is easy to understand.

Before any data are reformatted or exchanged or treated by any other service, the structure of these data is exactly described on the system, and format, independent conceptual level. A widely used graphical conceptual schema language (CSL) is the unified modeling language (UML).

The UML model shall be defined as a UML class diagram. This approach maps the data in classes, correspondent to the real object we want to store, and every class has different attributes, corresponding to the different attributes of an object. A UML class diagram can be constructed to represent the elements, relationships, and constraints of an XML vocabulary visually. With a little initial coaching, class diagrams allow complex vocabularies to be shared with non-technical business stakeholders. The purpose of the class diagram is to show the static structure of the system being modeled. The diagram specifically shows the entities in the system along which each entity's internal structure and relationships with other entities in the system. Because the classes are shown on a class diagram; specific instances are not shown.

The model-driven approach (we adopted in this phase of the research) addresses tasks around geo-data services by first describing the data to be treated on the system and format independent conceptual level. Data transfer using the model-driven approach starts always with an analysis and a system, and format, independent exact description of the structure of the data to be transferred. This descriptor is called conceptual data model or conceptual schema. The transfer format (description) can then automatically be derived from the conceptual schema according to rules, once fixed a standard, by a piece of software called compiler.

From this conceptual schema, once tested for syntactical correctness by a compiler, can automatically be calculated by the same compiler the description of the corresponding standard transfer format according to fixed rules (e.g. the description of a GML transfer format by the GML Schema language).

Encoding a UML class diagram into a GML/XML Schema can be done in a number of different ways. For that reasons it is very important to have fixed rules and a strategy to compute this transformation, which permit the reversible process and above all only one GML Schema for the same UML Model. As better explained in paragraph 3.4.1.1 INTERLIS enable us to have all these conditions.

One of the main advantages with being model-based is that the conceptual model represented by UML remains unchanged as new technical implementations are defined. The same conceptual model may be used to generate different XML Schemas (such as GML2.0, ISO 19118 XML Encoding and XMI) for the data level as well as other representations. Even if the world embraces a new technological infrastructure tomorrow, the conceptual UML model from yesterday remains the same. New mapping rules must be defined and new code generation tools must be implemented to support the new format. But this work is far more limiting than throwing away all the models and starting all over from scratch.

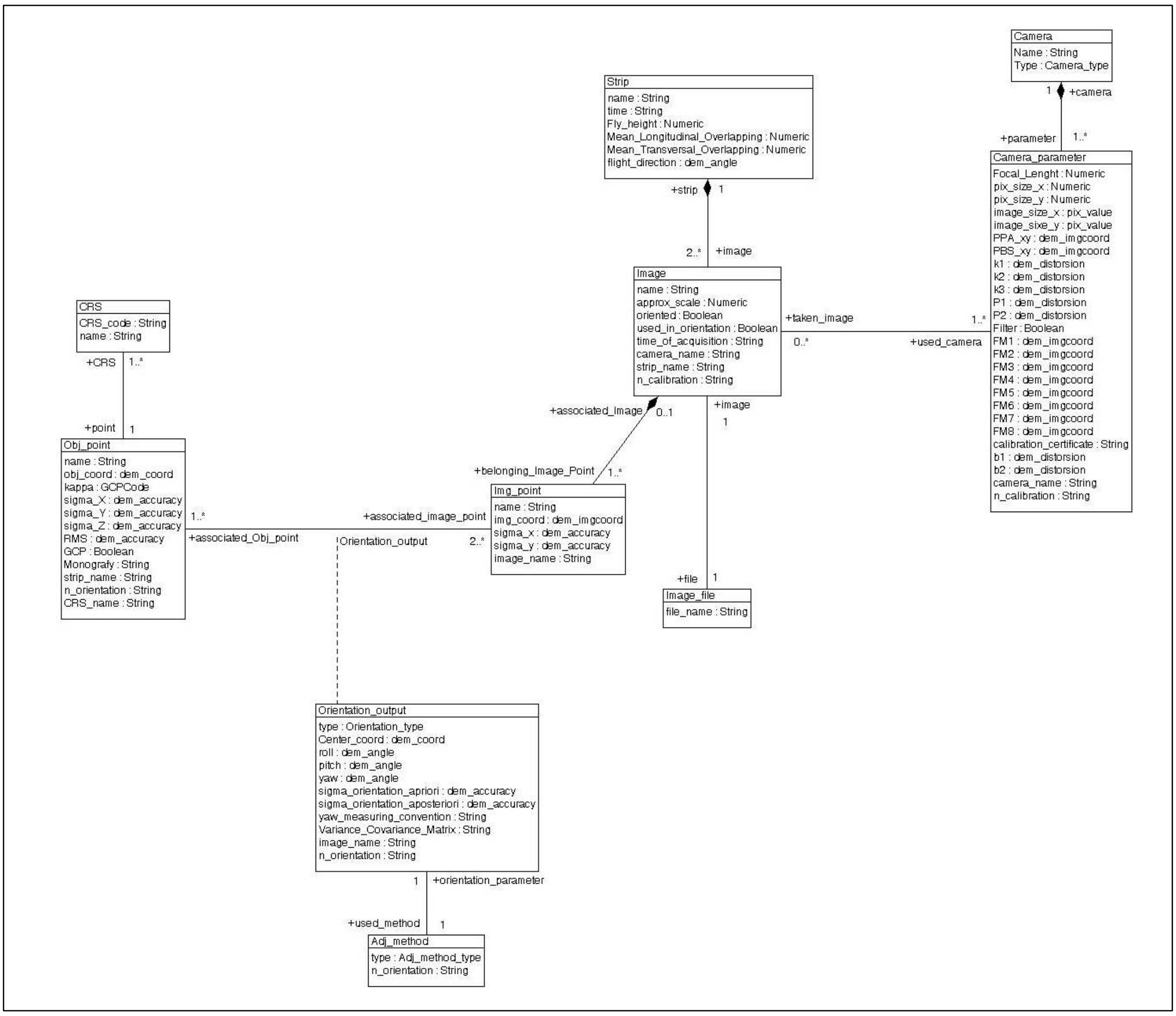


Figure 5.24. UML Model of the Photogrammetric Data

For our data coming from a photogrammetric survey we built the conceptual model of Figure 5.24 with the INTERLIS/UML Editor, where we defined every object of our database as a class, according to the class diagrams approach:

- strip,
- images,
- image file,
- image coordinate,
- camera,
- camera parameter,
- adjusted method,
- CRS
- object coordinate.

As you can see, every class is linked to another one by a relation that could be one-to-one, one-to many, or many-to-many. Every object (class) has different attributes, with different types and/or constraints. An accurate definition of every object and attribute permits an easier codification into the transfer format. In appendix A it is possible to see the whole INTERLIS file corresponding to the UML Model shown afterward.

5.3.2. The Transfer Format Automatically Generated from a Conceptual Model (GML Schema and GML/XML file)

Encoding a UML class diagram into an XML or GML Schema can be done in a number of different ways. As already said, this fact obliged us to act on a different level for exchanging data. Thanks to the model-driven approach and standard encoding rules, a GML Schema (or others transfer formats) could always be automatically regenerated starting from the same conceptual model. In this project a GML-based exchange format was used, whose description is given afterward.

A class in UML defines a complex data structure (and associated behavior) that maps by default to a `complexType` in xsd (Schema file). As a first step, the *DEM_model.Orientation_Info.Img_point* class and its UML attributes produce the following GML Schema definition:

```
<xsd:element name="DEM_model.Orientation_Info.Img_point"
type="DEM_model.Orientation_Info.Img_point" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Img_point">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="name">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="20"/>
            </xsd:restriction>
          </xsd:simpleType>
```

```
        </xsd:element>
        <xsd:element name="img_coord" type="DEM_model.dem_imgcoord"/>
        <xsd:element name="sigma_x" type="DEM_model.dem_accuracy" minOccurs="0"/>
        <xsd:element name="sigma_y" type="DEM_model.dem_accuracy" minOccurs="0"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
```

It is possible to see all the attributes with their own constraints and properties.

In the GML Schema we could find also all the descriptions of object relations. In the following lines we will present a part of the code correlated to the relation *Camera_Camera_parameter*.

```
<xsd:element name="DEM_model.Orientation_Info.Camera_Camera_parameter"
type="DEM_model.Orientation_Info.Camera_Camera_parameter" substitutionGroup="gml:_Feature"/>
                <xsd:complexType name="DEM_model.Orientation_Info.Camera_Camera_parameter">
                  <xsd:complexContent>
                       <xsd:extension base="gml:AbstractFeatureType">
                              <xsd:sequence>
                                     <xsd:element name="parameter" type="gml:ReferenceType">
                                     </xsd:element>
                                     <xsd:element name="camera" type="gml:ReferenceType">
                                     </xsd:element>
                              </xsd:sequence>
                       </xsd:extension>
                  </xsd:complexContent>
                </xsd:complexType>
```

A GML Schema needs a corresponding GML file which contains the data. The GML file (.xml) is a transfer format, it is written in XML grammar and the interpretation is not immediate. In this section we will briefly describe parts of the file. Starting from the GML Schema it was possible to write the corresponding GML file. This step of the work has been automated as much as possible. A short java program was done; it helped to write the GML file and to fill it with the right geo-data. This effort was really useful for any potential further development or modification of the database. Afterward we would like to show some extracts of the GML/XML file.

As in every XML file the first lines we have the declaration of the used version, the encoding rules and the reference web sites for GML specification.

```
<?xml version="1.0" encoding="UTF-8"?>
<DEM_model.Orientation_Info xmlns:gml=http://www.opengis.net/gml
xmlns:xlink="http://www.w3.org/1999/xlink">
```

Then there are the object (the UML classes) with their attributes. Every object needs a unique identifier that appear in the first tag next to the object name, and then you could find a list of the different attributes, with a syntax similar to html. Some examples will follow, object:

- Camera:

```
<DEM_model.Orientation_Info.Camera gml:id="c2">
    <name>web_00</name>
    <type>digital-non professional</type>
</DEM_model.Orientation_Info.Camera>
```

- Object Camera parameter:

```
<DEM_model.Orientation_Info.Camera_parameter gml:id="a1">
    <focal_lenght>4,836</focal_lenght>
    <gml:pos>5,600 5,600</gml:pos>
    <image_size_x>640,000</image_size_x>
    <image_size_y>480,000</image_size_y>
    <gml:pos>1,780 1,336</gml:pos>
    <gml:pos>0,000 0,000</gml:pos>
    <K1>0,00200</K1>
    <K2>0,00047</K2>
    <K3>0,00000</K3>
    <P1>0,00026</P1>
    <P2>0,00041</P2>
    <filter>false</filter>
    <FM1_x>0,000</FM1_x>
    <FM1_y>0,000</FM1_y>
    <FM2_x>0,000</FM2_x>
    <FM2_y>0,000</FM2_y>
    <FM3_x>0,000</FM3_x>
    <FM3_y>0,000</FM3_y>
    <FM4_x>0,000</FM4_x>
    <FM4_y>0,000</FM4_y>
    <FM5_x>0,000</FM5_x>
    <FM5_y>0,000</FM5_y>
    <FM6_x>0,000</FM6_x>
    <FM6_y>0,000</FM6_y>
    <FM7_x>0,000</FM7_x>
    <FM7_y>0,000</FM7_y>
    <FM8_x>0,000</FM8_x>
    <FM8_y>0,000</FM8_y>
    <calibration_certificate>D:\alice\Rilievo\Files
Photomodeler\cp_07\calge_07.txt</calibration_certificate>
    <b1>0,00000</b1>
    <b2>0,00000</b2>
    <camera_name>web_00</camera_name>
    <n_calibration>Photomodeler calibration_1</n_calibration>
</DEM_model.Orientation_Info.Camera_parameter>
```


alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

- Image:

```xml
<DEM_model.Orientation_Info.Image gml:id="i4">
    <name>CARTAPIENA_2_007_04_04_2005_12_19_14_133.BMP</name>
    <approx_scale>50</approx_scale>
    <used_in_orientation>true</used_in_orientation>
    <oriented>true</oriented>
    <date_of_acquisition>04.04.2005</date_of_acquisition>
    <camera_name>web_02</camera_name>
    <strip_name>cp_07</strip_name>
    <n_calibration>Photomodeler calibration_1</n_calibration>
</DEM_model.Orientation_Info.Image>
```

- Image point:

```xml
<DEM_model.Orientation_Info.Img_point gml:id="p0-1">
    <name>1</name>
    <gml:pos>97,223 145,826</gml:pos>
    <sigmax>1,000</sigmax>
    <sigmay>1,000</sigmay>
    <image_name>CARTAPIENA_0_007_04_04_2005_12_19_14_082.BMP</image_name>
</DEM_model.Orientation_Info.Img_point>
```

- Object point:

```xml
  <DEM_model.Orientation_Info.Obj_point gml:id="e2">
    <name>1</name>
    <gml:pos>-0,603 0,412 -2,950</gml:pos>
    <kappa>0</kappa>
    <sigmax>0,41172</sigmax>
    <sigmay>0,01082</sigmay>
    <sigmaz>0,03765</sigmaz>
    <rms>2,25893</rms>
    <gcp>false</gcp>
    <monografy>D:\alice\monography\img_12122000.jpg</monografy>
    <strip_name>cp_07</strip_name>
    <n_orientation>Photomodeler_01</n_orientation>
    <crs_name>WGS 84</crs_name>
</DEM_model.Orientation_Info.Obj_point>
```

- Strip:

```xml
<DEM_model.Orientation_Info.Strip gml:id="s1">
    <name>cp_07</name>
    <strip_date>12.12.2000</strip_date>
    <Fly_height>8000,000</Fly_height>
```


alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

```
    <Mean_Longitudinal_overlapping>0,650</Mean_Longitudinal_overlapping>
    <Mean_Transversal_overlapping>0,180</Mean_Transversal_overlapping>
    <flight_direction>15,000</flight_direction>
</DEM_model.Orientation_Info.Strip>
```

When we started to write the part of the code concerning the object relation we found some difficulties. In fact in the GML specifics [9] the *annex E*, the one relate to object relations codification, is not so clear and detailed, moreover we haven't found any clarifying example about that. After some researches we found that a possible codification of the object relations should contain the identifier of the related object. Afterwards we will show two examples:

```
<DEM_model.Orientation_Info.RelCam_CamParam gml:id="r11">
    <camera xlink:href="#c2" />
    <parameter xlink:href="#a1" />
</DEM_model.Orientation_Info.RelCam_CamParam>

<DEM_model.Orientation_Info.RelImage_Image_point gml:id="r575">
    <associated_image xlink:href="#i2" />
    <belonging_image_point xlink:href="#p0-168" />
</DEM_model.Orientation_Info.RelImage_Image_point>
```

For the relation *Rel_Orientation_output* it was a little bit different, in fact this association has attributes. As you can see afterwards, after the two links to the related object, we have a list of the attributes belonging to that association as it is shown afterward:

```
<DEM_model.Orientation_Info.Rel_Orientation_output gml:id="r63">
    <associated_image_point xlink:href="#e95" />
    <associated_obj_point xlink:href="#p0-100" />
    <Orientation_type>two_step_orientation-adjusted</Orientation_type>
    <gml:pos>0,351 -0,792 -0,175</gml:pos>
    <roll>14</roll>
    <pitch>6,48022</pitch>
    <yaw>0,22038</yaw>
    <sigma__orientation_apriori>999,00000</sigma__orientation_apriori>
    <sigma__orientation_aposteriori>999,00000</sigma__orientation_aposteriori>
    <yaw_measuring_convention>D:\alice\Rilievo\Files
Photomodeler\cp_07\yaw_measuring_convention.txt</yaw_measuring_convention>
    <variance_covariance_matrix>D:\alice\Rilievo\Files
Photomodeler\cp_07\var_cov_matix.txt</variance_covariance_matrix>
    <image_name>CARTAPIENA_0_007_04_04_2005_12_19_14_082.BMP</image_name>
    <n_orientation>Photomodeler_01</n_orientation>
</DEM_model.Orientation_Info.Rel_Orientation_output>
```


alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

5.3.3. *Application Field*

This kind of project it is a very melting pot of disciplines. Photogrammetric survey with an automatic compensation procedure could be useful in many environmental monitoring projects. Moreover this procedure for the data exchange in an interoperable way opens many different possibilities to the data management. Being easier understand and read the data coming from other data collectors also the application of the three image orientation could be more spread wide for no photogrammetric experts.

5.4. PART III CONCLUSIONS

The most current strategies strongly emphasize the role of models. Earlier on, the role of a conceptual model was to guide the implementation and possibly support some future re-engineering activities on the developed system. Nowadays, the role of these conceptual models has been extended as they are seen as mechanism to express system functionality; they can be interchanged and shared to facilitate interoperability among heterogeneous systems. Furthermore, model-driven approach promotes the independence of the application model (system specification) from the implementation technology and platform. Therefore, an application model can be developed independently from any implementation model and may have a formal mapping to many alternative platform infrastructures.

It is very important to notice that we didn't start to write directly the XML file from the GML Schema, nor we didn't start to write the GML Schema from the geo-data, we started from a conceptual model of them. The conceptual model permits to have a consistent description of the data with all the necessary information and constraints to understand them easily. The automatic transformation from the conceptual model to a GML Schema help us to avoid errors in writing the GML Schema "by hand", and also help us to reconstruct a conceptual model from a GML Schema with all the criteria of the inverse step.

In order to complete the presentation of all steps, which lead from data acquisition, through data processing, to data archiving and representation, the following considerations point out some topics about data modeling and mosaicking. Indeed data modeling defines the structure of data storage, while mosaicking collect different tools for data visualization.

Several applications in 3D imaging and modeling require the definition of conceptual models, which imply the knowledge of the 3D topology. Codification of topology is really important to avoid different interpretations of the same object or phenomenon:

- a classical approach lists all Boolean relations and selects among them the admissible ones from a geometric point of view;
- an alternative approach combines the topological and geometric relations between primary elements with the symmetries (in the spaces in which the complex objects are located).

The alternative has been recently developed in Milan; therefore between the two approaches there are some analogies and differences, which are explained in [240] and [241]. In appendix B a conceptual model for 3D modeling is defined according the same cardinalities between the elements of the topological and geometric relations, and the elements of the symmetry groups. Lists of elements of both samples are presented.

About mosaicking there are many implementation problems to be considered. The main difficulty is the boundary connection, which included the problems of database merging.

The necessity to document objects, reproducing continuity of surface, with its colors, geometric forms, perspective figures and degradation aspects carries to consider, beyond to classic shapes of photogrammetric restitution, a wider visualization series. Traditionally photogrammetry produces 2D restitution (maps, perspective-rectification, ortho-images, etc...), which have remarkable limits in many applications, for the difficulties to document, in clear and convenient way, all information referred to surveyed objects. Indeed if 2D restitution is sufficient in particular localization of an architectonic monument, 3D solid model is strictly necessary in its reconstruction. However the impressive development of hardware and software, in the filed of representation and visualization, very advantageously ties Computer Graphics and photogrammetry, offering many tools to manipulate three-dimensional objects.

The application of image raster, in the frame of metric visualization, can happen by several procedures, derived from the link between photogrammetry and Computer Graphics, related to object morphology and 2D or 3D effects to be studied in a cognitive approach. Indeed this approach obtains big advantages using images, due to great possibilities offered by images themselves to read and interpret phenomena and/or processes. Let recall the possibility to evaluate project impacts by simulation, as well to extend data acquisition integrating data of various sources). Moreover photo-realistic representations, based on direct use ortho-images, digital surface models (DSM), draping or texture mapping (i.e. superimposition of ortho-images and DSM), allow better visualizations, where there are excessive density of geometric details and irregularity in object model, related to volume and some other numerical attributes.

To this task, it is important to be able to create an interface, capable to manage information flow in every direction, starting from data and arriving to a synthesis and vice versa, starting from synthetic plans and returning to the analysis. Indeed the application fields involve some relevant questions, where management of large amounts of data is relevant, when different layers of information has to be integrated and how a complete vision of reality and its particulars can be taken into account. Therefore whilst techniques, in order to extract information from images and to reconstruct shape of an object, are in the frame of photogrammetric procedures, techniques, in order to manage and to link together color and shape, are referred to Graphics Computer.

The shapes of restitution of a survey are different because there are a great variety of objects to survey. For many applications a perspective-rectification can be the easier solution. However if the object surface cannot be approximated to a plan, or indirectly solvable in a plan (like for a cylinder, a cone, etc.), as well as to a close sequence of parallel plans, is necessary to improve representation quality, firstly reconstructing a DSM of an object and then producing an ortho-image. Let recall that principal problems in ortho-image production appear when a continuous surface has to be transformed in pixels. Indeed only a good coincidence in term of pixels between DSM and ortho-image guarantees that every pixel of original image fall according to its correct height. This means to correctly project original image pixels in mashes of a triangulation, in case of DSM vector data, or to capture and merge surrounding original image pixels, in case of DSM raster data.

On other hand, surface projection on a plan is not the more adapted way, to represent a generic object, which generally has a curvilinear course. As a consequence, the best solution represents it on a smooth surface. Thus an operating process for generating a digital ortho-image or other geo-referenced digital products realizes them as a vector description, obtained by a superimposition.

- the monoscopic technique is interesting, simple and economic, concurring with a final user (not necessary a specialist of photogrammetric product) to acquire 3D geometric ant thematic information.

- if the obtained ortho-image isn't the best description in object representation, a favorable alternative is given by solid modeling and eventually draping or texture mapping.
- an effective alternative, in case objects are rich of details, is the so-called oriented digital stereo-couple, i.e. an operating structure constituted by two stereoscopic images which are relative and absolute oriented and where suitable vision system permits to explore the stereo-couple.

Nowadays softcopy restitution is supported by digital products, where coordinates and attributes permit to overcome the rigidity of graphical restitution, selecting and assembling several parts according to various types of requests. Raster products replace old analogue 2D maps, which are inadequate for many tasks and present evident difficulties to be save and copied. Indeed 3D documents are powerful, dynamic and interactive, and many products (maps, 3D scenes, texture mapping, etc.) can be derived by, offering a valid alternative in metric and thematic object analysis.

Notice that high quality hardware requirement is important, in order to guarantee high standards in information elaboration, visualization, storage and retrieval. Furthermore hypertexts and multi-medial techniques are useful, in creation of base supports interfaced with GIS.

In conclusion our hope is the implementation of these techniques in our project. Concerning the data modeling some programs were still implemented (e.g. software called STRUCTURE was already implemented. It forms a 3D topology starting from the data, and it recognizes object boundaries and features). While concerning the representation of the photogrammetric data we know that one omnipresent problem is the mosaicking of images. Even in this case our hope is the implementation of some solution in our work. Moreover this is a wide spread topic in geographic data management. Let recall that, during my Ph. D. activities, I had the occasion to meet Dr. Sabry El Hakim of NRC Canada, who is particularly involved in 3D modeling and visualization [108].

6. CONCLUSION

6.1. Summary of the Achievements

After more than three years of research the achievements are many and the future works are still various.

The automation of the photogrammetric process was done. Thanks to a *two step* procedure for the image orientation, an exhaustive research, a linear problem for the absolute orientation and an image triplet we are able to obtain the preliminary values for the orientation, starting point of more refined and accurate orientation procedure (already automate). The survey of the hydraulic model was a really innovative application. The idea of the dynamic survey was suggested by experts as an interesting integration of the traditional and qualitative analysis already existing. The application permits also to test this non conventional procedure, and even if we used low resolution camera, we were able to verify and validate some of the hydraulic expected results and phenomena.

Once more the photogrammetric data modeling highlight many issues related to the geo-data archiving and their interoperability. A geo-data model for the description of data coming from photogrammetry survey was done. In this contest the integrated approach for data post-analysis is also an important achievement following the tradition of our department we create this powerful tool for an a posteriori control of the data.

In conclusion the achieved goals are:

- the creation of a new procedure for the automatic orientation of three simultaneous images for non–conventional photogrammetry;
- an integrated approach for the statistical data processing from robust adjustment to interpolation techniques for continuous data (this step uses already existing tools previously developed and implemented in Milan);
- the description of geo-data coming from photogrammetric survey with GML/XML language for interoperability data exchange;
- the survey of a hydraulic model to test the whole procedure.

Parts of this thesis were presented in some national and international meetings [229], [230], [231], [232], [233], [234], [240], [241]. As already said this thesis was developed in Milan, Lyon and Zurich. The movement among three places responded to a precise request. Indeed Milan had a long tradition in data processing and photogrammetry, Lyon the same tradition in computer science and geomatics, and Zurich had a long tradition in geomatics and data processing. This thesis studied innovative data processing and original photogrammetric modeling, which had to been inserted in the broad field of geomatics (terrain, images and visualization), also by means of several computer science techniques. The complementary capabilities of the three places respond very well to the above mentioned need.

6.2. FUTURE WORKS

The field of the geo-data exchange is in development and right for this reason the possible improvements of this thesis in that direction are still various. First of all the graphic problems of data modeling, and representation and mosaicking (already studied) could be included in this procedure and in the geo-data archiving treatment.

3D imaging and modeling require the definition of conceptual models, taking into account 3D topology. Since a classical approach analyzes all Boolean relations and selects among them the admissible ones from a geometric point of view, its practicability becomes very hard in 3D. Let recall that 4!, which represents the permutations of four letters, is equal to 24, while 8!, which represents the permutations of eight letters, is greater tham 40,000. Therefore being a square an elementary figure in 2D and a cube an elementary body in 3D, the first analysis is realistically feasible and the second one is not.

On the contrary an alternative approach considers topological and geometric relations between primary elements and compares them with symmetry elements (in the spaces in which the complex objects are located). The symmetries are algebraic groups, whose properties are well known (particularly it is easy to rank their cardinalities). Therefore according to these numbers, we fixed a certain numbers of relations among points, lines, faces and bodies, and between themselves. The obtained results are an incidence table between lines and points, an adjacence table between faces and bodies, and a cross-connection table between lines and faces. Starting from this primary information, duality and combination perform new information for further analysis.

After classical photogrammetric restitution a wider visualization series respond to the necessity to document objects, reproducing continuity of surface, with its colors, geometric forms, perspective figures and degradation aspects. Since 2D restitution (maps, perspective-rectification, ortho-images, etc.) has remarkable limits in many applications, 3D solid model is strictly necessary in the manipulation of three-dimensional objects. Let recall that the impressive development of hardware and software, in the field of representation and visualization, links computer graphics and photogrammetry.

Raster, like photo-realistic representations, based on direct use ortho-images, digital surface models (DSM), draping or texture mapping (i.e. superimposition of ortho-images and DSM), allow better visualizations, where there are excessive density of geometric details and irregularity in object model, related to volume and some other attributes. Moreover it permits the possibility to study project impacts by simulation, as well as to extend data acquisition integrating data of various sources.

A short list of detailed applications is briefly analyzed. The easiest solution is a perspective-rectification. On the other hand, because many object surfaces cannot be approximated to a plan (or to an euclidean surface), a DSM generation (e.g. by TIN) and an ortho-image production realize an optimal solution in 2D, completed by a superimposition of vector elements. Sometimes the study case is an object, which has got three comparable dimensions, so that 2D representation is largerly inadequate to characterize it. However 3D representation constitutes a powerful, flexible and interactive tool (mosaicking, 3D scenes, texture mapping, etc.), offering a valid alternative in metric and thematic object analysis.

The need of high quality requires adequate hardware and software, to assure an elevated standard in information elaboration, visualization, storage and retrieval, where hypertexts and multi-medial techniques provide to realize supports interfaced with GIS. Notice that GIS are largerly used since many time in 2D applications and for quasi-static databases, while the most promizing fields of interest involve 3D applications and dynamic behavior of phenomena and/or processes.

Concerning geo-data exchange the possible improvements and applications are really wide. One useful work could be the creation of a web tool for download the data in XML format. An auspicious development could be also the automatic integration with a GIS where for example we could obtain addictional information about hydraulic behavior or historical events. And even more interesting could be the integration of this database with an ontology plug in to avoid language inconsistencies. It is really important consider the internationalization of the database, making more fruible the geodata and usable by more people without the intervention of a person that has to translate.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

7. APPENDIX

A. SPATIO-TEMPORAL MODELING OF SCENE SEQUENCES: AN INTEGRATED APPROACH

A.1. Interpolation Techniques

Least squares methods and some other related procedures (e. g., cluster analysis, multiple regression, variance analysis, covariance estimation and linear filtering, robust procedures) are usually appropriate for two types of problems:

- network adjustment;
- interpolation and approximation.

In the first one, the observables are functions of point position differences, whilst in the second they are functions of point positions. Both point positions and the point position differences could depend on time.

The observables, depending on point position and time, are influenced by physical fields too, according to the data collection procedures.

Morphological factors and/or eventual kinematics parameters are functions of the point position, since they are supposed to have a similar behavior in the neighboring points.

In the case of network adjustment, the geometrical model is quite familiar. On the contrary, in the second one two main sub-cases may occur:

- a deterministic law for the behavior of the phenomenon under study has been previously checked, by a variety of causes, that may be physical, geometrical, or others;
- no deterministic law is previously known for the phenomenon behavior.

Least squares methods and some other related procedures may give solution to an important group of problems of image processing and spatial data analysis, as for example:

- network/block/joint adjustment;
- surface reconstruction, from descriptors;
- feature extraction and parsing;
- image/map/object matching.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

Going further to the above said division of adjustment and interpolation/approximation problems of photogrammetry, remote sensing, GIS and generally, of survey and mapping, the first area collects:

- triangulation of images: spaceborne, airborne and terrestrial;
- GPS and IMU (inertial measurement unit) navigation data processing, automatic surveying (robotics).

Prior to processing, it should be pointed out a pre-processing of data collected by space photogrammetry and remote sensing techniques with due care, as well as by satellite geodesy and related sciences.

As far as interpolation and approximation are concerned, one should remind a class of problems of photogrammetry, remote sensing and GIS, related to:

- measurement devices (camera calibration and other systems and sensors) and secondary effects;
- morphological feature extraction and grouping, image/map/object matching;
- shape from shading and phase unwrapping;
- DEM generation, orthoimage production and superimposition;
- transforming "spaghetti" into topologically consistent structures and mosaicking of convex hulls and concave stellar or not objects;
- image processing by spatial data analysis (classification) and understanding (semantic interpretation).

Regarding the solution strategies, there are three classes of data:

- network structures;
- dense, but irregular, fields of points;
- raster data and grid parameters,
- which imply some different numerical techniques:
- direct algorithms;
- iterative methods;
- special tools, involving regularity.

Notice that these problems usually involve a large number of observations and parameters; as a consequence, require the solution of large systems, i.e. systems with a large number of equations and unknowns.

A.1.1. The generalized Least Squares

A unique system collects all the observation and pseudo-observation equations, referred to observables and other data $\mathbf{y}$, and contains uncorrelated unknown parameters $\mathbf{x}$, as well as correlated ones that can be interpreted as stochastic signal $\mathbf{s}$ to filter from the random noise $\mathbf{n}$:

$$\mathbf{y} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{s} \tag{7.1}$$

The use of both stochastic and non-stochastic parameters causes the need to introduce a hybrid norm:

$$\frac{1}{2}\left[\hat{\mathbf{s}}^T \hat{\mathbf{n}}^T\right]\begin{bmatrix} \mathbf{C}_{ss}^{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{P}/\sigma_n^2 \end{bmatrix}\begin{bmatrix} \hat{\mathbf{s}} \\ \hat{\mathbf{n}} \end{bmatrix} + \boldsymbol{\lambda}^T\left(\mathbf{A}\hat{\mathbf{x}} + \mathbf{B}\hat{\mathbf{s}} - \hat{\mathbf{n}} - \mathbf{y}_0\right) = \min \tag{7.2}$$

where $\mathbf{y}_0$ indicates the observations, $\hat{\mathbf{x}}$, $\hat{\mathbf{s}}$, $\hat{\mathbf{n}}$ the estimated values of x, $\mathbf{s}$ and $\mathbf{n}$ respectively, $\mathbf{C}_{ss}$ the covariance matrix the signal, σ_n^2 the variance of the noise, $\mathbf{P}$ the weight matrix of the observations and $\boldsymbol{\lambda}$ a vector of Lagrange multipliers.

Unfortunately the solution of this kind of system isn't practically computable. Indeed it presents heavy computations, from the point of view of both storage requirements and time consuming, because the unknown parameters are split in two separate parts.

Therefore the above mentioned system of observation equations is rewritten as: $\mathbf{y} = \mathbf{B}\mathbf{s}$, with **s** containing both stochastic and non-stochastic parameters: $\mathbf{s}^T = \left[\mathbf{x}^T \ \mathbf{s}^T\right]$, and the design matrix $\mathbf{B}$ defined as: $\mathbf{B} = \left[\mathbf{A}\ \mathbf{B}\right]$, expressing both to chosen functional and stochastic modeling. The observed quantities $\mathbf{y}_0$ are related to the estimates $\hat{\mathbf{s}}$ of **s** by the same linearized model:

$$\mathbf{B}\hat{\mathbf{s}} - \hat{\mathbf{n}} - \mathbf{y}_0 = \mathbf{0} \tag{7.3}$$

The covariance matrix $\mathbf{C}_{ss}$ for the newly defined signal $\mathbf{s}$ contains four blocks, two diagonal blocks containing the covariance matrices of the stochastic and non-stochastic parts of the signal and two zero off-diagonal blocks:

$$\mathbf{C}_{ss} = \begin{bmatrix} h\mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{C}_{ss} \end{bmatrix} \tag{7.4}$$

The covariance matrix of the stochastic parameters is determined by one or more auto and crossvariance functions, which can be estimated empirically with the results of preceding separate adjustments. The covariance matrix of the non-stochastic parameters is a diagonal matrix, the elements of which (if not related to constraints) have to be chosen in balance with the covariance's of the stochastic parameters. In such a way, the solution is not constrained too much to either type of parameters.

The general variance of the noise which also has to be known a priori can be assumed equal to the estimated variance factor of preceding separate adjustments.

The generalized least squares criterion can be used to minimize simultaneously the norm $\hat{\mathbf{s}}^T \mathbf{C}_{ss} \hat{\mathbf{s}}$ and the norm of the residuals of the observation equations $\hat{\mathbf{n}}^T \mathbf{P}\hat{\mathbf{n}} / \sigma_n^2$:

$$\frac{1}{2}\begin{bmatrix} \hat{\mathbf{s}}^T & \hat{\mathbf{n}}^T \end{bmatrix} \begin{bmatrix} \mathbf{C}_{ss}^{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{P}/\sigma_n^2 \end{bmatrix} \begin{bmatrix} \hat{\mathbf{s}} \\ \hat{\mathbf{n}} \end{bmatrix} + \boldsymbol{\lambda}^T \left(\mathbf{B}\hat{\mathbf{s}} - \hat{\mathbf{n}} - \mathbf{y}_0 \right) = \min \tag{7.5}$$

According to this criterion, the estimate for the signal and noise becomes:

$$\hat{\mathbf{s}} = \mathbf{C}_{ss}\mathbf{B}^T \left(\mathbf{B}\mathbf{C}_{ss}\mathbf{B}^T + \sigma_n^2 \mathbf{P}^{-1} \right)^{-1} \mathbf{y}_0 \tag{7.6}$$

$$\hat{\mathbf{n}} = \sigma_n^2 \mathbf{P}^{-1} \left(\mathbf{B}\mathbf{C}_{ss}\mathbf{B}^T + \sigma_n^2 \mathbf{P}^{-1} \right)^{-1} \mathbf{y}_0 = \mathbf{y}_0 - \mathbf{B}\hat{\mathbf{s}} \tag{7.7}$$

and the covariance propagation law permits to compute their covariance matrices:

$$\mathbf{C}_{ee} = \mathbf{C}_{ss} - \mathbf{C}_{\hat{s}\hat{s}} = \mathbf{C}_{ss} \left(\mathbf{I} - \mathbf{B}^T \left(\mathbf{B}\mathbf{C}_{ss}\mathbf{B}^T + \sigma_n^2 \mathbf{P}^{-1} \right)^{-1} \mathbf{B}\mathbf{C}_{ss} \right) \tag{7.8}$$

$$\mathbf{C}_{nn} = \sigma_n^4 \mathbf{P}^{-1} \left(\mathbf{B}\mathbf{C}_{ss}\mathbf{B}^T + \sigma_n^2 \mathbf{P}^{-1} \right)^{-1} \tag{7.9}$$

being: $\mathbf{e} = \mathbf{s} - \hat{\mathbf{s}}$ the estimation error of the signal.

The computation of the preceding expressions requires the solution of a system with dimension m, equal to the number of observations. However it would be more convenient to have analogous expressions, which require the solution of a system with dimension $n < m$, equal to the number of parameters. A further requirement would be the absence of inverse matrices which contain inverse matrices. Both can be achieved by the application of the two famous theorems of linear algebra, which are stated below:

$$\left(\mathbf{Q} \pm \mathbf{RST} \right)^{-1} = \mathbf{Q}^{-1} \mp \mathbf{Q}^{-1}\mathbf{R} \left(\mathbf{S}^{-1} \pm \mathbf{T}\mathbf{Q}^{-1}\mathbf{R} \right)^{-1} \mathbf{T}\mathbf{Q}^{-1} \tag{7.10}$$

and:

$$\mathbf{Q}^{-1} \left(\mathbf{Q}^{-1} \pm \mathbf{S} \right)^{-1} \mathbf{Q}^{-1} = \left(\mathbf{Q} \pm \mathbf{QSQ} \right)^{-1} \tag{7.11}$$

Therefore the estimate for the noise can be rewritten as:

$$\hat{\mathbf{n}} = \mathbf{y}_0 - \mathbf{B} \left(\left(\mathbf{B}^T \mathbf{PB} \right)^{-1} - \sigma_n^2 \left(\mathbf{B}^T \mathbf{PB}\mathbf{C}_{ss}\mathbf{B}^T \mathbf{PB} + \sigma_n^2 \mathbf{B}^T \mathbf{PB} \right)^{-1} \right) \mathbf{B}^T \mathbf{P}\mathbf{y}_0 = \mathbf{y}_0 - \mathbf{B}\hat{\mathbf{s}} \tag{7.12}$$

Furthermore taking into account the last expression, the estimate for the signal becomes:

$$\hat{\mathbf{s}} = \left(\mathbf{B}^T\mathbf{PB}\right)^{-1}\mathbf{B}^T\mathbf{Py}_0 - \sigma_n^2\left(\mathbf{B}^T\mathbf{PBC}_{ss}\mathbf{B}^T\mathbf{PB} + \sigma_n^2\mathbf{B}^T\mathbf{PB}\right)^{-1}\mathbf{B}^T\mathbf{Py}_0 \quad (7.13)$$

With these new expressions, the covariance propagation law permits the computation of the corresponding covariance matrices, in equally convenient forms. Thus the covariance matrices of the estimation error of the signal and the residual noise become, respectively:

$$\mathbf{C}_{ee} = \mathbf{C}_{ss} - \mathbf{C}_{\hat{s}\hat{s}} = \sigma_n^2\left(\mathbf{B}^T\mathbf{PB}\right)^{-1} - \sigma_n^4\left(\mathbf{B}^T\mathbf{PBC}_{ss}\mathbf{B}^T\mathbf{PB} + \sigma_n^2\mathbf{B}^T\mathbf{PB}\right)^{-1} \quad (7.14)$$

$$\begin{aligned}\mathbf{C}_{\hat{n}\hat{n}} &= \sigma_n^2\mathbf{P}^{-1} - \mathbf{BC}_{ee}\mathbf{B}^T = \sigma_n^2\left(\mathbf{P}^{-1} - \mathbf{B}\left(\mathbf{B}^T\mathbf{PB}\right)^{-1}\mathbf{B}^T\right) + \\ &+ \sigma_n^4\mathbf{B}\left(\mathbf{B}^T\mathbf{PBC}_{ss}\mathbf{B}^T\mathbf{PB} + \sigma_n^2\mathbf{B}^T\mathbf{PB}\right)^{-1}\mathbf{B}^T\end{aligned} \quad (7.15)$$

Notice that, as already said before, heavy computation doesn't occur, from the point of view of both storage requirements and time consuming.

Let recall that, in case both the matrices $\mathbf{B}$ and $\mathbf{P}$ are identity matrices, the problem becomes a filtering of the stochastic signal from the random noise only. Therefore:

$$\hat{\mathbf{s}} = \mathbf{C}_{ss}(\mathbf{C}_{ss} + \sigma_n^2\mathbf{I})^{-1}\mathbf{y}_0 = \mathbf{y}_0 - \hat{\mathbf{n}} \quad \text{and} \quad \hat{\mathbf{n}} = \sigma_n^2(\mathbf{C}_{ss} + \sigma_n^2\mathbf{I})^{-1}\mathbf{y}_0 = \mathbf{y}_0 - \hat{\mathbf{s}} \quad (7.16, 7.17)$$

and the covariance matrices of the estimation error of the signal and the residual noise become, respectively:

$$\begin{aligned}\mathbf{C}_{ee} &= \mathbf{C}_{ss} - \mathbf{C}_{\hat{s}\hat{s}} = \mathbf{C}_{ss} - \mathbf{C}_{ss}(\mathbf{C}_{ss} + \sigma_n^2\mathbf{I})^{-1}\mathbf{C}_{ss} = \sigma_n^2\mathbf{I} - \mathbf{C}_{\hat{n}\hat{n}} \\ \mathbf{C}_{\hat{n}\hat{n}} &= \sigma_n^4(\mathbf{C}_{ss} + \sigma_n^2\mathbf{I})^{-1}\end{aligned} \quad (7.18, 7.19)$$

In this case, the calculation goes quickly, in a very easy way.

Finally by replacing $\hat{\mathbf{s}}$ with $\hat{\mathbf{x}}$ and $\mathbf{B}$ with $\mathbf{A}$, forcing a little the previous general expressions and evaluating σ_n^2 is equal to zero, the classical least squares solution is achieved, because second term of both expressions vanishes:

$$\hat{\mathbf{x}} = \left(\mathbf{A}^T\mathbf{PA}\right)^{-1}\mathbf{A}^T\mathbf{Py}_0 \quad \text{and} \quad \hat{\mathbf{v}} = \mathbf{y}_0 - \mathbf{A}\hat{\mathbf{x}} = \mathbf{y}_0 - \hat{\mathbf{y}} \quad (7.20, 7.21)$$

Regarding the covariance matrices, defining the cofactor matrices without sigma naught, as usual in the standard form, one gets:

$$\mathbf{C}_{\hat{x}\hat{x}} = \sigma_{'0}^2 \left(\mathbf{A}^T \mathbf{PA}\right)^{-1} \tag{7.22}$$

and:

$$\mathbf{C}_{\hat{v}\hat{v}} = \sigma_0^2 \left(\mathbf{P}^{-1} - \mathbf{A}\left(\mathbf{A}^T \mathbf{PA}\right)^{-1} \mathbf{A}^T\right) = \sigma_0^2 \mathbf{P}^{-1} - \mathbf{AC}_{\hat{x}\hat{x}} \mathbf{A}^T = \sigma_0^2 \mathbf{P}^{-1} - \mathbf{C}_{\hat{y}\hat{y}} \tag{7.23}$$

where the second term of both expressions vanishes once more.

The generalized least squares criterion, expressed in the formulation of the collocation method, can provide, besides an estimate for a filtered signal, also an estimate for a predicted signal. Indeed the stochastic parameters can also be estimated in points which don't make part of the data. One has to keep in mind however, that only the properly called stochastic parameters can be estimated.

As a consequence, the covariance matrix consists of the properly called stochastic parameters only and the cross-covariance matrix between the filtered and the predicted signal is divided in two parts: one containing the covariance between the predicted signal and the properly called stochastic parameters in the filtered signal and one identically zero. This null matrix is exactly the reason of the impossibility to predict the parameters which are strictly non stochastic.

Given the functional:

$$\frac{1}{2}\left[\hat{\mathbf{s}}^T \quad \hat{\mathbf{t}}^T \quad \hat{\mathbf{n}}^T\right]\begin{bmatrix} \mathbf{\Omega}^{-1} & \mathbf{0} \\ \mathbf{0} & \mathbf{P}/\sigma_n^2 \end{bmatrix}\begin{bmatrix} \hat{\mathbf{s}} \\ \hat{\mathbf{t}} \\ \hat{\mathbf{n}} \end{bmatrix} + \boldsymbol{\lambda}^{\mathbf{t}}(\mathbf{B}\hat{\mathbf{s}} + \mathbf{0}\hat{\mathbf{t}} + \hat{\mathbf{n}} - \mathbf{y}_0) = \min \tag{7.24}$$

where:

$$\mathbf{\Omega} = \begin{bmatrix} \mathbf{C}_{ss} & \mathbf{C}_{st} \\ \mathbf{C}_{ts} & \mathbf{C}_{tt} \end{bmatrix} \tag{7.25}$$

being λ a vector of Lagrange multipliers, and taking into account the expression of the estimate for the filtered signal one has:

$$\hat{\mathbf{t}} = \mathbf{C}_{ts}\mathbf{B}^T\left(\mathbf{BC}_{ss}\mathbf{B}^T + \sigma_n^2\mathbf{P}^{-1}\right)^{-1}\mathbf{y}_0 = \mathbf{C}_{ts}\mathbf{B}^T\mathbf{PB}\left(\mathbf{B}^T\mathbf{PBC}_{ss}\mathbf{B}^T\mathbf{PB} + \sigma_n^2\mathbf{B}^T\mathbf{PB}\right)^{-1}\mathbf{B}^T\mathbf{Py}_0 \tag{7.26}$$

or:

$$\hat{\mathbf{t}} = \mathbf{C}_{ts}\mathbf{z} \tag{7.27}$$

with a service vector:

$$\mathbf{z} = \mathbf{B}^T\mathbf{PB}\left(\mathbf{B}^T\mathbf{PBC}_{ss}\mathbf{B}^T\mathbf{PB} + \sigma_n^2\mathbf{B}^T\mathbf{PB}\right)^{-1}\mathbf{B}^T\mathbf{Py}_0 \tag{7.28}$$

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

which is to be computed once at the end of the filtering (notice: $\mathbf{z} = \left(\mathbf{C}_{ss} + \sigma_n^2 \mathbf{I}\right)^{-1} \mathbf{y}_0$ if $\mathbf{B} = \mathbf{P} = \mathbf{I}$).

Applying the covariance propagation law, the covariance matrix of estimation error of the predicted signal becomes:

$$\mathbf{C}_{ee} = \mathbf{C}_{tt} - \mathbf{C}_{\hat{t}\hat{t}} = \mathbf{C}_{tt} - \mathbf{C}_{ts}\mathbf{B}^T\mathbf{P}\mathbf{B}\left(\mathbf{B}^T\mathbf{P}\mathbf{B}\mathbf{C}_{ss}\mathbf{B}^T\mathbf{P}\mathbf{B} + \sigma_n^2\mathbf{B}^T\mathbf{P}\mathbf{B}\right)^{-1}\mathbf{B}^T\mathbf{P}\mathbf{B}\mathbf{C}_{st} \tag{7.29}$$

Unfortunately this expression isn't very convenient in computation and it is impossible to find others more suitable. Therefore its computation is usually omitted.

The variance of the noise can also be estimated a posteriori. Imposing its estimate to be unbiased, one obtains:

$$k = m - n + Tr\left(\sigma_n^2 \mathbf{P}^{\frac{1}{2}}\mathbf{B}\left(\mathbf{B}^T\mathbf{P}\mathbf{B}\mathbf{C}_{ss}\mathbf{B}^T\mathbf{P}\mathbf{B} + \sigma_n^2\mathbf{B}^T\mathbf{P}\mathbf{B}\right)^{-1}\mathbf{B}^T\mathbf{P}^{\frac{1}{2}}\right) \tag{7.30}$$

where m is the number of observations and n the number of parameters (notice: $k = m\text{-}n$, if $\sigma_n^2 = 0$). Therefore the a posteriori estimate of the variance of the noise becomes: $\hat{\sigma}_n^2 = \hat{\mathbf{n}}^T \mathbf{P}\, \hat{\mathbf{n}} / k$. The same formula can be used for the a posteriori estimate of variances and therefore also of weights of a priori defined groups of observations.

A.1.2. Covariance estimation

Covariance estimation and covariance function modeling are very important, because collocation filtering and prediction require appropriate models to interpolate the empirical covariance functions of the signal.

A hypothesis has been made: the data can be seen as realizations of a continuous, linear and normal stochastic process where: $C(P_1, P_2) = C(\|P_1 - P\|_2)$.

Notice that spatial stochastic processes can be assumed isotropic, as well as with orthogonal separability among the coordinates. The former uses the Euclidean distance which is invariant on a circle (a sphere, a hypersphere); the latter uses the Manhattan distance which is invariant on a square (a cube, a hypercube). Notice that L_1 norm implies orthogonal separability and offers a big gain from the numerical point of view.

With $X(P_i)$ the n observations at the different points, the estimates of the empirical auto-covariance function at the interval $\Delta^{(l)}$ are calculated from:

$$\gamma\left(\Delta^{(l)}\right) = \frac{1}{n}\sum_{i=1}^{n} v_i \frac{1}{n_i^{(l)}} \sum_{j=1}^{n_i^{(l)}} v_j^{(l)} \tag{7.31}$$

where: $\left\{ v_j^{(l)} : P_j \Rightarrow \Delta^{(l-1)} < \left\| P_i - P_j \right\| \le \Delta^{(l)} \right\}$ (7.32)

and: $v_k = x_k - \bar{x} \qquad k = 1, \cdots, n$ (7.33)

whilst the estimates of empirical cross-covariance function at the interval $\Delta^{(l)}$ are computed in similar way.

When the data points aren't equally spaced, the optimal interval size has to be found for the covariance estimates. In fact a too small interval will contain only few data points, whilst a too large interval will contain data points, which are too much dispersed. In both cases, the estimates are suppressed.

A criterion for the choice of the interval including the first auto-covariance zone is maximizing the first autocovariance estimate, as follows:

$r_{(1)} : \gamma\left(\Delta^{(1)}\right) = \max\left(\gamma\left(\Delta^{(l)}\right)\right)$ where: $\gamma\left(\Delta^{(l)}\right) = \frac{1}{n}\sum_{i=1}^{n} v_i \frac{1}{n_i^{(l)}} \sum_{j=1}^{n_i^{(l)}} v_j^{(l)}$ (7.34)

and: $\left\{ v_j^{(l)} : P_j \Rightarrow 0 < \left\| P_i - P_j \right\| \le \Delta^{(l)} \right\}$ (7.35)

In the case of vector quantities, the determination of the optimal interval spacing is obtained by minimizing the trace of the covariance matrix of the uncorrelated noise which is invariant with respect to rotations.

Furthermore by using the orthogonal separability among the coordinates, it is easy to obtain covariance estimates for each row and each column. The trimmed mean of the row covariance estimates and the trimmed mean of the column covariance estimates give the empirical auto-covariance functions for the rows and the columns.

The covariance estimation continues then by multiplying the row covariance estimates by the column covariance estimates, in order to obtain the covariance function of the data. The same procedure has to be done for the best fit covariance function and the noise variance.

In case of 3D (or ND) stochastic processes, the orthogonal separability among the three (or more) coordinates goes to the estimation of covariance's for each row, each column and each pile (etc. if necessary). Successively the trimmed means give the empirical auto-covariance functions and the product among the three (or more) covariance components supplies the covariance function of the data.

After empirically having estimated points of the covariance functions one has to interpolate them by using classes of approximation functions which are able to simulate the behavior of a covariance function.

Because covariance estimation doesn't satisfy positive definite property automatically, this last must be achieved by modeling the covariance estimates with a suitable set of positive definite models.

The best fit of the auto-covariance function of the signal is then chosen among some available models, where Euclidean distance is used only in 2D and Manhattan distance is used, otherwise, being the smoothness coefficient very high.

This library has been built according to the properties of covariance function: positive power spectrum, i.e. positive Fourier transforms, and Schwarz inequality for vector processes.

New covariance function can be created from the old ones by applying the following fundamental theorems:

- a linear combination with positive coefficients;
- a product;
- a convolution of function by itself.

The same list is used to interpolate a cross-covariance function: it is not correct in principle, but is acceptable in practice, provided that cross-covariance estimates are low enough. Many different approaches exist for the choice of a suitable class of approximation functions to interpolate empirical covariance estimates. A possible choice for the class of approximating functions is based on the analysis of the trend (concave or convex) in a region near the origin, on the presence of possible zeros and, if there are any zeros, on relative maxima and minima. Whatever the type of model chosen for the interpolation of the covariance estimates, the interpolating function can be imposed to coincide with the first empirical (optimized) covariance estimate.

The classes of approximation functions provide covariance functions which have zero function values in at most a countable infinite number of points and asymptotically tend to zero only at infinity. As a consequence, a full covariance matrix results for any set of points. This can lead to insurmountable computational problem, with respect to both storage requirements and time consuming.

A finite covariance function, i.e. a function which differs from zero only in a small part of its domain, provides a sparse covariance matrix. A sparse covariance matrix doesn't present insurmountable storage requirements, as only non-zero elements are stored (along with some service vectors). The time consuming is also much lower, if a suitable ordering of the unknowns can be found.

In the one-dimensional case, a reordering can be found clustering the non-zero elements near the diagonal; moreover a direct solution of the system can then be found using band algorithms. In the 2D, 3D (ND) cases, the non-zero elements in the matrix are fairly dispersed and it may not be possible to find a convenient ordering. In those cases, iterative solution algorithms, which work with sparse storage schemas, have to be used,

Furthermore in all cases, if there is regularity within the data, Toeplitz matrices have to be considered and Kronecker factorization have to be performed too, when the dimension of the problems is greater than one.

As above mentioned, a function $h(z)$ obtained by the convolution any function $f(x)$ with itself:

$$h(z) = \int_{-\infty}^{+\infty} f(x) f(z-x) dx \qquad (7.36)$$

has the property of a covariance function. Because the convolution of a finite with itself is a finite function, finite covariance functions can be obtained by subsequent convolutions.

Besides finite covariance functions are obtained by multiplying the best fit models by positive definite finite functions, which are given by convolution of a finite function with itself, respectively, in the isotropic case, considering only 2D stochastic processes:

$$\gamma(\Delta)=5\pi-15\Delta^2\pi/2+\left(5\Delta+20\Delta^3/3-5\Delta^5/12\right)\sqrt{1-\Delta^2/4}+\left(15\Delta^2-10\right)\arcsin\left(\sqrt{\Delta/2}\right)$$

with $\Delta \leq 2$ (7.37)

$$\gamma(\Delta)=0 \qquad \text{with} \quad \Delta \geq 2 \qquad (7.38)$$

and otherwise taking into account the orthogonal separability:

$$\gamma(\Delta)=16/15-4\Delta^2/3+2\Delta^3/3-\Delta^5/30 \qquad \text{with} \quad \Delta \leq 2 \qquad (7.39)$$

$$\gamma(\Delta)=0 \qquad \text{with} \quad \Delta \geq 2 \qquad (7.40)$$

In case of 3D (or ND) stochastic processes, a library of auto-covariance function models, especially when they are finite covariance functions, is difficult to construct. On the other hand, the orthogonal separability among the three (or more) coordinates allows to use three (or more) times the one-dimensional auto-covariance function models. The same is true for the finite covariance functions and the product among the three (or more) covariance components supplies positive definite models.

The extension to the space-time domain implies similar procedures. Notice that the covariance estimation in the space-time domain requires as additional hypotheses:

- the irrotational condition between the time and the space coordinates;
- the separability between the two types of coordinates in the empirical estimate, so that the space coordinates are free to run at any fixed time and the time is free to run in any fixed place.

This means that each covariance matrix must be split in two factors, according to the Hadamard product:

$$C(\Delta P,\Delta t)=C(\Delta P)*C(\Delta t) \qquad (7.41)$$

Cluster analysis could help to collect homogeneous covariance estimates, i.e. (intermediate) data with a similar behavior.

Finally the noise variance is found as $\sigma_n^2=\sigma^2-\sigma_s^2$, and the eventual noise covariance can be found with a similar formula.

A.1.3. Finite element interpolation

Finite element interpolation can be performed in different way; one the most promising method uses spline functions (e.g. cubic spline functions). A spline function, in the space and time domain, is given by the sum of the product of two or three orthogonal cubic spline functions (in the space domain), plus one cubic spline function (in the time domain):

$$S(P,t) = S(x)S(y)S(z) + S(t) \tag{7.42}$$

The choice for the number of cells and the number of knots depend on the number of observations m and the interpolation steps δ_p, δ_t.

The number of cells is the sum of the product of the number of classes in two or three directions x, y and z, plus the number of the classes in the time:

$$v = v_x v_y v_z + v_t \tag{7.43}$$

where: $v_x = \mathrm{int}(\Delta x/\delta_p)+1$, $v_y = \mathrm{int}(\Delta y/\delta_p)+1$, $v_z = \mathrm{int}(\Delta z/\delta_p)+1$, $v_t = \mathrm{int}(\Delta t/\delta_t)+1$, being Δx, Δy and Δz the dimensions of the space region in two or three directions and δ_p the chosen interpolation step in the space domain, whilst Δt is the dimension of the time interval and δ_t. the chosen interpolation step in the time domain. Consequently the number of knots is:

$$n = n_x n_y n_z + n_t = (v_x + 3)(v_y + 3)(v_z + 3) + (v_t + 3) \tag{7.44}$$

The spline interpolation is performed, as a classical least squares problem, by writing a system of observation equations:

$$\hat{s}_h = s_h^0 + \hat{v}_h = \sum_{i=1}^{4}\sum_{j=1}^{4}\sum_{k=1}^{4} \hat{a}_{I+i\,J+j\,K+k} S_{ijk}(\xi_h, \eta_h, \zeta_h) + \sum_{l=1}^{4} b_{L+l} S_l(\tau_h) \tag{7.45}$$

and associating it with the least squares norm:

$$\phi = \sum_{k=1}^{m} \hat{v}_k^2 = \min \tag{7.46}$$

The weights are mostly assumed equal one; however more complex stochastic model should be defined eventually including correlation among the observations, but they are usually omitted for sake of brevity. The following formulas are the list of the functional model. Indeed for the x direction, the coordinate of the *h-th* knot with respect to the initial corner is split in two parts:

$$\Delta x_h = I\delta_p + \delta x_h \tag{7.47}$$

where the number of the preceding knots is:

$$I = \mathrm{int}\left(\Delta x_h / \delta_p\right) \tag{7.48}$$

and the position inside the class is:

$$\xi_h = \delta x_h / \delta_p \tag{7.49}$$

being: $\delta x_h = \Delta x_h - I\delta_p$. Analogously for the y and z directions:

$$\Delta y_h = J\delta_p + \delta y_h \tag{7.50}$$

$$\Delta z_h = K\delta_p + \delta z_h \tag{7.51}$$

where: $J = \mathrm{int}\left(\Delta y_h / \delta_p\right)$, $\eta_h = \delta y_h / \delta_p$, $\delta y_h = \Delta y_h - J\delta_p$ and $K = \mathrm{int}\left(\Delta z_h / \delta_p\right)$, $\zeta_h = \delta z_h / \delta_p$, $\delta z_h = \Delta z_h - K\delta_p$.

Moreover for the time:

$$\Delta t_h = L\delta_t + \delta t_h \tag{7.52}$$

where: $L = \mathrm{int}\left(\Delta t_h / \delta_t\right)$, $\tau_h = \delta t_h / \delta_t$, $\delta t_h = \Delta t_h - L\delta_t$

Notice that suitable constraints for the knots should be introduced at the border and in empty regions, if any. Indeed the Tikhonov norm induces continuity of the model, by imposition of the regularity of the first derivates. It solves ill-conditioned subsystems, if any; whilst the low weights used don't destroy the model, in case of well-conditioning.

In practice finite difference equations of the first order are written, for each knot, taking into account: in the space domain, the knots left and right (along the same row), down and up (along the same column), lower and upper (along the same pile), and in the time, the knots preceding and following:

$$a_{I+i+1\,J+j\,K+k} - a_{I+i-1\,J+j\,K+k} = 0 \tag{7.53}$$

$$a_{I+i\,J+j+1\,K+k} - a_{I+i\,J+j-1\,K+k} = 0 \tag{7.54}$$

$$a_{I+i\,J+j\,K+k+1} - a_{I+i\,J+j\,K+k-1} = 0 \tag{7.55}$$

$$b_{L+l+1} - b_{L+l-1} = 0 \tag{7.56}$$

Notice that the pseudo-observations are always equal to zero, being it the median value of the first derivates. Furthermore the weights are chosen suitably low, so that the constraints solve the problems given by the border and the empty regions, whilst they respect the information supplied by the data.

B. TOPOLOGICAL MODELING[15]

Several applications in 3D imaging and modeling require the definition of conceptual models, which imply the knowledge of the 3D topology. Codification of topology is really important to avoid different interpretations of the same object or phenomenon:

- a classical approach lists all Boolean relations and selects among them the admissible ones from a geometric point of view;
- an alternative approach combines the topological and geometric relations between primary elements with the symmetries (in the spaces in which the complex objects are located).

The alternative has been recently developed in Milan. Therefore it will be presented firstly and the classical one will follow with some comments, in order to remark analogies and differences.

B.1. Alternative Approach

Object modeling allows the widest modalities to represent bodies and features for their studies and analysis. The relations between characteristic elements (points, lines, surfaces and 3D bodies) determine the validity of this modeling and their sets have correspondences with the groups of symmetry in the mono-dimensional, two-dimensional and three-dimensional spaces of the formal algebra.

The object (eventually dynamic) modeling is an innovative and technologically advanced instrument for the study of spatial phenomena and their temporal dynamics.

Unfortunately the use of this instrument is still rare; in fact it remarkably increases the complexity of realization and management of the informatics systems.

The production of the cartography has been, for a long time, a refined art. The maps, created from geodetic measurements and updated thickening by survey operations, are completed from the handicraft experience of the mapmakers.

The impressive spread of technology is carrying to give over the traditional map production systems, preferring the new and powerful digital systems of map production.

B.1.1. Object modeling

The object paradigm supplies a high level of abstraction of the physical structure of the data; it is able to model the system according to the definition of the data (objects), as

[15] In May 2005, at the TU of Bari (Italy), Prof. Max J. Egenhofer of the University of Maine (USA) presented some very interesting topics dealing with the arguments of this paragraph, which we summarize in order to establish a comparison between them and a partially different approach presented in a previous work of the authors [240].

well as to operate on the concept of attributes and relations, being both stored as an integrating part of the same objects. The object oriented representation permits to create complex objects, like polygons, 3D bodies, etc, to analyze and to manipulate them like single objects (even if they are combinations of objects). This characteristic eliminates the necessity of clarifying all the geographic and semantic attributes of the objects. Furthermore the object-oriented approach allows the easy description of new types of data, defining operations on new objects and structuring the objects in a hierarchical way. In this context it is of particular interest to use those tools, like the extensions, able to explore the data, to process them in external phases where specific operations are executed, and to import the results; because of their high qualification, the dimension and complexity of these external procedures exclude their insertion inside the system.

The development of object oriented systems is going in two different directions: adding all the typical functions of the object paradigm to a relational database, or constructing a new independent system. The first approach is very robust, because the databases are a mature product, while the second approach is still an open issue in the scientific and technological research. In both cases, the main objective is the production of a set of procedures able to process spatially referenced data, as well as common data independent from a reference frame.

The most important procedures for the data management tend to solve these main problems: data storage and information retrieval according to suitable requirements. Particularly for the management of spatially referenced data it is necessary to create new entities (polygons, 3D bodies, etc.) and to define rules for their processing, like distance, incidence, adjacency, etc. However in the object oriented systems, some problems with difficult solution, presented by the relational models, are still not completely solved. At present time, a hybrid system seems to be the best solution for the creation of robust physical (relational) data structures and flexible logical (object oriented) data models.

An object can be described as a conceptual entity, easily defined by its data and environment. The environment includes a set of operations and methods, valid on the object itself. Its state is represented by the values assumed by local variables. Every single object belongs to a class, which defines the type of object. The classes can have variables, describing the characteristics of the class itself. If some classes have common variables and methods, it is possible to define a super–class, which groups the variables and the methods of all these classes. For convention, the universal super–class (i.e. the root of the system) constitutes the first level of the hierarchical level structure describing the system.

An interesting object oriented data structure can be obtained by introducing a linkage between spatially referenced objects and their features, for example areas with their boundaries, edges with isolated vertices. Thus the spatially referenced objects are identified and described by means of their geometric and thematic features. This observation leads to a first formal requirement, in order to construct a formal data structure:

- every object must be associated to an identifier (name or number);
- every identifier must have a link to the attributes of an object.

Objects with common geometric or thematic aspects can be grouped into the same class (set of objects), identified by a certain name; the list of attributes of a class supplies the names of the attributes, whose values are assumed by the objects themselves. This means that every object, belonging to a class, has a list of values, one for each attribute of the class. Common attributes lead to a super–class (i.e. a class of classes), which is associated to the list of attribute values assumed by the classes. It is evident that the construction of a super – class introduces a hierarchy in the level structure of the classes.

At the top level, the super – class presents its list of attributes and methods.

At the intermediate level, the class presents a list of attributes subdivided in two parts: the former contains the values of the attributes associated to the super–class, the latter contains the list of attributes of the class itself. At the lowest level, the object presents a list of attributes estimated by the lists of the attributes of the super–class or the belonging class. The estimation of an attribute, at the class level, implies that all the objects belonging to the same class have the same value for the selected attribute. Furthermore it is possible to introduce more hierarchical levels: every level inherits the list of attributes of the higher level and transmits the list of attributes to the lower level. At the lowest level of the hierarchy, all the attributes must be estimated.

Classes of objects and objects are defined so that every object belongs to one (and only one) class; this requirement is equivalent to the convention according the classes to which must be mutually exclusive. The objects can be classified according to their geometric or thematic features; therefore a second convention states that a class contains only objects of a certain type. Sometimes this convention seems to be too rigid; however it allows the construction of a very simple and transparent structure. In some rare cases, a possible solution is the construction of complex objects. The last convention implies a relation many-to-one type between objects and classes.

Using this object-oriented approach, geometric structures with different complexity can be described by objects belonging to suitable classes of features. For instance:

- a punctual structure, by means of an object belonging to the class of the points;
- a liner structure, by means of an object belonging to the class of the lines;
- a bidimensional structure, by means of an object belonging to the class of the surfaces;
- a three-dimensional structure, by means of an object belonging to the class of the 3D bodies.

In order to construct a formal data structure, it is necessary to identify the geometric features of the object and their relations. This can be done with different methods. A possible approach uses the graph theory, putting into a one-to-one relation the thematic and the corresponding geometric elements, and describing the topological relations between the various elements. The elements can be described in two different ways:

- in a parametric form, i.e. through parameters, which define the equation of a mathematical curve;
- through a sequence of points connected by a polyline, being the link between two consecutive points a segment of one straight line.

The second solution implies the introduction of new types of points beyond the nodes: these new points only contain information concerning the point positions. In both cases, the following conventions are adopted:

- when a complex object is analyzed through a graph, all the points describing its geometry are treated as nodes, each node having the position given by the coordinates of the corresponding point;
- by using the duality principle, all the planar figures derived by the decomposition of a complex figure are treated like nodes of a dual graph, each node having the position given by the coordinates of the centroids of the same figure;

- by using the duality principle, the 3D bodies, derived by the decomposition of a complex solid object, are treated like nodes of a dual graph, each node having the position given by the coordinates of the centroids of the same body;
- all the segments of straight lines are represented by edges of the graph and each edge has an initial and a final node;
- by using the duality principle, all the surfaces in 3D space are represented by edges of a dual graph and each edge has an initial and a final node.

In order to avoid geometric ambiguities, two new conventions are introduced:

- for each couple of nodes, there is no more than one edge, connecting them;
- the edges cannot be intersected in the simple case of a planar graph; the same requirement is imposed for the entire planar sub – graphs, derived by a possible decomposition of a spatial graph.

The connection between geometric and thematic elements is performed through identifiers. The successive step, in the definition of a formal data structure for a complex object, consists of the analysis of the linkage between the geometric elements (nodes, edges) and the thematic elements (points, lines, surfaces and 3D bodies):

- the linkage between features, like points (thematic elements) and nodes (geometric elements) consists of the following condition: every point is represented by one node (and one only);
- if one node does not represent any feature, a null identifier is used.

The connection between the other geometric and thematic elements with more complexity is set up as follows:

- an edge can be part of a characteristic line;
- if an edge does not belong to a characteristic line, a null identifier is imposed;
- in the simple case (planar graph or planar subgraphs derived by a decomposition of a spatial graph) an edge has always one (and only one) characteristic area at its right and one (and only one) characteristic area at its left;
- a face (i.e. an edge, by using the duality principle) can be part of a characteristic surface (i.e. a characteristic line, by using the same duality principle);
- if a face does not belong to a characteristic surface, a null identifier is imposed;
- by using the duality principle, a surface in 3D space has always one (and only one) characteristic 3D body at its right and a characteristic 3D body 3D (and only one) at its left;
- if an edge (or a face) is a boundary element, one of the two characteristic surfaces (or one of the two characteristic 3D bodies) is called external element;
- if a characteristic line (or a characteristic surface) is a boundary element between two characteristic surfaces (or two characteristic 3D bodies), the edges (or the faces) belonging to this boundary are part of the same characteristic line (of the same characteristic surface);
- on the contrary, if an edge (or a face) is not part of a characteristic line (or a characteristic surface), or it does not belong to a certain boundary, the edge and

its characteristic line (or the face and its characteristic surface) intersect a characteristic surface (or a characteristic 3D body) and the right – left linkage is referred to the same surface (or to the same 3D body).

Finally in the case of 3D bodies modeling, it is necessary to establish a cross-connection table between edges and faces (or characteristic lines and characteristic surfaces), so that a topological linkage between primary graphs and dual graphs is present. In fact, while this linkage is directly defined by the edges in the planar graphs, the primary and dual spatial graphs are completely separated (if they are not previously decomposed in planar sub-graphs); as a consequence, the above mentioned cross-connection table is strictly required.

B.1.2. Relations among the object elements

The very well defined complex objects are in mutual relations in the space, where they are located. In order to better define this concept, terms like *at the right or at the left of*, *over or under to*, *inside or outside to*, *intersects*, *etc*. are usually adopted. In the previously analyzed formal data structure, two types of topological relations are introduced:

- relations within geometric data, described by graphs (nodes and edges) in the vectorial structures and by cells (pixels and voxels) for the rasters;
- relations within objects, described by the linkage between primary elements (points, lines, surfaces and 3D bodies) and the same primary elements and the complex objects, formed by the primary elements themselves.

In order to determine the proper application context of each element, some properties are suitably defined. While no particular relations are established for the points, on the other hand the lines and the surface are supposed continuous, open (i.e. simply connected) or close (i.e. not simply connected, but with a single hole) and the 3D bodies are assumed continuous and simply connected. Therefore, unless different indications, all the elements are finite in their geometric dimensions; moreover the lines have a fractal dimension (i.e. the effective dimension occupied in the space) equal to one, while the surfaces have a fractal dimension equal to two and their eventual closure does not take into account any pathological cases, like the ring of Moebius and the bottle of Klein.

In order to obtain a broad starting point, very general relations among complex objects are defined, as follows:

- 3 classes of relations in the monodimensional space: between points, points and lines, lines;
- 6 classes of relations in the bidimensional space: beyond to those of the previous case, between points and surfaces, lines and surfaces, surfaces;
- 10 classes of relations in the three-dimensional space: beyond to those of the previous cases, between points and 3D bodies, lines and 3D bodies, surfaces and 3D bodies, 3D bodies.

In one dimension, there exist 7 topological relations:

- Point – point: separate
  coincident
- Point – line: external
  internal
- Line – line: separate
  connected
  internal

In two dimensions, 10 new relations join to the previous ones, defined for the monodimensional case, reaching the number of 17 topological relations:

- Point – surface: external
  internal
- Line – surface: external
  connected
  secant
  internal
  enucleating
- Surface – surface: external
  connected
  internal

Finally in three dimensions, 15 new relations join the previous ones, defined for the bidimensional case, reaching the number of 32 topological relations:

- Point – body: external
  internal
- Line – body: external
  connected
  secant
  internal
  enucleating
- Surface – body: external
  connected
  secant
  internal
  enucleating
- Body – body: external
  connected

internal

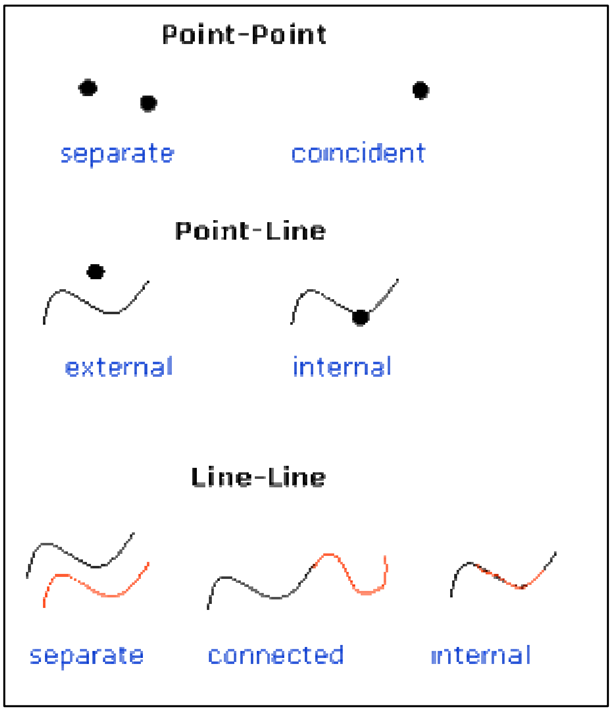


Figure 7.1. Topological Relation in 1D

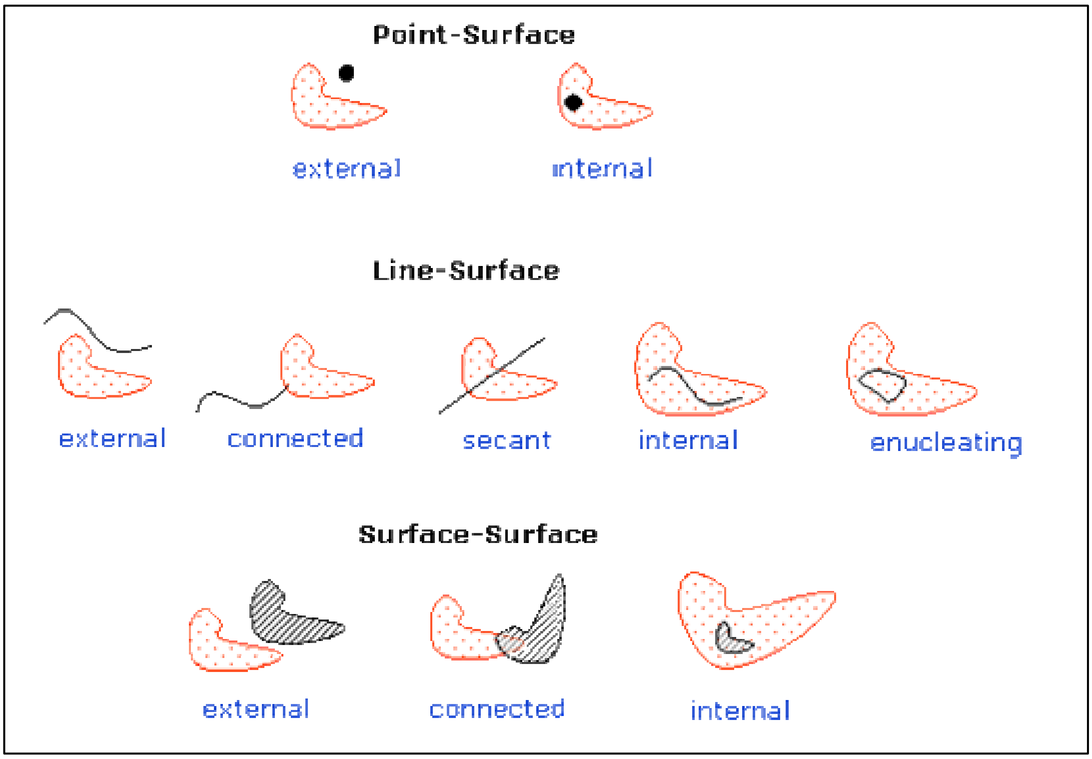


Figure 7.2. Topological Relations in 2D

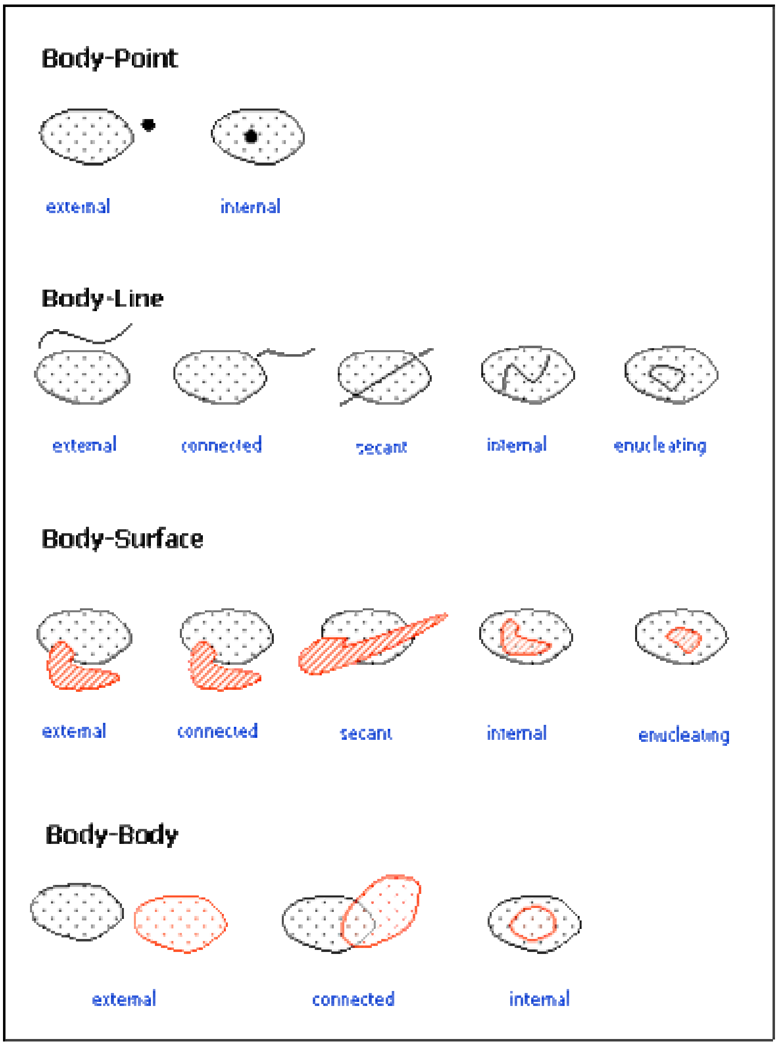


Figure 7.3. Topological Relations in 3D

The following lists present the main geometric relations among the primary elements:

- 10 geometric relations, for the mono-dimensional case;
- 32 geometric relations, for the two-dimensional case;
- 230 geometric relations, for the three-dimensional case.

B.1.2.1. Mono-dimensional Case

• Point – point:	separate	(1)
	coincident	(2)
• Point – line:	external	(3)
	marginal	(4)
	internal	(5)
• Line – line:	external	(6)
	semi-external	(7)
	overlapping	(8)
	semi-internal	(9)

	internal	(10)

B.1.2.2. Bidimensional Case

• Point – point:	separate	(1)
	coincident	(2)
• Point – line:	external	(3)
	marginal[16]	(4)
	internal	(5)
	included[17]	(6)
• Point – surface:	external	(7)
	marginal	(8)
	internal	(9)
• Line – line:	external	(10)
	semi-external[16]	(11)
	semi-intersecting[16]	(12)
	intersecting	(13)
	overlapping	(14)
	semi-internal[16]	(15)
	internal	(16)
	semi-included[18]	(17)
	included[18]	(18)
• Line – surface:	external	(19)
	semi-external[16]	(20)
	semi-marginal	(21)
	marginal	(22)
	intersecting	(23)
	secant	(24)
	semi-internal[16]	(25)
	internal	(26)
	enucleating[17]	(27)
• Surface – surface:	external	(28)
	semi-external	(29)
	overlapping	(30)
	semi-internal	(31)
	internal	(32)

[16] Note: only if the line is open.

[17] Note: only if the line is close.

[18] Note: only at least a line is close.

B.1.2.3. Three-Dimensional Case

In this case, the classification of the geometric relations allows various possibilities. In most cases considering the number of the geometric relations in correspondence to the cardinality of the group of spatial symmetry, it is quite easy to reach the number of 230 elements. In fact, while a point is a point and a body a body, a line can be open or close, and it can occupy an open area or close area, as well as a volume; moreover a surface can be open or close, and it can occupy a volume. Therefore five distinguished types of lines are taken into account: stick, ring, doily, basket and skein, and three distinguished types of superficial are also taken into account: leaf, ball and bag. The resulting connections are:

• Point – point:	separate	(1)
	coincident	(2)
• Point – stick:	separate	(3)
	marginal	(4)
	internal	(5)
• Point – ring:	separate	(6)
	internal	(7)
• Point – doily:	separate	(8)
	marginal	(9)
	internal	(10)
• Point – leaf:	separate	(11)
	marginal	(12)
	internal	(13)
• Point – basket:	separate	(14)
	internal	(15)
	included	(16)
• Point – ball:	separate	(17)
	internal	(18)
	included	(19)
• Point – skein:	separate	(20)
	marginal	(21)
	internal	(22)
• Point – bag:	separate	(23)
	marginal	(24)
	internal	(25)
• Point – body:	separate	(26)
	marginal	(27)
	internal	(28)
• Stick – stick:	separate	(29)
	marginal	(30)

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

	intersected	(31)
	internal	(32)
• Stick – ring:	separate	(33)
	marginal	(34)
	intersected	(35)
	internal	(36)
• Stick – doily:	separate	(37)
	marginal	(38)
	overlapping	(39)
	marginal	(40)
	internal	(41)
• Stick – leaf:	separate	(42)
	marginal	(43)
	overlapping	(44)
	marginal	(45)
	internal	(46)
• Stick – basket:	separate	(47)
	marginal	(48)
	overlapping	(49)
	marginal	(50)
	included	(51)
• Stick – ball:	separate	(52)
	marginal	(53)
	overlapping	(54)
	marginal	(55)
	included	(56)
• Stick – skein:	separate	(57)
	marginal	(58)
	overlapping	(59)
	marginal	(60)
	internal	(61)
• Stick – bag:	separate	(62)
	marginal	(63)
	overlapping	(64)
	marginal	(65)
	internal	(66)
• Stick – body:	separate	(67)
	marginal	(68)
	overlapping	(69)
	marginal	(70)

	internal	(71)
• Ring – ring:	separate	(72)
	tangent	(73)
	linked	(74)
	intersected	(75)
• Ring – doily:	separate	(76)
	tangent	(77)
	overlapping	(78)
	internal	(79)
• Ring – leaf:	separate	(80)
	tangent	(81)
	overlapping	(82)
	internal	(83)
• Ring – basket:	separate	(84)
	tangent	(85)
	overlapping	(86)
	marginal	(87)
	included	(88)
• Ring – ball:	separate	(89)
	tangent	(90)
	overlapping	(91)
	marginal	(92)
	included	(93)
• Ring – skein:	separate	(94)
	tangent	(95)
	overlapping	(96)
	marginal	(97)
	internal	(98)
• Ring – bag:	separate	(99)
	tangent	(100)
	overlapping	(01)
	marginal	(02)
	internal	(03)
• Ring – body:	separate	(04)
	tangent	(05)
	overlapping	(06)
	marginal	(07)
	internal	(08)

•	Doily – doily:	separate	(09)
		tangent	(10)
		overlapping	(11)
		internal	(12)
•	Doily – leaf:	separate	(13)
		tangent	(14)
		overlapping	(15)
		internal	(16)
•	Doily – basket:	separate	(17)
		tangent	(18)
		overlapping	(19)
		marginal	(20)
		included	(21)
•	Doily – ball:	separate	(22)
		tangent	(23)
		overlapping	(24)
		marginal	(25)
		included	(26)
•	Doily – skein:	separate	(27)
		tangent	(28)
		overlapping	(29)
		marginal	(30)
		internal	(31)
•	Doily – bag:	separate	(32)
		tangent	(33)
		overlapping	(34)
		marginal	(35)
		internal	(36)
•	Doily – body:	separate	(37)
		tangent	(38)
		overlapping	(39)
		marginal	(40)
		internal	(41)
•	Leaf – leaf:	separate	(42)
		tangent	(43)
		overlapping	(44)
		internal	(45)
•	Leaf – basket:	separate	(46)
		tangent	(47)

	overlapping	(48)
	marginal	(49)
	included	(50)
• Leaf – ball:	separate	(51)
	tangent	(52)
	overlapping	(53)
	marginal	(54)
	included	(55)
• Leaf – skein:	separate	(56)
	tangent	(57)
	overlapping	(58)
	marginal	(59)
	internal	(60)
• Leaf – bag:	separate	(61)
	tangent	(62)
	overlapping	(63)
	marginal	(64)
	internal	(65)
• Leaf – body:	separate	(66)
	tangent	(67)
	overlapping	(68)
	marginal	(69)
	internal	(70)
• Basket – basket:	separate	(71)
	tangent	(72)
	overlapping	(73)
	included	(74)
• Basket – ball:	separate	(75)
	tangent	(76)
	overlapping	(77)
	included	(78)
• Basket – skein:	separate	(79)
	tangent	(80)
	overlapping	(81)
	included / internal	(82)
• Basket – bag:	separate	(83)
	tangent	(84)
	overlapping	(85)
	included / internal	(86)

• Basket – body:	separate	(87)
	tangent	(88)
	overlapping	(89)
	included / internal	(90)
• Ball – ball:	separate	(91)
	tangent	(92)
	overlapping	(93)
	included	(94)
• Ball – skein:	separate	(95)
	tangent	(96)
	overlapping	(97)
	included / internal	(98)
• Ball – bag:	separate	(99)
	tangent	(200)
	overlapping	(01)
	included / internal	(02)
• Ball – body:	separate	(03)
	tangent	(04)
	overlapping	(05)
	included / internal	(06)
• Skein – skein:	separate	(07)
	tangent	(08)
	overlapping	(09)
	internal	(10)
• Skein – bag:	separate	(11)
	tangent	(12)
	overlapping	(13)
	internal	(14)
• Skein – body:	separate	(15)
	tangent	(16)
	overlapping	(17)
	internal	(18)
• Bag – bag:	separate	(19)
	tangent	(20)
	overlapping	(21)
	internal	(22)
• Bag – body:	separate	(23)

	tangent	(24)
	overlapping	(25)
	internal	(26)
• Body – body:	separate	(27)
	tangent	(28)
	overlapping	(29)
	internal	(230)

This long list could further be lengthened, taking into account particular conditions of tangency, intersection and superimposition. Furthermore these conditions can be simple, double or multiple and can be punctual, linear and aerial. Therefore taking into account the length of the present list and the richness of the proposed under – classifications, 4783 cases could be found according to the cardinality of the recently discovered four-dimensional symmetry group.

B.1.3. Linear, Planar and Spatial Symmetries

The prohibition of figurative arts for the Hebrew and the Arabs carried to the development of a pure abstract and geometric art and to the exploration of the possible types of decoration. In this field, the most elevated result was reached in Granada in the 14^{th} century, with the tessellation of the Alhambra. Although the number of decorations is nearly unlimited, they are limited as far as the type of symmetries adopted for their repetition. From a mathematical point of view, these symmetries can be classified based on the possible transformations, which leave them unvaried: translation along a direction, reflection with respect to a straight-line and rotation around to a point. In 1891 Fedorov demonstrated that only 7 types of symmetry for liner decorations and only 17 for the planar ones exist. Furthermore the planar groups can only present rotational symmetry for angles of 180°, 120°, 90°, 60°, which correspond to the axial, triangular, squared and hexagonal rotation angles. If the most common examples of planar symmetry are the decorations, the most common examples of spatial symmetry are the crystals. From 1849 with Auguste Bravais, the crystallography has been one of the first fields of application of the theory of the groups of symmetries. In 1890, before demonstrating the analogous results for the groups of planar symmetry [114] had demonstrated that only 230 types of spatial symmetry exist. The first part of the *18^{th} problem of Hilbert* asked whether the groups of symmetry in *n* dimensions are a finite number for every *n*. In 1910 a positive answer was given in [92]; however an explicit relation is not yet found giving the number of the groups of symmetry for any *n* given. In fact the existence of 4783 types of four-dimensional symmetry was demonstrated only in '70.

Symmetry means invariant respect to a group of transformations and, if the transformation is a distance, the symmetry becomes an isometry. In the plan, four types of isometry exist: translation, rotation, reflection and glisso-reflection. Notice that the rotation can be replaced by two suitable reflections, as well as the translation; moreover the glisso-reflection can be reduced to one reflection, followed by one translation. In details:

<u>Definition of translation</u>: translation means to move a figure along a direction for a certain distance. The translation happens along one single direction, for the linear symmetry, and along two (three) directions for the planar (spatial) symmetry.

Definition of rotation: a spin holds a point of the plan fixed and turns all the rest of an angle around the same point. The rotation angle can be arbitrary, but the angle must be a precise submultiple of 360°, i.e. 180°, 120°, 90° 60° and opposites.

Definition of reflection: a reflection fixes a line in the plan, called reflection axis, and exchanges the points on one side of the axis with the points on the other side, at the same distance from the axis. It is called reflection, because the same phenomenon happens with a mirror.

Definition of glisso-reflection: a glisso-reflection consists of one reflection through an axis and one translation parallel to the same axis.

The order of a rotation is the number of repetitions of the chosen rotation, in order to bring the figure back to the initial configuration. Consequently, a rotation of 60° has order 6, a rotation of 90° has order 4, a rotation of 120° has order 3 and a rotation of 180° has order 2.

A set of the symmetries on a regular stellar figure, with *n* equal branches, is called dihedral group of order *n*; it is left invariant by *n* rotations and *n* reflections. A set of the symmetries on a regular non-stellar figure, with *n* equal branches, is called cyclical group of order *n*; it is left invariant by *n* rotations, but it does not admit any reflection. The dihedral and cyclic groups are the only possible symmetries, where only a point (i.e. a center) is invariant; on the contrary, if an axis is invariant the unique possible symmetry is a reflection.

Definition of lactice: the set of the translations of a point through the symmetries of translation of a figure forms a lactice. The lactices can be classified in 5 different types.

- if a lactice has a square as fundamental region, it is called squared lactice; it admits translations, rotations of 180° and 90°, reflections and glisso–reflections (Figure 7.4a);
- if a lactice has a rhomb as fundamental region, with angles of 60°, it is called hexagonal lactice, because the points are located in the same disposition of the vertices of a regular hexagon; it admits translations, rotations of 60°, 120° and 180°, reflections and glisso-reflections (Figure 7.4b);
- if a lactice has a rhomb as fundamental region, with any angle, it is called rhombic lactice; it admits translations, rotations of 180°, reflections and glisso-reflections (Figure 7.4c);
- if a lactice has a rectangle as fundamental region, it is called rectangular lactice; it admits translations, rotations of 180° and reflections (Figure 7.4d);
- if a lactice has a more general fundamental region, it is called parallelogram lactice; it admits translations and rotations of 180°, but it does not have reflections (Figure 7.4e).

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

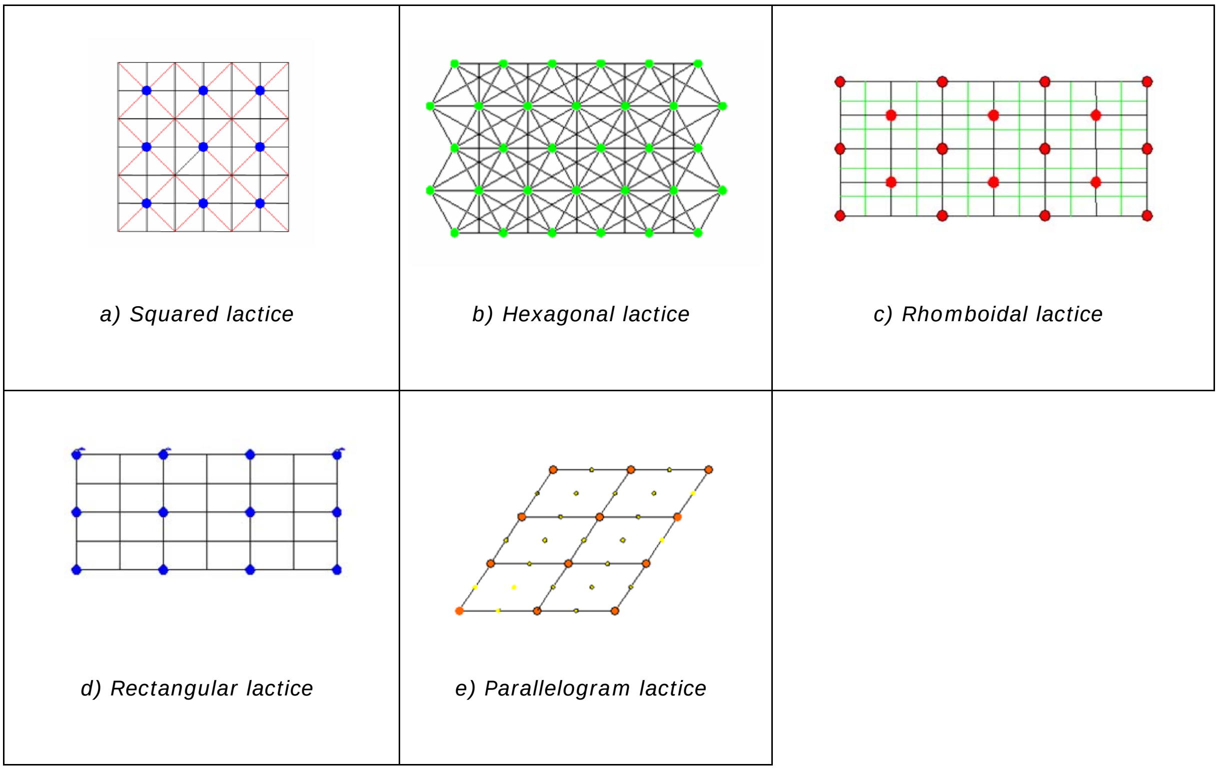


Figure 7.4. Lactices

If a composition has a reflection axis, its lactice can be rhombic, rectangular, square, or hexagonal. If it has a rotation of 90°, the lactice must be square, while if has a rotation of 60° or 120°, the lactice must be hexagonal.

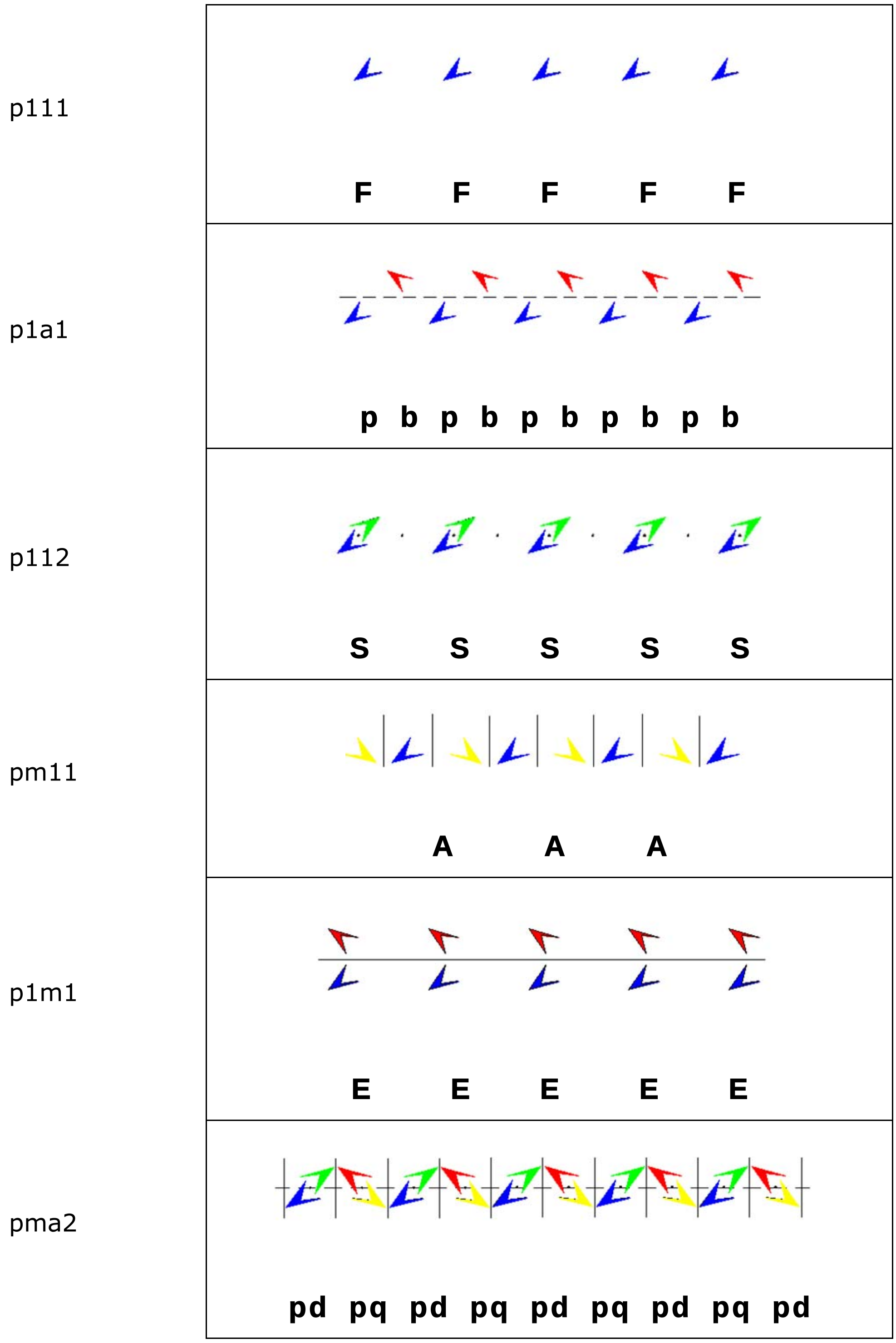
Linear symmetries: the liner symmetries, particularly used in the ornaments with friezes, have one single direction of translation. In order to identify the groups, the crystallographic notation is used; therefore:

- the first symbol is always **p**;
- the second symbol can be **m** or **1**, and indicates respectively the presence or the absence of a reflection, orthogonal respect to the translation direction;
- the third symbol can be **m**, a or **1**, and indicates the presence of a reflection, glisso-reflection or their absence, parallel to the translation direction;
- the last symbol can be **2** or **1**, and indicates respectively the presence or the absence of a rotation.

They are distinguished in 7 groups (Table 7.1):

- **p111** admits infinite translations;
- **p1a1** admits infinite glisso-reflections;
- **p112** is formed by one single rotation of 180° and admits infinite translations (after the translations, the centers of rotation form a series of equidistant points);
- **pm11** is formed by one single vertical reflection and admits translations;

- **p1m1** is formed by one single horizontal reflection and admits infinite translations;
- **pma2** is formed by one single rotation of 180° and admits infinite glisso-reflections (after the glisso-reflections, the centers of rotation form a series of equidistant points);
- **pmm2** is formed by two reflections, whose axes are orthogonal between themselves, and it admits infinite translations.



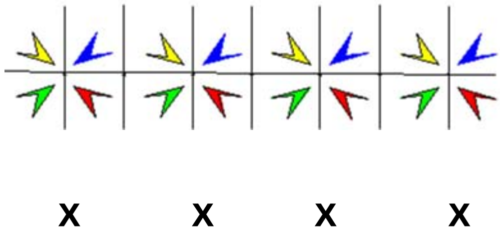
pmm2	

Table 7.1. Groups of Linear Symmetries

Planar symmetries: the planar symmetries, particularly used in the floorings with mosaics, have two directions of translation.

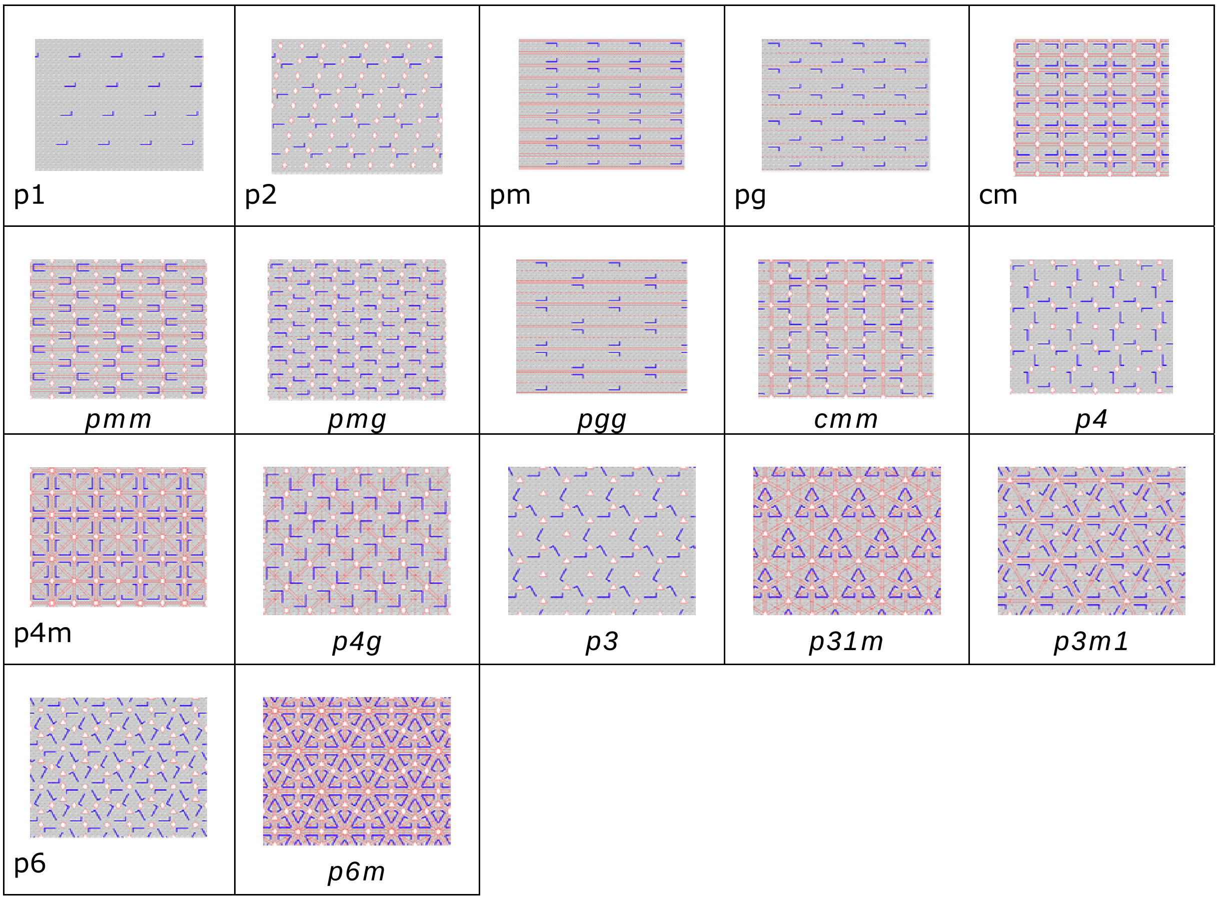


Table 7.2. Groups of Planar Symmetries

In order to identify the groups, the crystallographic notation is used again; therefore:

- the first symbol is **p** (primitive) or **c** (centered);
- the second symbol is a number and indicates the maximum number of admissible rotations;
- the third symbol can be **m** (mirror), **g** (glide) or **1**, and indicates respectively the presence of a reflection, glisso-reflection or their absence, in the first the translation direction;

- the last symbol can be **m** (mirror), **g** (glide) or **1**, and indicates respectively the presence of a reflection, glisso-reflection or their absence, in the second the translation direction.

They are distinguished in 17 groups (Table 7.2):

- **p1** admits translations; its lactice is a parallelogram and coincides with its fundamental region;
- **p2** admits translations and rotations of order 2 (i.e. 180°); its lactice is a parallelogram, as well as its fundamental region;
- **p3** admits translations and rotations of order 3 (i.e. 120°); its lactice is hexagonal and its fundamental region is a rhomb;
- **p4** admits translations and rotations of order 4 (i.e. 90°); its lactice is square and its fundamental region a triangle (notice that the centers of rotation of order 2 are in the half between the centers of rotation of order 4);
- **p6** admits translations and rotations of order 6 (i.e. 60°); its lactice is hexagonal and its fundamental region a kite;
- **pm** admits translations and reflections; its lactice is rectangular, as well as its fundamental region (notice that the reflection axes are parallel to a translation axis and perpendicular to the other one);
- **pg** admits translations and glisso-reflections; its lactice is rectangular, as well as its fundamental region (notice that the direction of the glisso-reflection is still parallel to a translation axis and perpendicular to the other one);
- **cm** admits translations, reflections and glisso-reflections; its lactice is rhombic and its fundamental region a rhomb;
- **pmm** admits translations, reflections and rotations of order 2 (i.e. 180°); its lactice is rectangular, as well as its fundamental region (notice that the reflection axes are parallel to a translation axis and perpendicular to the other one);
- **pmg** admits translations, reflections and rotations of order 2 (i.e. 180°); its lactice is rectangular, as well as its fundamental region (notice that the reflection axes are parallel to a translation axis and perpendicular to the other one, and the centers of rotation do not lay on these axes);
- **pgg** admits translations, glisso-reflections and rotations of order 2 (i.e. 180°); its lactice is rectangular, as well as its fundamental region (notice that the glisso-reflection axes are parallel to a translation axis and perpendicular to the other one, and the centers of rotation do not lay on these axes);
- **cmm** admits translations, reflections and rotations of order 2 (i.e. 180°); its lactice is rhombic and its fundamental region a triangle (notice that the reflection axes are parallel to a translation axis and perpendicular to the other one, and the centers of rotation do not lay on these axes);
- **p4m** admits translations, reflections and rotations of order 4 (i.e. 90°); its lactice is square and its fundamental region a triangle (notice that the reflection axes are tilted of an angle of 45° and the four reflection axes pass through the centers of rotation);
- **p4g** admits translations, reflections and rotations of order 4 (i.e. 90°); its lactice is square and its fundamental region a triangle (notice that the reflection axes are parallel to a translation axis and perpendicular to the other one, and the centers of rotation do not lay on these axes);
- **p3m1** admits translations, reflections and rotations of order 3 (i.e. 120°); its lactice is hexagonal and its fundamental region is a triangle (notice that he

reflection axes are tilted of an angle of 60° and the three reflection axes pass through the centers of rotation);

- **p31m** admits translations, reflections and rotations of order 3 (i.e. 120°); its lactice is hexagonal and its fundamental region is a triangle (notice that he reflection axes are tilted of an angle of 60° and the three reflection axes pass through the centers of rotation);
- **p6m** admits translations, reflections and rotations order 6 (i.e. 60°); its lactice is hexagonal and its fundamental region is a triangle (notice that he reflection axes are tilted of an angle of 30° and the six reflection axes pass through the centers of rotation);

Spatial symmetries: the spatial symmetries, particularly relevant in the study of crystals, have three directions of translation. There are 7 systems of crystals (being 4 the groups of symmetries for the polyhedrons): triclinic, monoclinic, orthorhombic, tetragonal, trigonal or rhombohedral, hexagonal and cubic.

Arranging these systems, the 14 lactices of Bravais are obtained. Moreover the number 17 is reached splitting in two parts the lactices whose orders range from less than 8 to greater than 12. There are then 32 groups of symmetries (see Table 7.3), considering the crystallographic restriction (where the rotations present only the orders 1, 2, 3, 4 and 6), and 230 groups of symmetries (see Table 7.4), without any restriction. In this case, the size of the 10 orders ranges from 1 to 48 (i.e. 1, 2, 3, 4, 6, 8, 12, 16, 24, 48). Except the number of the 14 lactices of Bravais, all the other numbers recall the numbers already found, considering the groups of the linear and planar symmetries (see Table 7.4).

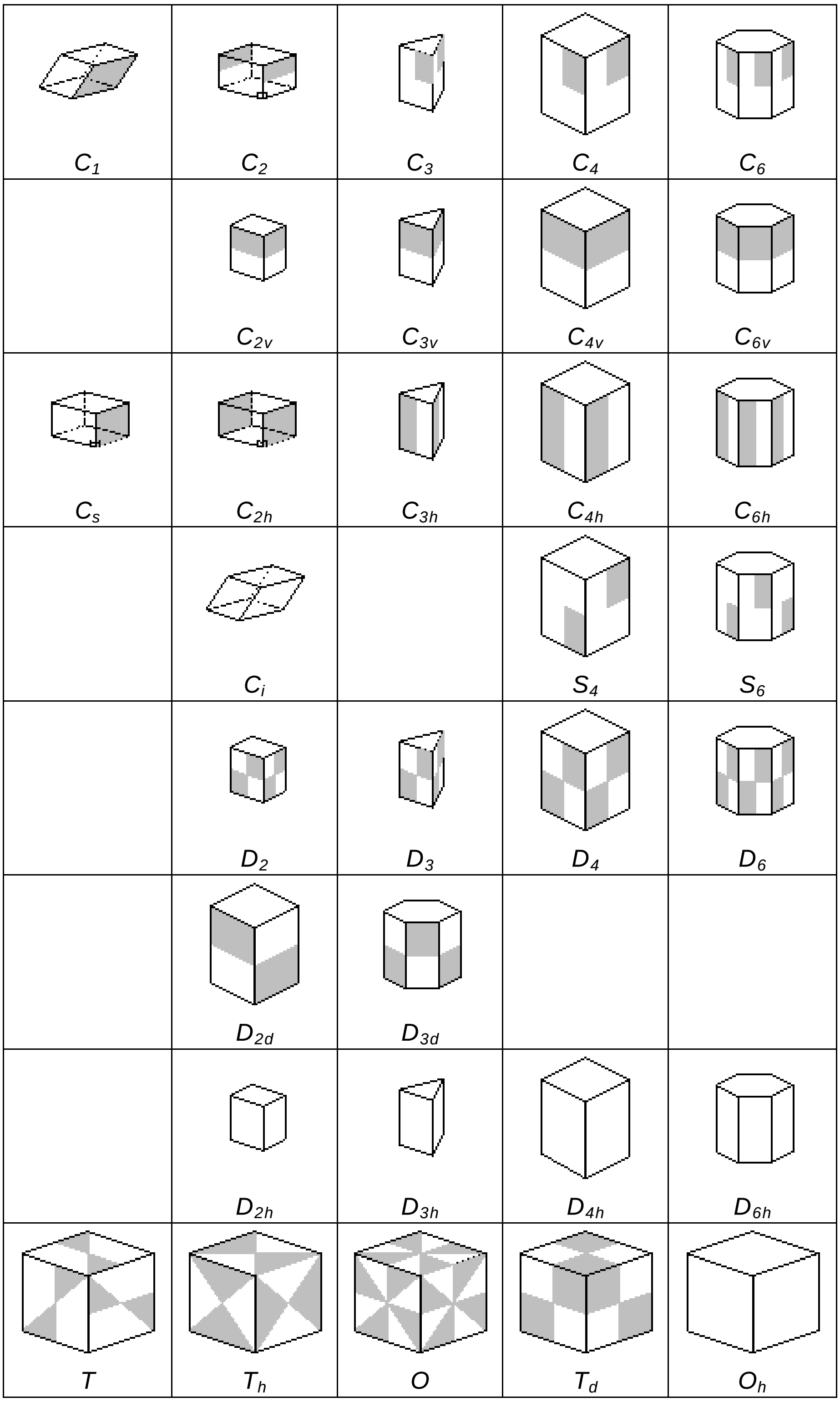


Table 7.3 Groups of Spatial Symmetries (with crystallographic restriction)

In addition, the following considerations can be taken into account. There exist 7 2D Euclidean and spherical surfaces (i.e. respectively the plane, the cylinder, the Moebius' tape, the torus and the Klein's bottle; the sphere and the projective plane) and the 3D Euclidean hypersurfaces are 17 (the Euclidean space and the Euclidean space with a hole are not considered). On the contrary, there are infinite 2D hyperbolic surface and 3D spherical and hyperbolic hypersurface. The studies about 4D hypersurfaces are not yet completed.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

Systems:	N.	Classes:	Orders:	N. of groups:
Triclinic	1	1	1	1
	2	$\bar{1}$	2	1
Monoclinic	3	2	2	3
	4	m	2	4
	5	2/m	4	6
Orthorhombic	6	222	4	9
	7	mm2	4	22
	8	mmm	8	28
Tetragonal	9	4	4	6
	10	$\bar{4}$	4	2
	11	4/m	8	6
	12	422	8	10
	13	4mm	8	12
	14	$\bar{4}2m$	8	12
	15	4/mmm	16	20
Trigonal	16	3	3	4
	17	$\bar{3}$	6	2
	18	32	6	7
	19	3m	6	6
	20	$\bar{3}m$	12	6
Hexagonal	21	6	6	6
	22	$\bar{6}$	6	1
	23	6/m	12	2
	24	622	12	6
	25	6mm	12	4
	26	$\bar{6}m2$	12	4
	27	6/mmm	24	4
Cubic	28	23	12	5
	29	m3	24	7
	30	432	24	8
	31	$\bar{4}3m$	24	6
	32	m3m	48	10

Table 7.4 Groups of Spatial Symmetries (without crystallographic restriction)

B.2. Classical Approach[19]

The topics related to geographic data and their applications are widely diffused, in the last decade, making more complex the direct solution of the problem itself. It's very important to clarify that GIS doesn't mean only a Geographic Information System able to describe the surrounding space, but also a true new – science. Indeed in the last years, the importance of data exchanging and interpretation, avoiding heavy expensive translations between two different systems, starts up an always increasing research of languages and standard methods, which would be able to allow for an easy interoperability among the systems.

B.2.1. From Reality to the Model [3]

The main goal of GIS is the representation of reality, using models that can represent it the best they can. Often we can have different interpretations of the same phenomenon and we don't have a unique solution for the creation of the model. The different interpretation of the phenomena often depends on the person who observes it, and on all the different persons involved in the modeling process. Each of them could have a different way to interpret and describe what they see. It is not always so easy to create a model of reality, for example deciding where is the beginning of a forest or a lake depends on the perspective with which the model's designer observes the phenomenon. We can have also time-depending objects that cannot have obviously a unique and defined interpretation, but it will depend on the instant of observation. Above all the representation of reality depends on the detail level we have to describe and from the future use of the model. The representation of reality:

- depends on the perspective of the model's designer;
- prescribes what users will be able to do when extracting information;
- is very difficult (or often impossible) to be transformed at a larger stage;
- is seldom for multiple purposes.

This subjectivity of representation obliges to make a formalization of abstraction processes of reality, in a way to set an efficient and consistent object able to interpret geographical information.

B.2.1.1. Abstraction of reality

There are different mechanisms for the abstraction and the creation of a conceptual model. Usually there is a *classification* that from a set of individuals with common behavior creates a class (instance-of relation). Then a *generalization* with which it is possible to pass from a set of classes to imaginary classes. At last there is an *aggregation* that creates more complex individuals starting from a set of individuals (part-of relation).

[19] In May 2005, at the TU of Bari (Italy), Prof. Max J. Egenhofer of the University of Maine (USA) presented some very interesting topics dealing with the arguments of this paragraph (B.2), which we summarize in order to establish a comparison between them and a partially different approach presented in a previous work of the authors [240] and here exposed in pharagraph B.1.

B.2.1.2. Object and Fields

The first problem we face for the description of a phenomenon is the digitalization of a continuous one. In fact it is possible to distinguish discrete or continuous spatial (and spatio-temporal) items. The discrete items are individual with an identity independent from any value of the object, their spatial extent is described by their boundaries, and usually they have some property values throughout the entire individual item. For discrete items we define the entity 'OBJECT'. The continuous items, called also distributions, have proprieties whose values change across the space and time (e.g. the temperature in a room), for this reason the values cannot be determined completely only by sampling. It doesn't already exist a technology able to measure continuously, therefore an interpolation process is needed to pass from a discrete measurement to a continuous representation of the phenomenon. An interpolation is required to derive punctual values, even if there aren't information (direct measurement) about one specific point. For continuous items we define the entity 'FIELDS'. For better characterize spatial objects is often necessary define a universal recognized boundary. For administrated spaces is easier because there are laws and norms that identify it, somewhere it is really difficult have a unique and universal boundary.

B.2.1.3. Spatial Object

After having defined the boundary of an object it is interesting measure the geographic space. Measures are punctual and provide comparable values in a standard reference system. Surely measures are not free of errors and usually refer to a conceptual model that the model's designer has made. It is necessary define elements of spatial cognition to have a spatial description not affected by personal interpretation of reality. First of all, it is important to categorize the space in classes. It is possible to choose a categorization by size (from sub-atomic to extraterrestrial) or by use. There are different schemas to classify the space by use, like the Zubin's Space. Zubin subdivides the space or the spatial objects in four categories (A, B, C, and D). Type A includes a variety of small, manipulable objects, typically their size is smaller than the human body. Type B objects are larger than the human body, they cannot be held in the hands or moved, but to observe and describe them is sufficient to turn ones head. Type C objects need a walk around to be described. Type D ones include spaces that are to big to be experienced.

B.2.1.4. Spatial Data Models

There are some fundamental properties to create a spatial model:

- coincidence: being in the same place at the same time. It is not always possible, but let recall imaginary objects;
- dimension: measure units (0, 1, 2, 3 dimension), or of a spatial object (point, line, polygon, volume);
- co-dimension: difference between the dimension of the embedding space and the dimension of the spatial object (i.e. a region in a 2D space has a co-dimension equal to 0, a line in a 2D space has a co-dimension equal to 1);
- order: establishes a sequence based on relation that are transitive, antisymmetric, reflexive, etc. in a way to make comparisons (less than, more than, equal to) and to create sequences 1D (e.g. along time) and 2D.

  Let's try to look for an order in a classical matrix. We can follow a row-order (Figure 7.5) but we are not able to preserve the near cells.

  Another possibility is a z-order, which preserve quite well the concept of near cell (Figure 7.6) [159] and [49].

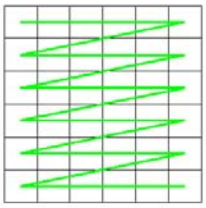


Figure 7.5. Row-order

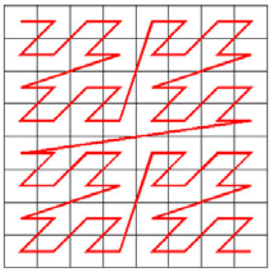


Figure 7.6. Z-order (Peano)

- connectivity: generally it is a symmetric property, means that 'there is a path' between two elements (A connected to B) and lack of separation between the objects;
- containment: it is the property of a thing to be completely inside another (A contained B);
- support: (A provides support to B) as shown in Figure 7.7.

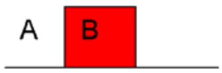


Figure 7.7. Support

- near: it is a relative concept, context-dependent, it can be associated to the time or to the space necessary to reach an object (opposite of 'far');
- metric: it is a multiple distance function (Euclidean distance, Manhattan distance, etc.);
- direction: it depends on the observer (egocentric concept), or it could be a global concept (North, South, East and West);
- partition: it is a subdivision of the space into parts, in a way that any intersections of two different parts is empty, or the union of all parts is equal to the whole.

B.2.1.5. **Number Systems**

The most used coordinate system is the Cartesian one. It assigns coordinates to points, and represents discretely the continuous space. One of the big problems in the representation of a finite space is the inconsistent calculation of line intersections. Things can shift for inconsistence of data and a straight line turn into a not continuous line, as shown in Figure 7.8.

Figure 7.8. Effect of a finite space

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

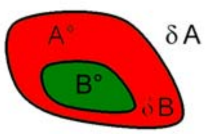
B.2.1.6. Spatial relation[106] [3]

Topology deals with properties that are preserved under groups of transformations (scaling, rotation, skewing). Binary topological relations consider regions like closed sets (homomorphic and homogenous 2D disk without separations, holes nor spikes) naming A° the interior and δA the boundary (Figure 7.9). For the Jordan Theorem, if J is a closed line in a R^2 space, then R^2 – J has an inside and an outside, and J is their boundary. Two points in a region can be always connected with a line, but if one of the points is outside the region, the line that joins them has necessarily to cross the boundary of the region. If we consider two regions, we will have two interior and two boundaries (Figure 7.10).

Figure 7.9. Interior and Boundary of a region

Figure 7.10. Interiors and Boundaries of two regions

These two regions could be related with 4 intersections, originating a matrix (2, 2) (Table 7.5):



	B^o	δB
A^o	$A^o \cap B^o$	$A^o \cap \delta B$
δA	$\delta A \cap B^o$	$\delta A \cap \delta B$

Table 7.5. Intersection Matrix for 2 regions

ø ø / ø ø	¬ø ø / ø ø	ø ¬ø / ø ø	ø ø / ¬ø ø
ø ø / ø ¬ø	¬ø ¬ø / ø ø	¬ø ø / ¬ø ø	¬ø ø / ø ¬ø
ø ¬ø / ¬ø ø	ø ¬ø / ø ¬ø	ø ø / ¬ø ¬ø	¬ø ¬ø / ¬ø ø
¬ø ¬ø / ø ¬ø	¬ø ø / ¬ø ¬ø	ø ¬ø / ¬ø ¬ø	¬ø ¬ø / ¬ø ¬ø

Table 7.6. Combinations for 2 regions

If we verify all the possible intersections for two regions we found 16 possible combinations with full (¬ø) or empty (ø) intersection, as shown in table 2. Only 8 of these 16 matrices are consistent in a geometric sense, and form equivalent classes with topology relations (Figure 7.11).

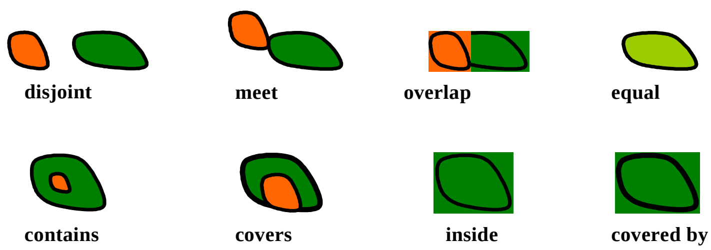


Figure 7.11. Terminology of topological relations for 2 regions

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

If there is a topological similarity that we are not able to distinguish by their matrix, we have to found alternative methods. For example a criterion could be to count the number of overlapping (the contact points) between the two objects.

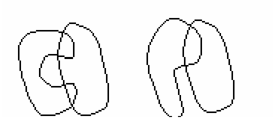


Figure 7.12. Topological Similarity

Properties of this set are:

- complete coverage (the set never leave empty areas);
- mutual exclusiveness (i.e.: two regions could be overlapped or one inside the other, both relations are impossible).

Concerning interior and boundary of spatial objects, in the following table there are summarized relations between the objects we are working about and the dimensions of the interior and boundary.

	Dim. of INTERIOR	Dim. of BOUNDARY
Volume	3	2
Region	2	1
Line	1	0
Point	0	-

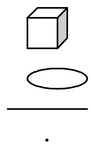


Table 7.1. Interiors and Boundary

In a R^1 space there are 4 possible intersections and, as said below, 8 possible geometric configurations. The perfect symmetry of 'cover', 'overlap' and 'equal' relations leads to 10 geometrical compatible configurations, like the linear symmetries without crystallographic restriction.

Ø	Ø
Ø	Ø

Disjoint

Ø	Ø
Ø	¬Ø

Meet

¬Ø	Ø
Ø	¬Ø

Equal

¬Ø	¬Ø
¬Ø	¬Ø

Overlap (in lines the overlapping is total, each node is completely inside the other line)

¬Ø	¬Ø
Ø	Ø

Contains

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

¬ø	¬ø
ø	¬ø

Covered

¬ø	ø
¬ø	ø

Inside

¬ø	ø
¬ø	¬ø

Covered by

If we consider a R^2 space we have 2 more possible geometrical configurations with the same intersection matrix of the 'equal' case:

¬ø	ø
ø	¬ø

Part of the red line's interior runs through the black line's exterior.

¬ø	ø
ø	¬ø

Part of the red line's boundary belongs to the black line's exterior.

Figure 7.13. 2 line-line configurations in a R2 space

Now we have to introduce the concept of interior, exterior and boundary. We indicate with A^- and B^- the exterior of the regions A and B, and like we have done for interior and boundary we can do an intersection matrix (3, 3), like as before (table 4). If we verify all the possible intersections we found 81 possible combinations with full (¬ø) or empty (ø) intersection, but not all of them have a geometric sense.

	B^o	δB	$B-$
A^o	$A^o \cap B^o$	$A^o \cap \delta B$	$A^o \cap B-$
δA	$\delta A \cap B^o$	$\delta A \cap \delta B$	$\delta A \cap B-$
$A-$	$A- \cap B^o$	$A- \cap \delta B$	$A- \cap B-$

Table 7.2. Intersection Matrix for 2 regions.

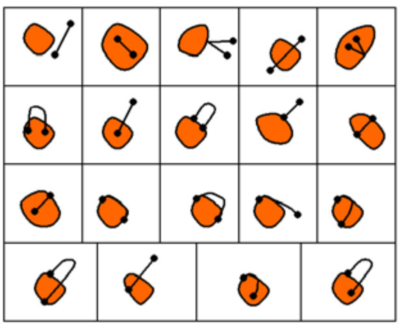


Figure 7.14. Line-Region Relations

For example only 19 of the line-region topological relations have a geometric sense (Figure 7.14).

If we sum the 8 region-region relations to the 10 line-line relations and to the 19 line-region ones, the amount reaches 37.However because of the symmetry conditions 'contains-inside' and 'covered-covered by', and reducing to one the extension of the 'equal' case in 2D (notice that several extensions are possible and they could be very various), the number of compatible configurations is exactly 32 like the planar symmetries without crystallographic restriction.

For sake of brevity, a 3D analysis and discussion is here omitted; nevertheless in a previous work [241] it is proved that the number 230 of the spatial symmetries without crystallographic restriction is reached also by topological relations with a geometric sense in 3D.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

B.3. Comparison and Conclusion

For the conclusion of this chapter, we emphasize particularly curious identities between the number of the topological and geometric relations among primary elements, and the cardinality of the groups of symmetries, in the spaces where the complex objects are located. In fact, the topological relations in one dimension are 7, as many as are the elements of the group of liner symmetries, which have one single direction of translation. The same analogy is evident in two dimensions where, in correspondence to 17 topological relations, an identical number of elements form the group of symmetries in the plan, considering two directions of translation. Still to the 32 topological relations, characterized in three dimensions, correspond the elements of the group of symmetries in the 3D space, considering three directions of translation and the crystallographic restriction. Furthermore considering the main geometric relations (being 4 the number of the elements of the group of liner symmetries, considering the crystallographic restriction):

- 10 (number of elements in mono-dimensional case) corresponds to the number of the elements of the group of symmetries in the plan, considering the crystallographic restriction;
- 32 (number of elements in the two-dimensional case) corresponds to the number of the elements of the group of symmetries in the 3D space, again considering the crystallographic restriction;
- 230 (number of elements in the three-dimensional case) corresponds to the number of the elements of the group of symmetries in the 3D space, without any restriction.

However some fundamental differences exist between the symmetries and the topological and geometric relations among objects. Firstly the symmetry form groups (i.e. they have a composition law and the association property, the identity and the inverse element of each element of the group according to the composition law), while the topological and geometric relations only constitute sets. Successively, the sets of the topological and geometric relations are included each one in the other, in agreement with the increasing of the dimension of the space, where the complex objects are located, while the groups of symmetries are all separate among them. Finally the present considerations want only to express a qualitative point of view, while mathematical implications would often require to proof complex theorems.

In addiction we quote that there exist 7 2D Euclidean and spherical finite surfaces, and 17 the 3D Euclidean finite hypersurfaces (omitting the Euclidean space and the Euclidean space with a hole). Notice that the 2D hyperbolical surfaces and the 3D spherical and hyperbolical surfaces are infinite, and the 4D hypersurface study has been not yet finished.

A more curious connection could be found taking into account some grammar properties common to the Indo-European languages. Indeed both the temporal prepositions and/or adverbs (now, before-after, often-seldom, shortly-long term) and the plural adjectives (few, some, several, many, less than, as much as, more than) are 7, as well as the linear symmetries with crystallographic restriction, whilst the spatial prepositions and/or adverbs (here, near-far, forward-backward, right-left, over-under, in-out, next to-on, along-across, dense-sparse) are 17, as well as the planar symmetries with crystallographic restriction. Furthermore taking into account 3D bodies, a two-folder table, where the rows express four conditions of position (inside, on the surface, adherence, outside), and the columns express four conditions of location (place, motion away, motion towards, motion within a close range space) has 16 cells. The number 32 (i.e. the number of the spatial symmetries with crystallographic restriction) could be ranged multiplying two times the previous result, because the objects are simple or complex.

C. INTERLIS FILE

In this appendix you can find the full version of the INTERLIS file. It is possible to see more in detail the all constrains defined by the INTERLIS/UML Editor while constructing the data model. Thanks to the the INTERLIS/UML Editor, the UML model creation is also available in this standard language, which could be read from any computer and could be used for the generation of a database and its applications.

```
INTERLIS 2.2;

MODEL DEM_model (de) = IMPORTS Units,INTERLIS;

  TOPIC Orientation_Info = DOMAIN

      Adj_method_type = (reweighted,robust);

      Camera_type = (analogue,digital);

      dem_accuracy = -1000000000.000..1000000000.000 [Units.mm];

      dem_angle = 0.000..399.999 [Units.Gon];

      dem_coord = COORD -1000000000.000..1000000000.000 [Units.mm], -
1000000000.000..1000000000.000 [INTERLIS.m], -1000.000..1000000000.000
[INTERLIS.m];

      dem_distorsion = 0.00000..100000.00000 [Units.mm];

      Orientation_type = (TA(bundle_adj,indipendent_models
                        ,TAA)
                        ,two_steps_orientation(preliminary,adjusted));

    CLASS CRS = CRS_code : TEXT*1000;
    END CRS;

    CLASS Image_files = file_name : TEXT*20;
    END Image_files;

    CLASS Images =
      name : MANDATORY TEXT*100;
      approx_scale : MANDATORY 0.000..1000000000.000 [INTERLIS.m];
      file_name : TEXT*20;
      oriented : BOOLEAN;
      used_in_orientation : BOOLEAN;
      time_of_acquisition : TEXT*10;
    END Images;

    CLASS Adj_method =
      type : Adj_method_type;
    END Adj_method;

    CLASS Camera_parameter =
      Focal_Lenght : MANDATORY 0.000..1000000.000 [Units.mm];
      pix_size : MANDATORY 0.000..1000.000 [Units.mm];
      pix_width : MANDATORY 0..1000000000 [Units.mm];
      pix_heigh : MANDATORY 0..1000000000 [Units.mm];
```

```
      Image_size_x : 0.000..1000000000000000.000;
      Image_size_y : 0.000..1000000000000000.000;
      PPS_xy : MANDATORY COORD -1000000000.000..1000000000.000 [Units.mm],
-1000000000.000..1000000000.000 [Units.mm];
      k1 : dem_distorsion;
      k2 : dem_distorsion;
      k3 : dem_distorsion;
      P1 : dem_distorsion;
      P2 : dem_distorsion;
      PPA_xy : MANDATORY COORD -1000000000.000..1000000000.000 [Units.mm],
-1000000000.000..1000000000.000 [Units.mm];
      Filter : MANDATORY BOOLEAN;
    END Camera_parameter;

    CLASS Cameras =
      Name : MANDATORY TEXT*20;
      Type : MANDATORY Camera_type;
    END Cameras;

    CLASS Img_points =
      name : MANDATORY TEXT*20;
      img_coord : MANDATORY dem_coord;
      sigma_x : dem_accuracy;
      sigma_y : dem_accuracy;
    END Img_points;

    CLASS Obj_points =
      name : MANDATORY TEXT*20;
      obj_coord : MANDATORY dem_coord;
      kappa : MANDATORY 0..3;
      sigma_X : dem_accuracy;
      sigma_Y : dem_accuracy;
      sigma_Z : dem_accuracy;
      RMS : dem_accuracy;
      GCP : BOOLEAN;
      Monografy : TEXT*20;
      MANDATORY CONSTRAINT bla bla;
    END Obj_points;

    CLASS Strip =
      name : TEXT*20;
      time : TEXT*100;
      Fly_height : MANDATORY -1000.000..1000000000.000 [INTERLIS.m];
      Mean_Longitudinal_Overlapping : 0.000..100.000 [Units.Percent];
      Mean_Transversal_Overlapping : 0.000..100.000 [Units.Percent];
      flight_direction : dem_angle;
    END Strip;

    ASSOCIATION AssociationDef13 =
      file -- {1} Image_files;
      image -- {1} Images;
    END AssociationDef13;

    ASSOCIATION AssociationDef260 =
      belonging_Image_Point -- {1..*} Img_points;
      associated_Images -<#> {0..1} Images;
    END AssociationDef260;

    ASSOCIATION AssociationDef368 =
      images -- {2..*} Images;
      strip -<#> {1} Strip;
    END AssociationDef368;
```

```
    ASSOCIATION AssociationDef45 =
      parameters -- {1..*} Camera_parameter;
      camera -<#> {1} Cameras;
    END AssociationDef45;

    ASSOCIATION AssociationDef52 =
      taken_image -- {0..*} Images;
      used_camera -- {1} Camera_parameter;
    END AssociationDef52;

    ASSOCIATION AssociationDef53 =
      CRS -- {1..*} CRS;
      points -- {1} Obj_points;
    END AssociationDef53;

    ASSOCIATION Orientation_output =
      associated_Obj_point -- {1..*} Obj_points;
      associated_image_point -- {2..*} Img_points;
      type : MANDATORY Orientation_type;
      Center_coord : MANDATORY dem_coord;
      roll : MANDATORY dem_angle;
      pitch : MANDATORY dem_angle;
      yaw : MANDATORY dem_angle;
      sigma_orientation_apriori : dem_accuracy;
      sigma_orientation_aposteriori : dem_accuracy;
      yaw_measuring_convention : MANDATORY TEXT*1000;
      Variance_Covariance_Matrix : TEXT*1000000000;
    END Orientation_output;

    ASSOCIATION AssociationDef6 =
      orientation_parameters -- {1} Orientation_output;
      used_method -- {1} Adj_method;
    END AssociationDef6;

  END Orientation_Info;

END DEM_model.
```

D. GML SCHEMA (DEM_MODEL.XSD)

In this appendix it is shown the full text of the GML Schema. This file was automatically generated by the INTERLIS/UML Editor, fixed standard encoding rules (see chapter 3.4.1.1 and 5.3.2).

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns="http://www.interlis.ch/INTERLIS2.2/preGML32"
targetNamespace="http://www.interlis.ch/INTERLIS2.2/preGML32" elementFormDefault="qualified"
attributeFormDefault="unqualified"  xmlns:gml="http://www.opengis.net/gml"  >
<xsd:import namespace="http://www.opengis.net/gml"/>
<xsd:simpleType name="DEM_model.Adj_method_type">
  <xsd:restriction base="xsd:normalizedString">
  </xsd:restriction>
</xsd:simpleType>
<xsd:simpleType name="DEM_model.Camera_type">
  <xsd:restriction base="xsd:normalizedString">
  </xsd:restriction>
</xsd:simpleType>
<xsd:complexType name="DEM_model.dem_coord">
  <xsd:complexContent>
    <xsd:restriction base="gml:PointPropertyType">
    </xsd:restriction>
  </xsd:complexContent>
</xsd:complexType>
<xsd:simpleType name="DEM_model.dem_distorsion">
  <xsd:restriction base="xsd:double">
    <xsd:minInclusive value="0.0"/>
    <xsd:maxInclusive value="100000.0"/>
  </xsd:restriction>
</xsd:simpleType>
<xsd:simpleType name="DEM_model.GCPCode">
  <xsd:restriction base="xsd:normalizedString">
  </xsd:restriction>
</xsd:simpleType>
<xsd:simpleType name="DEM_model.Orientation_type">
  <xsd:restriction base="xsd:normalizedString">
  </xsd:restriction>
</xsd:simpleType>
<xsd:simpleType name="DEM_model.dem_accuracy">
  <xsd:restriction base="xsd:double">
    <xsd:minInclusive value="-1.0E9"/>
    <xsd:maxInclusive value="1.0E9"/>
  </xsd:restriction>
</xsd:simpleType>
```

```
<xsd:simpleType name="DEM_model.dem_angle">
  <xsd:restriction base="xsd:double">
    <xsd:minInclusive value="0.0"/>
    <xsd:maxInclusive value="399.999"/>
  </xsd:restriction>
</xsd:simpleType>
<xsd:complexType name="DEM_model.dem_imgcoord">
  <xsd:complexContent>
    <xsd:restriction base="gml:PointPropertyType">
    </xsd:restriction>
  </xsd:complexContent>
</xsd:complexType>
<xsd:simpleType name="DEM_model.pix_value">
  <xsd:restriction base="xsd:double">
    <xsd:minInclusive value="0.0"/>
    <xsd:maxInclusive value="100000.0"/>
  </xsd:restriction>
</xsd:simpleType>
<xsd:element name="DEM_model.Orientation_Info.Adj_method"
type="DEM_model.Orientation_Info.Adj_method" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Adj_method">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="type" type="DEM_model.Adj_method_type" minOccurs="0"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Camera" type="DEM_model.Orientation_Info.Camera"
substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Camera">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="Name">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="20"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="Type" type="DEM_model.Camera_type"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Camera_parameter"
type="DEM_model.Orientation_Info.Camera_parameter" substitutionGroup="gml:_Feature"/>
```

```
<xsd:complexType  name="DEM_model.Orientation_Info.Camera_parameter">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="Focal_Lenght">
          <xsd:simpleType>
            <xsd:restriction base="xsd:double">
              <xsd:minInclusive value="0.0"/>
              <xsd:maxInclusive value="1000.0"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="pix_size_x">
          <xsd:simpleType>
            <xsd:restriction base="xsd:double">
              <xsd:minInclusive value="0.0"/>
              <xsd:maxInclusive value="100.0"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="pix_size_y">
          <xsd:simpleType>
            <xsd:restriction base="xsd:double">
              <xsd:minInclusive value="0.0"/>
              <xsd:maxInclusive value="100.0"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="image_size_x" type="DEM_model.pix_value"/>
        <xsd:element name="image_sixe_y" type="DEM_model.pix_value"/>
        <xsd:element name="PPA_xy" type="DEM_model.dem_imgcoord"/>
        <xsd:element name="PBS_xy" type="DEM_model.dem_imgcoord"/>
        <xsd:element name="k1" type="DEM_model.dem_distorsion" minOccurs="0"/>
        <xsd:element name="k2" type="DEM_model.dem_distorsion" minOccurs="0"/>
        <xsd:element name="k3" type="DEM_model.dem_distorsion" minOccurs="0"/>
        <xsd:element name="P1" type="DEM_model.dem_distorsion" minOccurs="0"/>
        <xsd:element name="P2" type="DEM_model.dem_distorsion" minOccurs="0"/>
        <xsd:element name="Filter" type="xsd:boolean"/>
        <xsd:element name="FM1" type="DEM_model.dem_imgcoord"/>
        <xsd:element name="FM2" type="DEM_model.dem_imgcoord"/>
        <xsd:element name="FM3" type="DEM_model.dem_imgcoord"/>
        <xsd:element name="FM4" type="DEM_model.dem_imgcoord"/>
        <xsd:element name="FM5" type="DEM_model.dem_imgcoord" minOccurs="0"/>
        <xsd:element name="FM6" type="DEM_model.dem_imgcoord" minOccurs="0"/>
        <xsd:element name="FM7" type="DEM_model.dem_imgcoord" minOccurs="0"/>
        <xsd:element name="FM8" type="DEM_model.dem_imgcoord" minOccurs="0"/>
        <xsd:element name="calibration_certificate" minOccurs="0">
          <xsd:simpleType>
```

```
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="50"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="b1" type="DEM_model.dem_distorsion" minOccurs="0"/>
        <xsd:element name="b2" type="DEM_model.dem_distorsion" minOccurs="0"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.CRS" type="DEM_model.Orientation_Info.CRS"
substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.CRS">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="CRS_code" minOccurs="0">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="1000"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Image" type="DEM_model.Orientation_Info.Image"
substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Image">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="name">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="100"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="approx_scale">
          <xsd:simpleType>
            <xsd:restriction base="xsd:double">
              <xsd:minInclusive value="0.0"/>
              <xsd:maxInclusive value="1.0E9"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
```

```
        <xsd:element name="oriented" type="xsd:boolean" minOccurs="0"/>
        <xsd:element name="used_in_orientation" type="xsd:boolean"/>
        <xsd:element name="time_of_acquisition" minOccurs="0">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="10"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Image_file"
type="DEM_model.Orientation_Info.Image_file" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Image_file">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="file_name" minOccurs="0">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="20"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Img_point"
type="DEM_model.Orientation_Info.Img_point" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Img_point">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="name">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="20"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="img_coord" type="DEM_model.dem_imgcoord"/>
        <xsd:element name="sigma_x" type="DEM_model.dem_accuracy" minOccurs="0"/>
        <xsd:element name="sigma_y" type="DEM_model.dem_accuracy" minOccurs="0"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
```

```
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Obj_point"
type="DEM_model.Orientation_Info.Obj_point" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Obj_point">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="name">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="20"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="obj_coord" type="DEM_model.dem_coord"/>
        <xsd:element name="kappa" type="DEM_model.GCPCode"/>
        <xsd:element name="sigma_X" type="DEM_model.dem_accuracy" minOccurs="0"/>
        <xsd:element name="sigma_Y" type="DEM_model.dem_accuracy" minOccurs="0"/>
        <xsd:element name="sigma_Z" type="DEM_model.dem_accuracy" minOccurs="0"/>
        <xsd:element name="RMS" type="DEM_model.dem_accuracy" minOccurs="0"/>
        <xsd:element name="GCP" type="xsd:boolean" minOccurs="0"/>
        <xsd:element name="Monografy" minOccurs="0">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="20"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Strip" type="DEM_model.Orientation_Info.Strip"
substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Strip">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="name">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="20"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="time" minOccurs="0">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="100"/>
```


alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

```
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="Fly_height">
          <xsd:simpleType>
            <xsd:restriction base="xsd:double">
              <xsd:minInclusive value="-1000.0"/>
              <xsd:maxInclusive value="20000.0"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="Mean_Longitudinal_Overlapping" minOccurs="0">
          <xsd:simpleType>
            <xsd:restriction base="xsd:double">
              <xsd:minInclusive value="0.0"/>
              <xsd:maxInclusive value="100.0"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="Mean_Transversal_Overlapping" minOccurs="0">
          <xsd:simpleType>
            <xsd:restriction base="xsd:double">
              <xsd:minInclusive value="0.0"/>
              <xsd:maxInclusive value="100.0"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="flight_direction" type="DEM_model.dem_angle"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Camera_Camera_parameter"
type="DEM_model.Orientation_Info.Camera_Camera_parameter" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Camera_Camera_parameter">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="parameter" type="gml:ReferenceType">
        </xsd:element>
        <xsd:element name="camera" type="gml:ReferenceType">
        </xsd:element>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.CRS_Obj_point"
type="DEM_model.Orientation_Info.CRS_Obj_point" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.CRS_Obj_point">
```

```
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="CRS" type="gml:ReferenceType">
        </xsd:element>
        <xsd:element name="point" type="gml:ReferenceType">
        </xsd:element>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Image_Camera_parameter"
type="DEM_model.Orientation_Info.Image_Camera_parameter" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Image_Camera_parameter">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="taken_image" type="gml:ReferenceType">
        </xsd:element>
        <xsd:element name="used_camera" type="gml:ReferenceType">
        </xsd:element>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Image_Image_file"
type="DEM_model.Orientation_Info.Image_Image_file" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Image_Image_file">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="file" type="gml:ReferenceType">
        </xsd:element>
        <xsd:element name="image" type="gml:ReferenceType">
        </xsd:element>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Image_Img_point"
type="DEM_model.Orientation_Info.Image_Img_point" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Image_Img_point">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="belonging_Image_Point" type="gml:ReferenceType">
        </xsd:element>
        <xsd:element name="associated_Image" type="gml:ReferenceType">
        </xsd:element>
```

```
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Orientation_output"
type="DEM_model.Orientation_Info.Orientation_output" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Orientation_output">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="type" type="DEM_model.Orientation_type"/>
        <xsd:element name="Center_coord" type="DEM_model.dem_coord"/>
        <xsd:element name="roll" type="DEM_model.dem_angle"/>
        <xsd:element name="pitch" type="DEM_model.dem_angle"/>
        <xsd:element name="yaw" type="DEM_model.dem_angle"/>
        <xsd:element name="sigma_orientation_apriori" type="DEM_model.dem_accuracy"
minOccurs="0"/>
        <xsd:element name="sigma_orientation_aposteriori" type="DEM_model.dem_accuracy"
minOccurs="0"/>
        <xsd:element name="yaw_measuring_convention">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="1000"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="Variance_Covariance_Matrix" minOccurs="0">
          <xsd:simpleType>
            <xsd:restriction base="xsd:normalizedString">
              <xsd:maxLength value="1000000000"/>
            </xsd:restriction>
          </xsd:simpleType>
        </xsd:element>
        <xsd:element name="associated_Obj_point" type="gml:ReferenceType">
        </xsd:element>
        <xsd:element name="associated_image_point" type="gml:ReferenceType">
        </xsd:element>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Strip_Image"
type="DEM_model.Orientation_Info.Strip_Image" substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Strip_Image">
  <xsd:complexContent>
    <xsd:extension base="gml:AbstractFeatureType">
      <xsd:sequence>
        <xsd:element name="image" type="gml:ReferenceType">
        </xsd:element>
        <xsd:element name="strip" type="gml:ReferenceType">
```

```
      </xsd:element>
    </xsd:sequence>
  </xsd:extension>
 </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.Orientation_output_Adj_method"
type="DEM_model.Orientation_Info.Orientation_output_Adj_method"
substitutionGroup="gml:_Feature"/>
<xsd:complexType  name="DEM_model.Orientation_Info.Orientation_output_Adj_method">
 <xsd:complexContent>
  <xsd:extension base="gml:AbstractFeatureType">
   <xsd:sequence>
    <xsd:element name="orientation_parameter" type="gml:ReferenceType">
    </xsd:element>
    <xsd:element name="used_method" type="gml:ReferenceType">
    </xsd:element>
   </xsd:sequence>
  </xsd:extension>
 </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info.member" type="DEM_model.Orientation_Info.member"
substitutionGroup="gml:abstractFeatureMember"/>
<xsd:complexType name="DEM_model.Orientation_Info.member">
 <xsd:complexContent>
  <xsd:extension base="gml:AbstractFeatureMemberType">
   <xsd:sequence>
    <xsd:choice>
     <xsd:element ref="DEM_model.Orientation_Info.Adj_method"/>
     <xsd:element ref="DEM_model.Orientation_Info.Camera"/>
     <xsd:element ref="DEM_model.Orientation_Info.Camera_parameter"/>
     <xsd:element ref="DEM_model.Orientation_Info.CRS"/>
     <xsd:element ref="DEM_model.Orientation_Info.Image"/>
     <xsd:element ref="DEM_model.Orientation_Info.Image_file"/>
     <xsd:element ref="DEM_model.Orientation_Info.Img_point"/>
     <xsd:element ref="DEM_model.Orientation_Info.Obj_point"/>
     <xsd:element ref="DEM_model.Orientation_Info.Strip"/>
     <xsd:element ref="DEM_model.Orientation_Info.Orientation_output"/>
    </xsd:choice>
   </xsd:sequence>
  </xsd:extension>
 </xsd:complexContent>
</xsd:complexType>
<xsd:element name="DEM_model.Orientation_Info" type="DEM_model.Orientation_Info"
substitutionGroup="gml:_GML"/>
<xsd:complexType name="DEM_model.Orientation_Info">
 <xsd:complexContent>
  <xsd:extension base="gml:AbstractGMLType">
   <xsd:sequence>
    <xsd:element name="DEM_model.Orientation_Info.member" minOccurs="0"
maxOccurs="unbounded"/>
```

```
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
</xsd:schema>
```

REFERENCES

WEB

[1] Comité Européen de Normalisation (CEN) **[on line].** Avaliable on : http://www.cen.org (consulted on April 2005)

[2] CityGML **[online].** Avaliable on: http://www.citygml.org/ (consulted on December 2007)

[3] Egenhofer M. Website **[on line].** Avaliable on: http://www.spatial.maine.edu/~max (consulted on June 2005)

[4] INTERLIS **[on line].** Avaliable on: http://www.interlis.ch (consulted on September 2006)

[5] International Organization for Standardization (ISO) **[on line].** Avaliable on: http://www.iso.org/iso/home.htm (consulted on April 2005)

[6] LandXML Consortium **[on line].** Avaliable on: http://www.LandXML.org (consulted on February 2005)

[7] Object Management Group (OMG) **[on line].** Avaliable on: http://www.omg.org/ (consulted on September 2006)

[8] Open Geospatial Consortium **[on line].** Avaliable on: http://www.opengeospatial.org (consulted on April 2005)

[9] Open GIS Consortium – (GML) **[on line].** Avaliable on: http://www.opengeospatial.org/standards/gml (consulted on October 2005)

[10] SensorML **[on line].** Avaliable on: http://vast.nsstc.uah.edu/SensorML/ (consulted on December 2007)

[11] SVGFR – le premiere portail francophone du SVG **[on line].** Avaliable on: http://www.svgfr.org (consulted on February 2005)

[12] Unified Model Language (UML) **[on line].** Avaliable on: http://altas.kennesaw.edu (consulted on September 2006)

[13] W3 Council-(SVG) **[on line].** Avaliable on: http://www.w3.org/TR/SVG (consulted on February 2005)

[14] W3 Council-(XML) **[on line].** Avaliable on: http://www.w3.org/TR/REC-xml (consulted on February 2005)

Books

[15] Agresti A. (1984): Analysis of Ordinal Categorical Data. Wiley and Sons , New York.

[16] Andersen E.B. (1980): Discrete Statistical Models with Social Science Applications. North Holland Publishing Company, Amsterdam (Nederlands).

[17] Bury K.V. (1975): Statistical Models in Applied Science. Wiley and Sons, New York.

[18] Acheson J.D. (1952): Quality Control and Industrial Statistics. Richard D. Irwin Inc., Homewood (Il).

[19] Barnett V., Lewis T. (1978): Outliers in statistical data. Wiley and Sons, New York.

[20] Bézier P. (1974): Mathematical and Practical Possibilities of UNISURF. Computer Aided Geometric Design, Academic Press, New York.

[21] Bjerhammar A. (1973): Theory of Errors and Generalized Matrix Inverses. Elsevier Scientific Publishing Company, Amsterdam (Nederlands).

[22] Carosio A. et al. (2005): Interopérabilité pour l'utilisation généralisée de la Géoinformation. A.Carosio (Ed), ETHZ, Zurich.

[23] Cox D.R., Hinkley D.V. (1974): Theoretical Statistics. Chapman and Hall, London.

[24] Cressié N. A. (1991): Statistics for Spatial Data. Wiley and Sons, New York.

[25] Cunietti M. (1964): Corso Teorico Pratico sulle Misure. Libreria CORTINA, Milan.

[26] Dantzig G. B. (1963): Linear Programming and Extensions. Princeton University Press, Princeton (NJ).

[27] Davies O.L. (1960): The Design and Analysis of Industrial Experiments. Oliver and Boyd, London.

[28] Davies O.L. (1961): Statistical Methods in Research and Production. Oliver and Boyd, London.

[29] Draper N.R., Smith H. (1961): Applied Regression Analysis. Wiley and Sons, New York.

[30] Forlani, G. (1990): Ricerche di Geodesia, Topografia e Fotogrammetria. Vol. 8, Clup, Milan.

[31] Fischer F.E. (1973): Fundamental Statistical Concepts. Canfield Press, San Francisco.

[32] Gentle J.E., Kennedy W.J. (1980): Statistical computing. Dekker, Basel.

[33] George A., Liu J.W.H. (1981): Computer solution of large sparse positive definite systems. Prentice Hall, Englewood Cliffs (NJ).

[34] Golub G.H., van Loan C.F. (1983): Matrix computation. North Oxford Academic, Oxford.

[35] Grafarend E.W., Sansò F. et al. (1985): Optimization and Design of Geodetic Networks. Springer, Berlin.

[36] Hampel F.R., Ronchetti E.M., Rousseeuw P.J., Stahel W.A. (1986): Robust Statistics. The Approach Based on Influence Functions. Wiley and Sons, New York.

[37] Hartley R.I. and Zisserman A. (2000): Multiple View Geometry. Cambridge University Press, Cambridge.

[38] Hawkins D.M. (1980): Identification of outliers. Chapman and Hall, London.

[39] Hawkins D.M. (1982): Topics in Applied Multivariate Analysis. Cambridge University Press, London.

[40] Hestenes M.R., Stiefel E. (1952): Methods of conjugate gradients for solving linear systems. In: Journal of Research of the National Bureau of Standards, Vol. 49, n. 6.

[41] Huber P.J. (1981): Robust Statistics. Wiley and Sons, New York.

[42] Jobson J.D. (1991/2): Applied Multivariate Data Analysis. Vol. I & II. Springer, New York.

[43] Johnson M. (1987): The Body in the Mind. Chicago University Press, Chicago.

[44] Kaufman L.,Rousseeuw P.J. (1990): Finding Groups in Data. Wiley and Sons, New York.

[45] Koch K.R. (1987): Parameter Estimation and Hypothesis Testing in Linear Models. Springer, Berlin.

[46] Kraus, K. (1993): Photogrammetry. Vol. 1 and 2. Dümmler Verlag, Bonn.

[47] Laurini R., Thompson D. (1996): Fundamentals of Spatial Information Systems. Academic Press, London.

[48] Lawson G.L., Handson R.J. (1974): Solving least squares problems. Prentice Hall, Englewood Cliffs (NJ).

[49] Mandelbrot B. B. (1983): The Fractal Geomerty of Nature. W. H. Freeman, New York.

[50] McPherson G. (1990): Statistics in Scientific Investigation. Springer, New York.

[51] Middlebroks E.J. (1976): Statistical Calculation, How to Solve Statistical Problems. Ann Arbor Science, Ann Arbor (MI).

[52] Mikhail E.M., Ackermann F. (1976): Observations and Least Squares. IEP-A Dun-Donnelley Publisher, New York.

[53] Mood A.M., Graybill F.A., Boes D.C. (1974): Introduction to the Theory of Statistics. Mc Graw-Hill Book Company, London.

[54] Moritz H. (1980): Advanced Physical Geodesy. Wichmann, Karlsruhe.

[55] Okabe A. et al. (1992): Spatial Tessellations: Concepts and Applications of Voronoi Diagrams. Wiley and Sons, New York.

[56] Preparata F.P., Shamos M.I. (1985): Computational Geometry: an Introduction. Springer, New York.

[57] Rao C.R. (1965): Linear Statistical Inference and its Applications. Wiley and Sons, New York.

[58] Rousseeuw P.J, Leroy A.M. (1987): Robust Regression and Outlier Detection. Wiley and Sons, New York.

[59] Strang G. (1988): Linear Algebra and its Applications. Harcourt Brace Janovich, San Diego.

[60] Tanner M.A. (1996): Tools for Statistical Inference. Springer, New York

[61] Tewarson R.P. (1972): Sparse Matrices. N. 99. Academic Press, New York.

[62] Thurston W. (1997): Three-dimensional Geometry and Topology. Princeton University Press, Princeton.

[63] Togliatti G. (1976): Fondamenti di Statistica. CLUP, Milan.

[64] Varga M.S. (1962): Matrix Iterative Analysis. Prentice Hall, Englewood Cliffs (NJ).

[65] Wald A. (1947): Sequential Analysis. Wiley and Sons, New York.

[66] Watson G.N. (1948): A Treatise on the Theory of Bessel Functions. Cambridge University Press, Cambridge.

[67] Weeks J. (1985): The Shape of Space. Dekker, New York.

[68] Weng J., Huang T.S. and Ahuja N. (1993): Motion and Structures from Image Sequences. Springer-Verlag, Berlin.

PUBLICATIONS

Part I

[69] Caputo M. (1957): Rilievo Fotogrammetrico della Superficie di un Liquido in Moto in una Canaletta Sperimentale. L'Energia Elettrica. Vol XXXIV/4. AEIT, Milan (Italy).

[70] Carosio A., Nocera R. (2004): Il Trasferimento dei Dati, I Metadati, I Modelli e l'Interoperabilità nei GIS. Proc. of the 8th ASITA, Rome (Italy).

[71] Carosio A., Nocera R. (2001): Norme Tecniche e Internazionali per l'Informazione Geografica: Il Ruolo dell'Europa. Proc. of 5th ASITA 2001, Rimini (Italy).

[72] Carosio A., Nocera R. (2001): Interoperabilità e Trasferimento di Dati nei Sistemi Informativi Geografici. Proc. of 5th ASITA 2001, Rimini (Italy).

[73] Drap P., Grussenmeyer P., Curtinot P. Y., et al. (2004): Presentation of the web based ARPENTEUR Tools: towards a Photogrammetry based Heritage Information System. Int. Archives of Photogrammetry and Remote Sensing, Istanbul (Turkey), Vol. 35/6, pp. 123-128.

[74] Gnägi H. R., Morf A., Staub P. (2006): Semantic Interoperability through the Definition of Conceptual Model Transformations. Proc. of 9th AGILE Conference on Geographic Information Science, Visegrád (Hungary), pp. 128-138.

[75] Gnägi H. R., Stahel N. (2006): System-Independent and Quality Tested Availability of Railway Data Across Country and System Borders by the Model-driven Approach. Comprail 2006, Prague (Czech Republic).

[76] Laurini R. (2004): Interoperabilità semantica dei dati territoriali. Proc. of the 8th ASITA 2004, Rome (Italy).

[77] McKee L. (2001): OGC's Role in the Spatial Standards World [on line]. OGC White Paper. Avaliable on: http://www.opengeospatial.org/pressroom/papers (consulted on september 2005).

[78] Acheriteguy C., Paul F., Perrin L. (2003): Synthèse bibliographique: Formats de Donnée Géographiques pour Internet. LIRIS-INSA de Lyon, Lyon (France).

[79] Boussuge N., Careme S., Chebrou B., Sentissi B. (2004): Synthèse bibliographique: Visualisation des Données Géographiques sur Internet. LIRIS-INSA de Lyon, Lyon (France).

Part II

[80] Ackermann F. (1995): Automation of Digital Aerial Triangulation. Proc. of 2nd Course on Digital Photogrammetry, UniversitSt Bonn und LVA Nordrhein-Westfalen, Bonn (Germany), pp.19.

[81] Akaike H. (1973): Block Toeplitz Matrix Inversion. In: SIAM Journal of Applied Mathematics, Vol. 24/2.

[82] Baarda W. (1967): Statistical Concepts in Geodesy. Netherlands Geodetic Commission, Publications on Geodesy New Series, Vol. 2/4, Delft (Holland).

[83] Baarda W. (1968): A Testing Procedure for Use in Geodetic Networks. Netherlands Geodetic Commission, Publications on Geodesy New Series, Vol. 2/5, Delft (Holland).

[84] Bajaj L. C., Ihm I.: (1992): Smoothing Polyhedra using Implicit Algebraic Splines. Computer Graphics 26, pp. 79-86.

[85] Ball G.H. and Hall D.J. (1967): A Clustering Technique for Summarizing Multivariate Data. In: Behavioral Science, Vol. 12, p. 153-155.

[86] Baltsavias E.P. (1991): Multiphoto Geometrically Constrained Matching. Dissertation IGP-ETHZ Mitteinungen, N.49. Zürich (Switzerland).

[87] Barrodale I. and Roberts F. (1973): An Improved Algorithm for Discrete L_1 Linear Approximation. SIAM Journal of Numerical Analysis, n. 10.

[88] Barrodale I. and Roberts F. (1974): Solution of an Overdeterminated System of Equations in the l_1 Norm. In: Communication of the ACM, Vol. 17/6, New York.

[89] Bartels R.H. and Golub G.H. (1969): The Simplex Method of Linear Programming Using LU-decomposition. In: Communication of the ACM, Vol. 12/5, New York.

[90] Bartles R., J. Beatty and B.Barsky (1987): An introduction to the Serpent user Interface Management System. Software Engineering Institute. Carnegie-Mellon University, Pittsburgh (PA).

[91] Beckman R. J. and Cook R. D. (1983): Outlier…s. Technometrrix, Vol. 25/2.

[92] Bieberbach L. (1910): Über die Bewegungsgruppen des n-dimensionalen euklidischen Raumes mit einem endlichen Fundamentalbereich, Gött. Nachr., pp. 75-84.

[93] Bieberbach L. (1911/12): Über die Bewegungsgruppen der Euklidischen Räume I, II , Math. Ann, Vol.70, pp. 297-336 and Vol.72, pp. 400-412.

[94] Blais J.A.R. (1982): Recursive Least-Squares Estimation Using Givens Transformations. In: Int. Arch. Photogram. Remote Sensing, Helsinki, Vol. 24/3.

[95] Blais J.A.R. (1984): Optimization of least-squares computations in on-line photogrammetry. In: Int. Arch. Photogram. Remote Sensing, Rio de Janeiro (Brasil), Vol. 25/3.

[96] Boissonant J.D. (1984): Geometric Structures for Three-dimensional Shape Representation. ACM Trans. Graphics, Vol. 3, pp. 266-286.

[97] Brown D.C. (1971): Colose-range Camera Calibration. In Photogammetric Engineering. Vol.37/8, pp. 855-866.

[98] Catmull E. and Rom R., (1974): A class of Local Interpolating Splines. In: Barnhill R., Riesenfeld R. (Ed's) Computer Aided Geometric Design, San Francisco, pp. 317-326.

[99] Cross P.A. (1982): Computer Aided Design of Geodetic Networks. In: Int. Symp. on Geodetic Networks and Computations , DGK Reihe B Heft 258/III, Munich (Germany).

[100] Cross P.A. and Fagir A.H. (1982): Procedures for the First and Second Order Design of Vertical Control Networks. In: Survey Control Networks, n. 7, Aalborg, Denmark, July, 7-9.

[101] Cuthill E. and Mckee J. (1969): Reducing the Bandwidth of Sparse Symmetric Matrices. In: Proc. ACM National Conference. New York, p.157-172.

[102] Dufour H.M. (1974): Propriétés des Systèmes Linéaires Symmétriques Déduits des leur Forma Spectrale. In: Bollettino di Geodesia e Scienze Affini, year 33, n. 4.

[103] Dufour H.M. (1964): Résolution des Systèmes Linèaires par le Méthode des Résidus Conjugués. In: Bulletin Géodésique, n. 71.

[104] Dufour H.M. and Burette D. (1974): Présentation Synthétique des Méthodes Semi-intératives des Résolution des Systémes Linéaires. In: Bulletin Géodésique, n. 113.

[105] Edberg E. (1976): Matrix Computation. In: Lectures given in the Academic Training Program of CERN 1975-1976, CERN 76-22, Geneve (Switzerland).

[106] Egenhofer M. J., Clementini E. and Di Felice P. (1994): Topological Relations between Regions with Holes. In: International Journal of Geographical Information Systems, Vol. 8/2, pp. 129-142.

[107] Egenhofer M. J. and Mark D. M. (1995): Naive Geography, COSIT 1995, Austria.

[108] El Hakim S. (1997): Object Model Creation fom Multiple Range Images: Adquisition, Calibration, Model Building and Verification. IEEE Computer Society Press, pp. 326-333.

[109] Erisman A.M. and Tinney W.F. (1975): On Computing Certain Elements of the Inverse of Sparse Matrix. In: Comunication of the ACM, vol. 18, n.3, New York, pp. 177-179.

[110] Faddajev D. K. and Faddajeva W. N. (1964): Numerische Methoden der Linearen Algebra. R. Oldenburg Verlag, Munich (Germany).

[111] Fang T.P. and Piegl L.A. (1993): Delaunay Triangulation Using a Uniform Grid. IEEE Computer Graphics Applications, Vol. 13, n.3, pp. 36-47.

[112] Fang T.P. and Piegl L.A. (1994): Algorithm for Constrained Delaunay Triangulation. The Visual Computer, Vol. 10, pp. 255-265.

[113] Faugeras O.D., Luong Q.T., and Maybank S.J. (1992): Camera self-calibration: Theory and experiments. In Proc. of European Conf. on Computer Vision, Santa Margherita Ligure (Italy), pp. 321-334.

[114] Fedorov, E. S. (1949): Symmetry and the Structure of Crystals. Fundamental Works , Moscow (Russia), pp. 111–255

[115] Floriani D. L. (1987): Surface Representation Based on Triangular Grids. The Visual Computer, Vol. 3, pp. 27-50.

[116] Floriani D. L. and Bruzzone E. (1990): Two Data Structures for Building Tetrahedralizations. The Visual Computer, Vol. 3, pp. 27-50.

[117] Foley Th. A. and Nielson G. M. (1989): Knot Selection for Parametric Spline Interpolation. In: Lyche T., Shumaker L. (Ed's) Mathematical Methods in Computer Aided Geometric Design, Academic Press, Boston, pp. 261-272.

[118] Forstner W. (1986): Reliability, Error detection and Self Calibration. In: Int. Arch. of Photogram. Remote Sensing, Rovaniemi (Finland), vol. 26, Part 3/4.

[119] Franwaert E. (1987): L1 in Fuzzy Clustering. In: Y. Dodge (Ed), Statistical Data Analysis Based on the L1-norm and Related Methods, North Holland, pp. 417-426.

[120] Frederiksen P., Kubik K., Weng W. (1984): Oh, Grossororors!. In: Int. Arch. of Photogram. Remote Sensing, Rio de Janeiro (Brasil), Vol. 25/A3a.

[121] Fuchs H. (1982): Contributions to the Adjustment by Minimizing the Sum of Absolute Residuals. In: Manuscripta Geodaetica, n. 7.

[122] Finsterwalder S. (1899): Die Geometrischen Grundlagen der Photogrammetrie. Jahresbericht der Deutschen Mathematiker-Vereinigung, Vol. 6. Teubner Press, Leipzig (Germany).

[123] Fourcade H.G. (1926): A new method of aerial surveying. Trans. of the Royal Society of South Africa, Signal Processing, Vol. 14/3, Academic Press, South Africa, pp. 93-112.

[124] Gibbs N.E., Poole W.G., Stochmeyer P.K. (1976): An algorithm for reducing the bandwidth and profile of a sparse matrix. In: SIAM Journal of Numerical Analysis, vol. 13, n. 2.

[125] Giubas L. and Stolfi J. (1985): Primitive for the Manipulation of General Subdivision and the Computation of Voronoi Diagrams. ACM Trans. Graphics, Vol. 4, pp. 74-123.

[126] Gottschalk S. and Wrobel B.P. (1978): Reducing the bandwidth of Normal-equation Matrices. In: Processing of Special Large Matrices for Geodesy Interpretation of the Results (CERN), Geneve (Switzerland), pp. 22-35.

[127] Green P.J. and Gibson R. (1978): Computing Dirichlet Tesselations in the Plane. Computer Journal, Vol. 21, pp.168-173.

[128] Groten E., Hein G. (1978): On the use of bandwidth minimization in geodetic and photogrammetric problems. In: Processing of Special Large Matrices for Geodesy Interpretation of the Results (CERN), Geneve (Switzerland), pp. 18-22.

[129] Grudig L. (1980): Feasibility Study of the Conjugate Gradient Method for Solving Large Sparse Equation Sets. NOAA Technical Report, NOS 82 NGS 13, pp.19.

[130] Halstead M., Kass M., De Rose T. (1993): Efficient, Fair Interpolation using Catmull-Clark surface. Computer Graphics, Annual Conference Series, pp. 35-43.

[131] Hannan B. (1994): A Data Reduction Scheme for Triangulated Surface. Computer Aided Geometric Design, Vol. 11, pp. 197-214.

[132] Hartley R. (1994): Self-calibration from Multiple Views with Rotating Camera. In Proc. of ARPA Image Understanding Workshop, pp.1009-1016.

[133] Heiskanen W.A. and Moritz H. (1967): Physical Geodesy. Freeman and Company, San Francisco.

[134] Hoppe H., De Rose T., Duchamp (1992): Surface Reconstruction from Unorganized Points. Computer Graphics, Vol. 26, pp. 71-78.

[135] Hoppe H., De Rose T., Duchamp (1993): Mesh Optimization. Proc. Computer Graphics, Annual Conference Series, pp. 19-25.

[136] Huber P.J. (1964): Robust Estimation of a Location Parameter. In: Ann. Math. Statist., n. 35, pp. 73-101.

[137] Huber P.J. (1972): Robust statistics: a review. In: Ann. Math. Statist., n. 43, p. 1041-1067.

[138] Joe B. (1989): Three Dimensional Triangulation from Local Transformations. SIAM J. Sci. Stat. Comput., Vol. 10, pp. 718-741.

[139] Joe B. (1991): Construction of Three Dimensional Delaunay Triangulation using Local Transformations. Computer Aided Geometric Design, Vol. 8, pp. 123-142.

[140] Jorgensen P., Frederiksen P., Kubik K., Weng W (1984): Ah, robust estimation. In: Int. Arch. of Photogram. Remote Sensing, Rio de Janeiro (Brasil), Vol. 25, part A3a.

[141] Kaufman L. and Rousseeuw P.J. (1987): Clustering by Means of Medoids. In: Y. Dodge (Ed), Statistical Data Analysis Based on the L1-norm and Related Methods, North Holland, pp. 405-416.

[142] Kendall M.G. and Stuart A. (1968): The Advanced Theory of Statistics. Vol. 1, 2 and 3, Griffin, London (UK).

[143] Kershaw P.S. (1978): The Incomplete Cholesky Conjugate Gradient Method for the Iterative Solution of Systems of Linear Eequations. In: Journal of Computational Physics, n. 26.

[144] Krarup T. (1981): A Measure for Local Redundancy, A Contribution to the Reliability Theory for Geodetic Networks. Unpublished manuscript, Geodaetisk Institut.

[145] Inghilleri G. (1980): Simposio Calcoli e Compensazioni di Triangolazioni Aeree. In G. Inghilleri Ed., *Calcoli* e Compensazioni di Triangolazioni Aeree. SIFET, Parma (Italy).

[146] Lawson C.L. (1977): Software for C^1 Surface Interpolation. In: Rice J.R. (Ed.) Mathematical software, Vol. III, Academic Press, New York, pp. 161-194.

[147] Lee D.T., Sachter B.J. (1980): Two Algorithmis for Constructing Delaunay Triangulations. Int. Journal of Computer and Information Sciences, Vol. 9, pp. 219-242.

[148] Loop C. (1994): A G^1 Triangular Spline Surface of Arbitrary Topological Type. Computer Graphics, Vol. 11, pp. 303-330.

[149] Lounguet-Higgins H.C. (1981): A Computer Algorithm for Reconstructing a Scene from two Projections. Nature, pp. 133-135.

[150] Maas H.G. (1991): Digital Photogrammetry for Determination of Tracer Particle Coordinates Turbolent Flow Research. PE&RS, Vol.57/2, pp.1593-1597.

[151] Mark A.N. and Poder K. (1981): Ordering and Dissection of Geodetic Least Squares Equations. In: Proc. of the 6^{th} International Symposium on Geodetic Computations, DGK Reihe B Heft 258/VIII, pp. 100-112.

[152] Mark D. M. (1993): Human Spatial Cognition. In Medyckyj-Scott D. and Hearnshaw H. M. (Ed's) Human Factors in Geographical Information Systems, London, Belhaven Press, pp. 51-60.

[153] Meijering J.A. and Van Der Vorst H.A. (1977): An Iterative Solution Method for Linear System of which the Coefficient Matrix is a Symmetric M-matrix. In: Mathematics of Computation, Vol. 31, n. 138.

[154] Meissl P. (1982): Least Squares Adjustment a Modern Approach. Mitteilungen der geodätischen Institute der Technischen Universität Graz, Vol. 43, Graz (Austria).

[155] Meyers D. and Skinner Sh. (1992): Surface from Contours, ACM Trans. Graphics Vol. 11/3.

[156] Mirante A. and Weingarten N. (1982): The Radial Sweep Algorithm for Constructing Triangulated Irregular Networks. IEEE Computer Graphics & Applications, Vol. 2, pp. 11-21.

[157] Muller H. (1984): A Numerically Efficient Solution of the Second Order Design Problem. In: Bulletin Géodésique, n. 58.

[158] Muller H. (1985): Second Order Design of Combined Linear-Angular Networks. In: Bulletin Géodésique, n. 59.

[159] Peano G. (1890): Sur une courbe, qui remplit toute une aire plane. In: Math. Annalen, Vol.36/1, pp. 157-160.

[160] Pope J.A. (1970): An advantageous, Alternative Parameterization of Rotations for Analytical Photogrammetry. ESSA Technical Report. CGS 39. Coast and Geodatic Survey, US. Department of Commerce, Rockville, MA.

[161] Pope A. J. (1975): The Statistics of Residuals and Detection of Outliers. Presented at IUGG XVI General Assembly, Grenoble (France).

[162] Ressl C. (2000): An Introduction to the Relative Orientation Using the Trifocal Tensor. ISPRS, Amsterdam (Nederlands), Vol. 33/B3, pp.769-776.

[163] Rinner K. and Burkhardt R. (1972): Photogrammetrie. In Handbuch der Vemessungskunde. Vol. 3 a/3, Jordan, Eggert, Kneissel, Stuttgart: Metzlersche J.B, Verlagsbuchhandlung, p. 2286.

[164] Rizzi A. et al. (1988): Some Relations between Matrices and Structures of Multidimensional Data Analysis. In: A. Rizzi (Ed) Applied Mathematics Monographs – Comitato Nazionale per le Scienze Matematiche – Consiglio Nazionale delle Ricerche. Giardini, Pisa (Italy).

[165] Rosen R. (1968): Matrix Bbandwidth Minimization. In: Proc. ACM National Conference, Brandon System Press, Princeton (NJ), pp. 585-595.

[166] Sarjakoski T. (1981): Concept of a Completely Digital Stereoplotter. The Photogrammetric Journal of Finland, n. 2, pp. 95-100.

[167] Schmid H. (1954): An Analytical Treatment of the Orientation of a Photogrammetric Camera. Photogrammetric Engineering, Vol. 20, pp. 765-781.

[168] Schut G. H. (1960): On Exact Linear Equations for the Computation of the Rotational Elements of Absolute Orientation. Photogrammetria, Vol.15/1, pp. 34-37.

[169] Sachs L. (1984): Applied Statistics. A handbook of Techniques. Springer, New York.

[170] Schaffrin B. (1981): Some proposals concerning the diagonal second order design of geodetic networks. In: *Manuscripta Geodaetica*, n. 6.

[171] Schaffrin B. (1982): Some considerations on the optimal design of geodetic networks. In: Int. Symp. on Geodetic Networks and Computations, DGK Reihe B Heft 258/III, Munich (Germany).

[172] Schaffrin B. (1985): On Design Problems in Geodesy Using Models with Prior Information. In: Statistics & Decision, suppl. Issue n. 2.

[173] Schmitt G. (1977): Experiences with the Second Order Design of Geodetic Networks. In: Proc. Int. Symp. on Optimization of Design and Computation of Control Networks, Sopron.

[174] Schmitt G. (1978): Numerical Problems Concerning the Second Order Design of Geodetic Networks. In: Proc. 2nd Int. Symp. Related to the Redefinition of North American Geodetic Networks, Washington DC.

[175] Schmitt G. (1987): Optimal Design Problems. In: Geodetic Theory and Methodology, University of Calgary, Calgary.

[176] Schumaker L. (1987): Triangulation Methods. In: Chui C.K., Schumaker L., Utreas F.I. (Ed's) Topics in Multivariate Approximation, Academic Press, Boston, pp. 219-232.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

[177] Schwarz H.R. (1970): Die Metode der Cojugierten Gradienten in der Ausgleichsrechung. In: Zeitschrift für Vermessungswesen, year 95, n. 4.

[178] Semple J.K. and Kneebone G.T. (1952): Algebraic Projective Geometry. Clarendon Press, Oxford (England).

[179] Spath H. (1987): Using the L1 Norm within Clauster Analysis. In: Y. Dodge (Ed), Statistical Data Analysis Based on the L1-norm and Related Methods, Elsevier Science Pub., North Holland, pp. 427-433.

[180] Spetsakis M.E. and Aloimonos J. (1990): A Unified Theory of Structure from Motion. In Proc. of Image Understanding Workshop. Pittsburg (PA), pp. 271-283.

[181] Stefanovic P. (1973): Relative Orientation – a new approach. ITC Journal, pp. 417-448.

[182] Stefanovic P. (1978): Blunders and Least Squares. ITC Journal, n. 1.

[183] Thomas N. J. T.: A Note on Schema and Image Schemata.[on line]. Los Angeles: California State University. Available on: http://www.calstatela.edu/faculty/nthomas/schemata.html (consulted on june 2005)

[184] Thompson W. R. (1935): On a Criterion for the Rejection of Observations and the Distribution of the Ratio of Deviation to Sample Standard Deviation. Annals of Mathematical Statistics, n. 6.

[185] Thompson E.H. (1958): On Exact Linear Solution of the Problem of Absolute Orientation. Photogrammetria, Vol.13/4, pp.163-178.

[186] Thompson, E.H. (1959): A Rational Algebraic Formulation of the Problem of the Relative Orientation. Photogrammetric Record, Vol. 3/14, pp. 152-159.

[187] Tienstra J. M. (1969): Calculation of Orthogonal Matrices. ITC Journal. A 48. Delft Series, ITC, Delft (Holland).

[188] Torr P.H.S. and Murray D.W. (1997): The Development and Comparison of Robust Methods for Estimating the Fundamental Matrix. Int. Journal of Computer Vision, n 24/3, pp. 271-300.

[189] Trench W.F. (1964): An algorithm for the Inversion of Finite Toeplitz Matrices. In: Journal of Soc. Industr. Applied Mathematics, Vol. 12, n. 3.

[190] Trench W.F. (1965): An algorithm for the Inversion of Finite Hankel Matrices. In: Journal of Soc. Industr. Applied Mathematics, Vol. 13, n. 4.

[191] Trench W.F. (1974): Inversion of Toeplitz Band Matrices. In: Mathematics of Computation, Vol. 28, n.128.

[192] Van Kreveld M. (1997): Algorithms for Triangulated Terrains. Tech. Report UU-CS. N.32, Utrech (Holland).

[193] Welch B. L. (1947): The Generalization of Student's Problem when several different Population Variancies are Involved. Byometrika, Vol. 34, pp. 28-35.

[194] Wimmer H. (1982): Second Order Design of Geodetic Networks by an Interactive Approximation of a Given Criterion Matrix. In: Int. Symp. on Geodetic Networks and Computations, DGK Reihe B Heft 258/III, Munich (Germany).

INTERNAL REFERENCES

Part I

[195] Carrion D., Migliaccio F. (2005): Importanza degli satndard nella Valutazione della Qualità dei Dati in un Sistema Informativo Territoriale. Proc. of the 9th ASITA, Catania (Italy).

Part II

[196] Ammannati F. , Benciolini B. , Mussio L., F. Sansò (1983): An Experiment of Collocation Applied to Digital Height Model Analysis. In K. Torlegard (Ed) Int. Colloquium on Mathematical aspects of digital elevation models, Dept. of Photogrammetry, Royal Institute of Technology, Stockholm (Sweden).

[197] Ammannati F., Betti B., Mussio L. (1984): Statistical Analysis of Relevant Terrain Features through Digital Elevation Models. In Int. Archives of Photogrammetry and Remote Sensing, Vol. XXV, Part A3a/b, Rio de Janeiro (Brasil).

[198] Barbarella M. and Mussio L. (1985): A Strategy for a Robust Identification of the Outliers in the Geodetic Sciences. In: E.J. Dudewicz, D. Plachky, P.K. Sen (Ed's) Statistics and Decisions – Suppl. Issue n. 2. R. Oldenbourg-Verlag, Munich (Germany), pp. 397-405.

[199] Barzaghi R., Benciolini B., Betti B., Forlani G., Mussio L., Sansò F. (1990): A Numerical Experiment of Integrated Geodesy. Bulletin Geodesique, Vol. 64, n. 3.

[200] Barzaghi R., Crippa B., Forlani G., Mussio L. (1988): Digital Modeling by using the Integrated Geodesy Approach. In. Int. Archives of Photogrammetry and Remote Sensing, Vol. XXVII, Part B3, Kyoto (Japan).

[201] Bellone T., Crippa B., Mussio L. (1996): A Recommended Procedure for Image Quality Assessment. In L. Mussio, G. Forlani (Ed's) Int. Archives of Photogrammetry and Remote Sensing, Vol. XXX, Part 1.bis, Milan (Italy).

[202] Bellone T., Crippa B., Mussio L. (1996): Restoration and Validation of Image Data. In L. Mussio, G. & F. Forlani, Crosilla, (Ed's) Data Acquisition and Analysis for Multimedia GIS, Courses and Lectures, n. 365, Springer, Wien (Austria).

[203] Bellone T., Giacobbe L., Mussio L. (2000a): Classification by a Proximity Matrix. Int. Archives of Photogrammetry and Remote Sensing, vol. XXXIII, part B6. Amsterdam (Nederlands), pp. 29-36.

[204] Bellone T., Giacobbe L., Mussio L. (2000b): Processing of Correlated Information. Int. Archives of Photogrammetry and Remote Sensing, vol. XXXIII, part B6. Amsterdam (Nederlands), pp. 215-222.

[205] Benciolini B., Betti B., Mussio L., Sansò F. (1988): Experiments of Integrated Geodesy in Geodesy and Related Sciences. Bollettino di Geodesia e Scienze Affini, Vol. 47, n. 3.

[206] Benciolini B., Mussio L., Sansò F.(1982): An approach to Gross Errors Detection more conservative than Baarda Snooping. Proc. Of the Int. Symp. of ISPRS, Comm. III, Helsinki (Finland).

[207] Betti B., Mussio L., Sansò, F. (1983): A new Proposal of Sphere Reconstitution in Hipparcos Project. In P.L. Bernacca (Ed) The FAST thinkshop Processing of scientific data from the ESA astrometry satellite Hipparcos, CNR-PSN University of Padua, Padua (Italy).

[208] Betti B., Mussio L., Sansò F. (1985): Experiments with the Arcwise Sphere Reconstitution. In J. Kovalevsky (Ed) The 2nd FAST thinkshop Processing of scientific data from the ESA astrometry satellite Hipparcos, CERGA, Grasse (France).

[209] Colombo L., Fangi.G., Mussio L., Radicioni F. (1986): Further Development on Digital Models in a Control Problem for the ''Ancona '82'' Landslide. In E. Kilpelae, A. Savolainen, A. Laiho (Ed's) Int. Archives of Photogrammetry and Remote Sensing, Vol. XXVI, Part 3.1, Rovaniemi (Finland).

[210] Colombo L., Fangi G., Mussio L., Radicioni F. (1987): Kinematic Processing and Spatial Analysis of Leveling Control Data of the Ancona '82 landslide. In H. Pelzer and W.Niemeier (Ed's) Determination of Heights and Height Changes, Duemmler Verlag, Bonn (Germany).

[211] Crespi M., Crippa B., Mussio L. (1990): Integrated Approach to Kinematic Adjustment and Spatial Analysis of Leveling Control Data of the Ancona 82 Landslide. In P. Vyskocil, C. Reigber and P.A. Cross (Ed's) Global and Regional Geodynamics, Springer-Verlag, New York.

[212] Crippa, B. & M. Crosetto, & L. Mussio, 1998, The Use of Interferometric SAR for Surface Reconstruction. In Int. Archives of Photogrammetry and Remote Sensing, Vol. XXXII, Part 1, Bangalore (India).

[213] Crippa B., De Haan A., Mussio L. (1989): The Formal Structure of Geodetic and Photogrammetric Observations. In ISPRS IC-WG III/VI Tutorial on Mathematical Aspects of Data Analysis, Polytechnic of Milan, Milan (Italy).

[214] Crippa B., De Haan A., Mussio L. (1992): The Creation of a DEM from SPOT Data. In European International Space Year-Space in the service of the changing Earth-Environment Observation and Climate Modelling through Int. Space Projects, ESA ISY-1, Paris (France).

[215] Crippa B., Forlani G., Mussio L. (1993): Digital elevation model of the Torre del Sale (Piombino) Thermal Power Plant area. In Harts, J. & H.F.L. Ottengs, & H.I.J. Scholten (Ed's) EGIS 93, Vol. I, EGIS Foundation, Utrecht-Amsterdam (Nederlands).

[216] Crippa B., Maas H.G., Mussio L. (1992): Spatial Analysis of Turbulent Flow Fields by Deterministic and Stochastic Approaches. In L.W. Fritz, J.R. Lucas (Ed's) Int. Archives of Photogrammetry and Remote Sensing, Vol. XXIX, Part B5, American Society for Photogrammetry and Remote Sensing, Washington D.C. 1992.

[217] Crippa B., Malinverni E.S., Mussio L. (1995): Dynamic Modelling of Scene Deformation for Crustal Movement Monitoring. In A. Gruen, E. Baltsavias (Ed's) Int. Archives of Photogrammetry and Remote Sensing, Vol. XXX, Part 5W1, Zürich (Switzerland).

[218] Crippa B. and Mussio L. (1996): Modelli Analitici della Fotogrammetria, ETH Zürich (Switzerland).

[219] Crippa B. and Mussio L. (1987): The new ITM System of the programs MODEL for digital modelling. In O. Jacoby and P. Frederiksen (Ed's) Int. Colloquium on Progress in Terrain Modelling, TU of Denmark, Copenhagen (Denmark).

[220] Crippa B., Mussio L., Sharif H. (1994): The Torre del Sale (Piombino) DEM and its contribution to an Environmental Monitoring oriented GIS. In G. Guariso and B. Page (Ed's) Computer support for Environmental Impact Assessment, North Holland, Amsterdam (Nederlands).

[221] Crippa B., Mussio L., Zacco G. (1994): Data Understanding by Form Descriptors on the Way of Compression. In L. Mussio, G. Forlani (Ed's) Int. Archives of Photogrammetry and Remote Sensing, Vol. XXX, Part 1.1, Milan (Italy).

[222] Cunietti M., Fangi G., Mussio L., Radicioni F. (1984): Block Adjustment and Digital Model of Photogrammetric Data in a Control Problem for the ''Ancona '82'' Landslide. In Int. Archives of Photogrammetry and Remote Sensing, Vol XXV, Part A3a/b, Rio de Janeiro (Brasil).

[223] De Haan A., Maas H.G., Malik N., Mussio L. (1994): Statistical Analysis of Spatially Referenced Data. Inst. fuer Geodaesie und Photogrammetrie ETH- Zürich, Bericht 238.

[224] De Haan A. and MussioL. (1989): Kinematic Levelling Adjustments with Polynomials and Polynomial Splines. Geodesia and Scienze Affini, Vol. 48, n. 3.

[225] Forlani G. and Mussio L. (1986): Test on joint Adjustment of Geodetic and Photogrammetric Data. In E. Kilpelae, A. Savolainen, A. Laiho (Ed's) Int. Archives of Photogrammetry and Remote Sensing, Vol. XXVI, Part 3.1, Rovaniemi (Finland).

[226] Forlani G. and Mussio L. (1986): The kinematic Adjustment of Leveling Network. In M. Unguendoli (Ed) Modern trends in deformations measurements, CUSL, Bologna (Italy).

[227] Mussio L., Nocera R., Poli D. (1999): Spatial-Temporal Modeling. Int. Archives of Photogrammetry and Remote Sensing, Vol. XXXI, part 4W12. Beijing (PRC), pp.155-162.

[228] Mussio L., Nocera R., Poli D. (1998): Numerical Solution Strategies in Data Processing and Spatial Data Analysis. Int. Archives of Photogrammetry and Remote Sensing, vol. XXXII, part 3/1. Columbus (OH), pp.138-145.

[229] Mussio L. and Pozzoli A. (2003): Quickly Solutions Particularly in Close Range Photogrammetry. Int. Archives of Photogrammetry and Remote Sensing, vol. XXXIV, part 5W12. Ancona (Italy), pp.273-278.

[230] Mussio L. and Pozzoli A. (2003): Non-linear Problems of Analytical Photogrammetry. Int. Archives of Photogrammetry and Remote Sensing, vol. XXXIV, part 6W11, Zagreb (Croatia).

[231] Pozzoli A. and Mussio L. (2004a): Modelling Techniques for Temporal GIS. In E. Fendel, M. Rumor (Ed's), Proc. Of UDMS'04-24th Urban Data Management Symposium. Chioggia (Italy), 7.II.2.

[232] Pozzoli A., Mussio L., Scaioni M. (2004b): A Solution for the General Case of Three-image Orientation. Int. Archives of Photogrammetry and Remote Sensing, vol. XXXV, part B3. Istanbul (Turkey), pp. 992-997.

[233] Pozzoli A., Mussio L., Scaioni M. (2004c): A Project for the Survey of a Hydraulic Stream Confluence Model Based on a General Procedure for Three-image Orientation. In: E. Baltsavias (Ed), Commemorative volume for the 60th birthday of Prof. Dr. Armin Gruen. Zurich (Switzerland), pp. 201-208.

[234] Pozzoli A. (2005): Rilievo di una Confluenza di Torrenti in zona Alpina grazie all'Orientamento Automatico di tre Immagini. Proc. of the 9th ASITA, Catania (Italy).

[235] Sansò F. (1973): An Exact Solution of the Rototranslation Problem. Photogrammetria, Vol. 29, pp.203-216.

Part III

[236] Ballio F., Franzetti S., Orsi E. (2004): Studio su Modello Fisico della Confluenza dei Torrenti Val Lunga e Val Corta in Comune di Tartano. Internal Report of 'Fantoli' Hydraulic Laboratory (TU of Milan), Milan (Italy), pp. 1-47.

[237] Bellone T., Mussio L., Nardinocchi C. (1997): On Data Processing in Photogrammetry and Cartography. In Mussio, L. & B. Crippa, & A. Vettore (Ed's) Int. Archives of Photogrammetry and Remote Sensing, Vol. XXXII, Part 6W1, Milan (Italy).

[238] Carminati I. and Mussio L. (2005): Simmetrie e Topologie. Proc. of the 9th ASITA, Catania (Italy).

[239] Mussio L., Nocera R., Poli D. (1999b): Discrete Mathematics for Spatial Data Classification and Understanding. In S.F. El Hakim, A. Gruen (Ed's), Videometrics VI-SPIE, vol 3641. SPIE, San Jose (CA), pp.217-226.

[240] Pozzoli A. and Mussio L. (2004): Symmetries and Topology for the Definition of Conceptual Models, 2nd Italy-Canada Workshop on 3D Digital Imageing and Modeling – Applications of Heritage, Industry, Medicine and Land, 2005, Padua (Italy).

[241] Pozzoli A. and Mussio L. (2006): New Tools for Spatio-Temporal Database. In E. Fendel, M. Rumor (Ed's), Proc. Of UDMS'06-25th Urban Data Management Symposium, Aalborg (Denmark).

ABSTRACT

Data and Quality Metadata for Continuous Fields: Terrains and Photogrammetry.

This thesis deals with data processing in Geomatics. It ranges from data acquisition in Photogrammetry to data representation as well as in Cartography. Thanks to a co-supervision agreement with INSA de Lyon (LIRIS) and the Politecnico di Milano (DIIAR), it has been enriched with new knowledge about links between Geomatics and Computer Science.

The objective of this research was to use statistical techniques of data processing for the creation of digital surface models starting from photogrammetric images.

The main function of photogrammetry is the transformation of data coming from the image space to the object space. We can make this transformation in a direct way, with collinearity equations, or in two steps, with the formation of a model and, only in a second time, reconstructing the original object. We choose a two-step procedure which permits the definition of the problem of absolute orientation, separately from the relative orientation one. An easy solution for three image orientation is proposed. Firstly, each model coming from two images of the triplet is analyzed and a relative orientation between them computed. Usually the solution for this task can be obtained after a linearization of a non-linear functional model, in which the preliminary values of the unknown parameters are strictly required. In this new solution, we use an exhaustive research of preliminary values (of parameters) for relative orientation. This non-conventional approach gives good results for the orientation of two images, taking into account also a priori information among four basic solutions. The automatic procedure of orientation implies to skip the manual assessment by using three images, which allows the solving for the ambiguous solutions in an automatic way. Once each model has been relatively registered, the absolute orientation is computed by using a linear parameterization of this problem.

The orientation procedure above described has some relevant advantages for environmental and monitoring applications, and makes it a very powerful tool in addition to more traditional methodologies. This method runs automatically without requiring the interactive control of the user, who has only to set up some initial parameters and it doesn't need any preliminary values of the unknown parameters. These features allow that this method could be easily used also by users not skilled in photogrammetry. Among many different applications, an interesting project for the survey of a hydraulic 3D model of a stream confluence in the mountain area (Laboratory of the Hydraulics and Water Infrastructure Sections of the DIIAR at the TU of Milan-Italy) has been performed. Our purpose was to perform a static and a dynamic survey, for the realization of temporal digital surface models. The static survey has been carried out by traditional close range photogrammetry, while in a second stage, the dynamic survey of the water flooding surface has been carried out by using three digital video-cameras, focusing on the confluence area.

The dynamic survey was done by means of a system of three synchronized webcams, with a triangular configuration. We performed the survey in different conditions of flows and improve the contrast on the water surface by using sawdust and pieces of paper. Sensor orientation has been performed by using the generalized procedure proposed along the thesis. The successive step has been the physical plotting of DSM for every sequence, and the spatio-temporal interpretation of the water surface dynamics.

From a computing point of view, we propose a description of the photogrammetric data based on the XML format for geographic data (Geographic Markup Language). The aim is to optimize the archiving and management of geo-data. Starting from the creation of a

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

conceptual model for the photogrammetric data by using the UML/INTERLIS Editor, a GML Schema was created for the whole model. With this model it was possible to describe the whole photogrammetric process from image acquisition to the representation and mosaicking of the geo-data. Then a XML/GML file has been developed from the Schema with a common XML editor. XML permits the creation of an interoperable mean for geo-data coming from photogrammetric survey. Thanks to the knowledge of all the concerned metadata it becomes really easy to get information about the data and use them without a further contact with the data producers.

As a conclusion, an original software product which allows to model terrains starting from three-image photogrammetry has been developed and tested.

Keywords: photogrammetry, automatic orientation, spatio-temporal modeling, GML, geo-data interoperability, environmental monitoring.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

RESUME

Données et Métadonnées de Qualité pour les Champs Continus : Modèles de Terrain et Photogrammétrie.

Le sujet principal de ma thèse est le traitement des données en géomatique allant de l'acquisition des données photogrammétriques à la représentation cartographique. Grâce à la convention de cotutelle signée entre l'INSA de Lyon (LIRIS) et le Politecnico di Milano, j'ai eu la possibilité d'enrichir ce sujet avec des connaissances nouvelles qui lient la Géomatique à l'Informatique.

L'objectif de ma recherche est ainsi l'utilisation des techniques statistiques pour le traitement des données géomatiques afin de créer des modèles numériques des terrains en partant des données photogrammetriques.

La fonction principale de la Photogrammétrie est la transformation des données en partant de l'espace-image à l'espace-objet. On peut réaliser cette transformation avec les équations de colinéarité d'une façon directe, ou avec une procédure en deux étapes qui sépare la formation du modèle de la reconstruction de l'objet original. Dans ce travail, nous avons choisi la procédure en deux étapes pour définir différemment le problème de l'orientation absolue de celui de l'orientation relative. Nous avons proposé une solution pratique pour l'orientation automatique à partir de trois images. En premier lieu, chaque couple d'images du triplet doit être orienté relativement. Normalement la solution pour cette procédure peut être obtenue après une linéarisation du modèle fonctionnel non-linéaire, où les valeurs approximées des paramètres inconnus sont indispensables. Avec cette nouvelle solution, est utilisée une recherche exhaustive des valeurs (des paramètres) approximées d'orientation relative. Cette méthode non conventionnelle donne des bons résultats pour l'orientation de couples d'images, après avoir considéré certaines informations de base pour discriminer entre les quatre solutions obtenues après ce premier pas. La procédure automatique d'orientation implique l'absence d'intervention humaine grâce à l'introduction de la troisième image, qui permet de résoudre l'ambiguïté de manière automatique. Une fois chaque modèle relatif enregistré, on peut réaliser l'orientation absolue en utilisant une paramétrisation linéaire du problème.

Cette méthodologie d'orientation présente de nombreux avantages pour les applications environnementales et de surveillance, et elle est un puissant instrument que l'on peut utiliser à côté de méthodologies plus traditionnelles. Cette méthodologie fonctionne automatiquement sans l'intervention interactive de l'utilisateur, qui doit seulement l'initialiser avec quelques paramètres, mais sans aucune valeur approchée des inconnues. Cette caractéristique fait que la procédure peut être utilisée également par des personnes non expertes en photogrammétrie. Parmi diverses applications possibles, on a choisi de construire le relief d'un modèle hydraulique 3D qui représente la confluence de deux torrents dans une région montagneuse.

Notre but a été de produire un relief statique et un relief dynamique pour la réalisation des modèles numériques temporels de la surface de l'eau. Le relief statique a été exécuté avec une méthodologie classique de photogrammétrie terrestre, alors que dans une seconde étape nous avons réalisé le relief dynamique de la surface de l'eau (en mouvement) avec un système de trois video-caméras numériques encadrent la zone de confluence.

Le système a été formé de trois Webcams synchronisées disposées triangulairement ; il a permis de créer le relief sous différentes conditions de débit d'eau et de contraste de la surface d'eau (illumination transversale, morceaux de papier et de sciure). Nous avons modifié l'orientation des capteurs appliquant la procédure généralisée expliquée dans ma

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

thèse, avons tracé le modèle numérique pour chaque séquence, et ensuite avons interprété la surface de l'eau avec une interpolation spatio-temporelle.

D'un point de vue informatique, nous avons proposé une description de données photogrammétriques basée sur le format XML pour les données géographiques (extension de GML, Geographic Markup Language). L'objectif est d'optimiser l'archivage et la gestion des données géomatiques. Le premier pas a été celui de faire un modèle conceptuel avec l'éditeur INTERLIS d'UML ; puis nous avons pu générer un Schéma GML du modèle tout entier. Avec ce modèle, il a été possible de décrire tout le processus photogrammétrique : acquisition d'images, représentation, et mosaïquage de données photogrammétriques. Ensuite nous avons développé un fichier XML/GML à partir du Schéma à l'aide d'un éditeur XML. XML nous a ainsi permis de construire un système interopérable pour les données qui proviennent d'un relief photogrammétrique. Grâce à la connaissance des métadonnées, il est très facile d'avoir des informations concernant les données et de les utiliser sans aucun contact ultérieur avec le producteur des données.

Enfin, un logiciel original a été produit, qui permet de modéliser les terrains en utilisant la photogrammétrie à trois images.

Mots-clés : photogrammétrie, orientation automatique, modélisation spatio-temporelle, GML, données géographiques, interopérabilité, surveillance environnementale.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

RIASSUNTO

Dati e Metadati di Qualità per i Campi Continui: DEM e Fotogrammetria.

Questa tesi si occupa del trattamento dei dati in Geomatica. Spazia dalla Fotogrammetria alla rappresentazione dei dati propria della Cartografia. Grazie ad un accordo di tesi in cotutela con l'INSA di Lione (LIRIS) e il Politecnico di Milano (DIIAR) è stata arricchita di nuove conoscenze che legano la Geomatica all'Informatica.

L'obiettivo di questa ricerca è quello di usare tecniche statistiche di processamento dei dati per la creazione di superfici digitali del terreno partendo da immagini fotogrammetriche.

Lo scopo principale della fotogrammetria è la trasformazione di dati dallo spazio immagine allo spazio oggetto. E' possibile eseguire questa trasformazione in maniera diretta con le equazioni di collinearità, o in due passi con la creazione del modello, e solo in un secondo momento, ricostruendo l'oggetto. In questo lavoro si è scelta la procedura in due passi che permette la risoluzione dell'orientamento assoluto separatamente da quella dell'orientamento relativo. E' stata proposta/utilizzata una soluzione attraverso/per l'orientamento di tre immagini sincrone. In primo luogo viene analizzato ciascun modello proveniente da una coppia della tripletta di immagini, e si effettua l'orientamento relativo dello stesso. Normalmente la soluzione dell'orientamento relativo si può ottenere solo dopo una linearizzazione del modello funzionale non lineare adottato, dove valori approssimati delle incognite sono strettamente necessari per la sua risoluzione. In questo lavoro si è adottato un nuovo approccio, che utilizza una ricerca esaustiva dei valori approssimati delle incognite (dei parametri) nella fase di orientamento relativo. Questo approccio non convenzionale da dei buoni risultati per l'orientamento relativo di due immagini, tenendo in considerazione alcune informazioni a priori per poter discriminare tra le quattro soluzioni di base che si ottengono. E' possibile automatizzare la procedura di orientamento, evitando così l'intervento umano per la scelta della soluzione cercata, attraverso l'uso di tre immagini. Una volta effettuato l'orientamento relativo, è possibile calcolare l'orientamento assoluto, usando una parametrizzazione lineare del problema.

La procedura di orientamento appena descritta possiede alcuni notevoli vantaggi per applicazioni di sicurezza e monitoraggio ambientale, diventando uno strumento potente da affiancare alle metodologie classiche. Questo metodo procede automaticamente senza l'intervento iterativo dell'utilizzatore, una volta inizializzato il processo, e non necessita di valori approssimati delle incognite a priori. Questo permette il suo utilizzo anche da parte di utilizzatori non esperti in fotogrammetria. Tra le diverse possibili applicazioni, si è scelto di eseguire il rilievo fotogrammetrico di un modello idraulico 3D della confluenza di tre torrenti ubicati in zona alpina (Laboratorio di Idraulica e di Infrastrutture Idrauliche del DIIAR del Politecnico di Milano). Il nostro obiettivo è quello di effettuare un rilievo statico e uno dinamico per la creazione di modelli digitali temporali della superficie dell'acqua. Il rilievo statico è stato effettuato attraverso metodologie classiche di fotogrammetria terrestre, mentre in un secondo momento è stato eseguito il rilievo dinamico dell'acqua in movimento attraverso l'uso di un sistema formato da tre webcams puntate sull'area di confluenza.

Il rilievo dinamico è stato eseguito con un sistema di tre webcams sincronizzate, disposte in una configurazione triangolare. Il rilievo è stato eseguito in diverse condizioni di portata, e per migliorare il contrasto della superficie dell'acqua si è usata segatura e pezzetti di carta. Orientamento dei sensori è stata fatta con la procedura descritta lungo la tesi. Il passo successivo è stato quello del plottaggio delle singole scene in modelli digitali della superficie dell'acqua, e successivamente di una loro interpretazione dinamica nel tempo.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr

Da un punto di vista computazionale si è proposta una descrizione dei dati fotogrammetrici attraverso il formato XML per i dati geografici (Geographic Markup Language). L'obiettivo è quello di ottimizzare l'archiviazione e la manipolazione dei dati geografici. Partendo dalla creazione di un modello concettuale dei dati fotogrammetrici utilizzando l'Editor di UML, è stato possibile creare lo Schema GML per l'intero modello. Grazie a questo modello è possibile descrivere l'intero processo fotogrammetrico, dall'acquisizione di immagini alla rappresentazione dei dati geografici. Successivamente con un comune editor di XML si è sviluppato un file XML/GML relativo allo Schema GML. XML permette la creazione di un mezzo interoperabile per i dati geografici provenienti da un rilievo fotogrammetrico. Grazie alla conoscenza dei relativi metadati diventa davvero semplice ottenere informazioni circa i dati e usarli senza un ulteriore contatto con il produttore di dati.

Per concludere, in questo lavoro di tesi è stato sviluppato un software originale che permette di modellizzare i terreni partendo da un rilievo fotogrammetrico a tre immagini, e inoltre archiviare e scambiare i dati relativi a rilievo stesso.

Parole chiave: Fotogrammetria, orientamento automatico, modellazione spazio-temporale, GML, interoperabilità dei dati geografici, monitoraggio ambientale.

alice.pozzoli@polimi.it alice.pozzoli@insa-lyon.fr