3D SURFACE MODELING FROM PLANAR SECTIONS

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Abstract

In this paper we propose a method to reconstruct a smooth surface from a set of planar contours. In order to fit better the initial data, we search for a good alignment of the baseline to avoid any twist on the reconstructed object. We perform the skinning of intermediate contour B-spline curves which are made compatible by bringing them to a common averaging knot vector. To improve the final result we have proposed a simple way to close the object on top and bottom.

1 Introduction

Modern conformal radiotherapy allows the clinician to precisely define the geometrical arrangement under which a patient is treated. The beam can be shaped using devices such as a multi-leaf collimator and radiation delivered from a number of different directions. The intention is that over a number of radiation fractions the patient's tumor will receive a lethal dose of radiation while the surrounding healthy tissue will suffer a minimum of collateral damage.

One major problem with this approach is that patients are not like engineering components. They cannot be precisely aligned by mechanical means. The major objective of the INFOCUS project - sponsored by the BIOMED initiative of the European Commission - is to investigate the development of new techniques and sensors which allow the initial geometrical set-up of patients and the subsequent in-treatment monitoring of patient position.

This paper reports the work so-far in the calculation of 3D surface model of the patient's body shape as well as the computation of organ's volume model. Both models at this phase of the project are considered static and rigid. Nevertheless, it is actually possible to modify locally the obtained shapes and to simulate some basic dynamic behaviours.

The calculation of both models are based on B-Spline techniques. For the external shape, a B-Spline surface model is fitted to a set of data points obtained by a digitising device using fringe analysis methods. The calculation of the organs' volume model is inspired from B-Spline skinning techniques: fitting a surface ("skin") through an ordered set of space curves, called as the section curves. These section curves are obtained by digitising the organs' contour on different CT-Scan images. For the closure of the surface model, periodic and uniform B-Spline basis functions are chosen.

2 Description of the optical system

An other area of the INFOCUS project is leaded by the "Coherent and Electro Optics Research Group" in Liverpool John Moores University and deals with the patient position monitoring.

They have investigated the possibility of using fringe analysis for the high speed, high resolution, measurement and inspection of three dimensional surfaces [1]. Two fringe analysis methods have been evaluated in this context; Fourier transform profilometry (FTP) and phase stepping profilometry (PSP).

One of the major problems in this application is the damage induced in many optical systems by the high levels of radiation which are encountered in the vicinity of the treatment machine. This radiation means that conventional optical glass discolours (turning a dark shade of brown) within a few days or weeks exposure. For this reason it is necessary to design interference fringe creation and delivery systems which have no constituent lenses or mirrors. The system which has been developed for this application is based on a laser diode pigtailed to a pure fused silica fibre which is highly resistant to radiation damage

3 Surface reconstruction

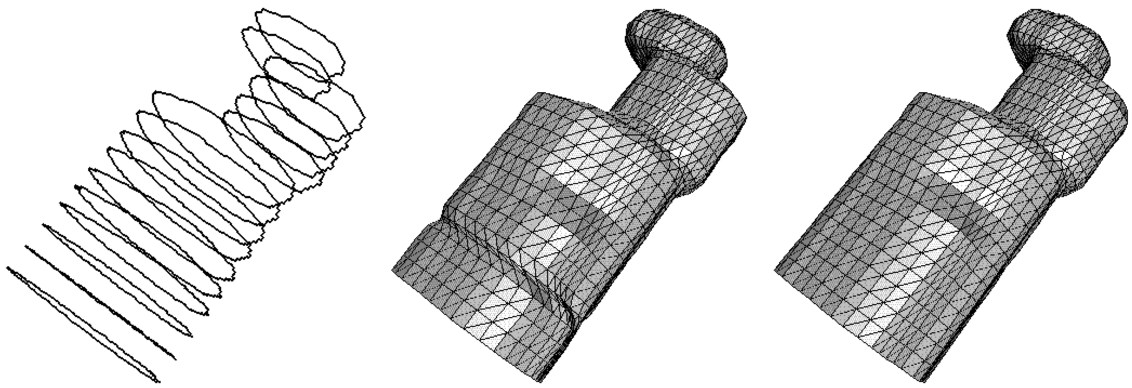
3.1 Data preprocessing

The reconstruction of the patient's body shape needs its digitisation. The Liverpool's digitising system produces too many points, therefore we have to undertake a strategy of data reduction [2]. This leads to the conservation of some pertinent data points organized into planar sections.

On the other hand, the reconstruction of the organs' form necessitates the use of planar CT scan sections (points organized into planar sections). In (Figure 2(a)), an example of these contours, representing a rectum, a prostate and a bladder is given. For the reconstruction we have to fit a surface to above sections. For this we use the "B-Spline skinning techniques" [4] and we proceed in two steps: the construction of a set of intermediate curves and the surface skinning of all the curves.

The data provided by the optical system cannot be used directly. As an object may have several branches, when digitised, each section may contain several contours. To be able to reconstruct the surface model of each branch independently, we find first the correspondence between the contours on different adjacent sections. Once the branches have been identified, their surface models are calculated and finally they are "glued" together using joining patches.

An other important step of the preprocessing is the contours alignment. To prevent the surface to be twisted, the starting points of the contours should be aligned. For this, we have developed an algorithm that computes a good baseline among all the possible baselines, which has intuitively a short length. The result of the choice of an aligned and misaligned baseline is shown on (Figure 1).



(a) Initial data

(b) Misaligned baseline: twisted contours

(c) Aligned baseline: correct contours

Figure 1: Consequence of the choice of a baseline

3.2 Cross-section approximation

We assume here that the data have been properly preprocessed. This means that we are treating just one branch defined by uniformly spaced data points (in the other case, an uniform re-sampling can easily be performed on the contours). All the contours are oriented in the same order, for example clock-wisely.

First, we approximate each contour with an open parametric B-spline curve with degree k and $m+1$ control points P_i , with $i = 0, \ldots, m$. We use the least squares fitting technique which has been fully studied in [3].

For internal organs' shape, as each contour is a closed curve, we use closed periodic B-spline curves defined by:

$$P(u) = \sum_{i=0}^{m} P_{i\, mod(m+1)} N^k_{i\, mod(m+1)}(u) \quad \text{with } u \in \mathbb{R}$$

where the $N^k_{i\, mod(m+1)}$ are the spline basis.

To ensure periodicity, we transform the open curve into a closed B-spline curve. For this, we add $(k-1)$ control points $P_{m+i} = P_i$, for $i = 1, \ldots, k-1$, and the new knot sequence is:

$$-\frac{k-1}{m},\ \ldots,\ -\frac{1}{m},\ 0,\ \ldots\ldots,\ 1,\ \frac{m+1}{m},\ \ldots,\ \frac{m+k-1}{m}$$

The periodicity ensure a C^{k-1} continuity at low cost for a spline's degree k. To obtain the same result with a non-periodic B-spline it is necessary to impose strong derivatives constraints on control points.

3.3 Surface skinning

At last, we approximate the control points in the v direction to create a biparametric B-spline surface of degree $k \times l$, closed in the u direction.

$$P(u,v) = \sum_{j=0}^{n} \left[\sum_{i=0}^{m} P^{j}_{i\, mod(m+1)} N^{k}_{i\, mod(m+1)}(u) \right] N^{l}_{j}(v) \text{ with } u \text{ and } v \in \mathbb{R}$$

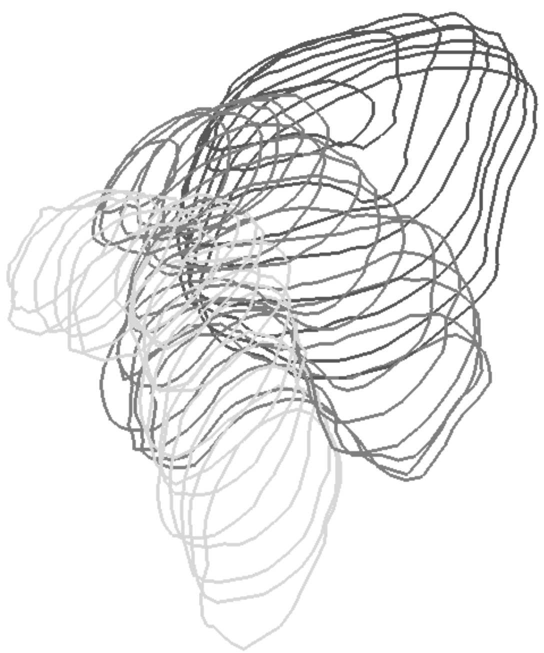
With this method, the object remains open on top and bottom (in the v direction).

To provide more realistic modeling, we have developed two methods to close the object. In the first one, we simply put a planar cap on the extremities of the object,leading to the introduction of discontinuities on both ends. In the second method, we extend smoothly the surface to converge it to a single point.

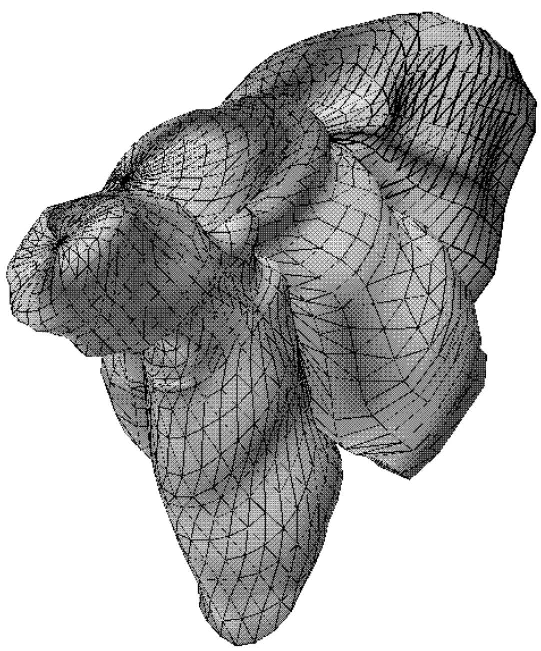
For this, we have introduced arbitrarily, on top and bottom, two sections, reduced to one point, and we have performed the skinning of all the contours.

4 Results

The initial data are planar slices representing internal organs (Figure 2(a)). We have reconstructed this object with bicubic periodic B-spline surfaces with 20x15 control points (Figure 2(b)). This has permitted us to reduce dramatically the amount of the initial data.



(a) Initial data



(b) Periodic B-Spline surface model

Figure 2: Reconstruction of internal organs: rectum, prostate and bladder

We have also reconstructed lungs from particularly perturbed contours containing approximatively 5000 points (Figure 3). The lungs have been modeled with periodic biquadratic spline surfaces with 30x25 control points. The results are shown on (Figure 4)

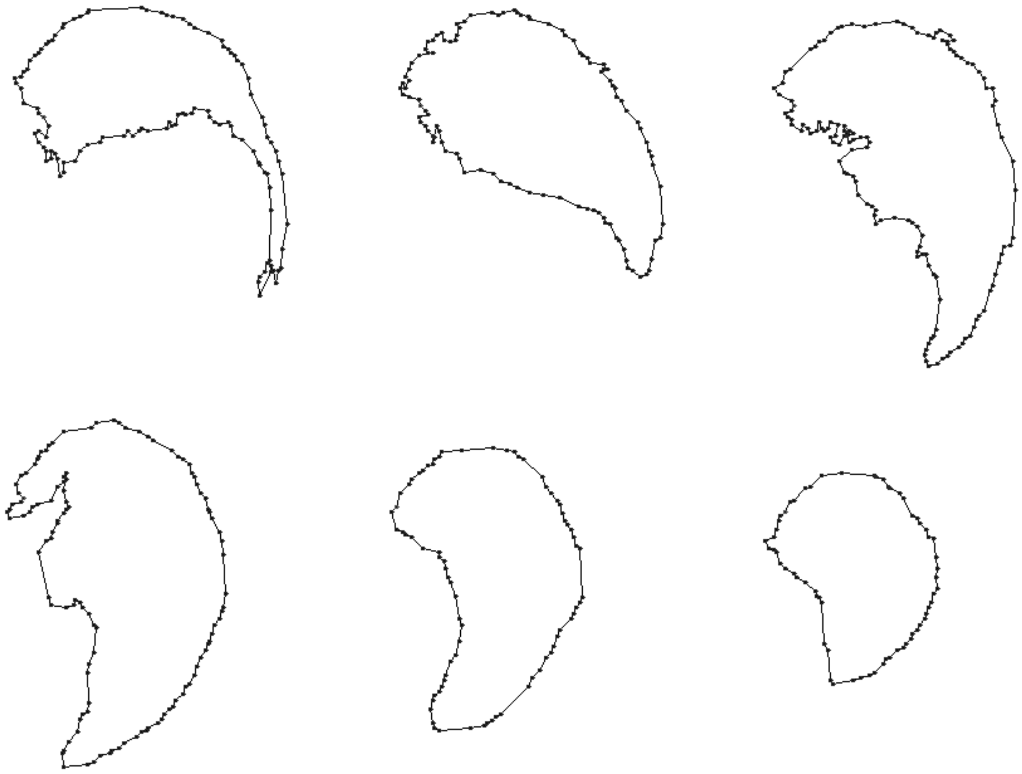


Figure 3: Some initial contours of the left lung

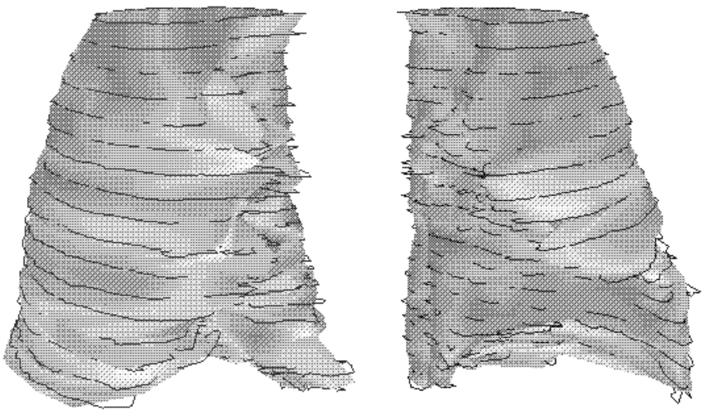


Figure 4: Reconstructed lungs

5 Conclusion

In our work, we have used a data acquisition system using fringe analysis for the high speed, high resolution, measurement of patient body exterior.

The proposed reconstruction method of open or closed anatomical objects is very simple. It permits to represent smooth and regular shapes. The degree is independent of the number of data points. It is continuous and the model could be refined by adding some control points.

However, the patient moves during the treatment and the simulation of the organ's biomechanical behaviour is difficult to handle with a biparametric model; indeed the calculation of the deformation, due to external forces on such models is not trivial.

So, for more realism in our calculations, we are introducing the necessary tools to handle the dynamic and deformable behaviour of cancerous tissues and organs based on particle system techniques. The particle system seems adequate to be integrated in a much more complete model of the human body, which could help the physicians during the treatment.

We are also introducing necessary tools for the simulation of the dynamic and deformable behaviour of the organs.

References

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