Computer Aided Geometric Design,
Lungs surface modelling

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3D MODEL OF THE LUNGS

The paper presents the 3D model of lungs, which will be use in a Computer Aided Diagnosis workstation of volumetric measurement of pneumothorax. Presented 3D model is useful in the lungs segmentation process. It allows the prior knowledge of the shape to be considered in segmentation algorithm. If the segmentation process is based on active contours method the prior knowledge may be use in the different form: initial conditions, data constraints or constraints on the model shape parameters. The paper describes current status of the project: methodology, selected curves and surfaces.

1. INTRODUCTION

The presented study is a part of a project on Computer Aided Diagnosis Workstation of volumetric measurement of pneumothorax [1]. The first stage of methodology is the lungs segmentation. If the segmentation method is based on active contour, the result depends on initial points of the contour. In order to improve the segmentation quality the prior knowledge of the shape can be used in the form of initial conditions, data constraints, and constraints on the model shape parameters, or into model fitting procedure [2]. A 3D model of the lungs allows the prior knowledge of the shape to be taken into account in lungs segmentation process.

2. CURVES AND SURFACES

There are few important issue in Computer Aided Geometric Design in order to obtain the surface of the preferable object. We must decide and select:

- type of the curves
- type of the surface
- knots sequence
- algorithm of surface fitting

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2.1 FORM OF THE CURVES

The most common method of representing curves and surfaces in geometric modelling, which is also used in this study is a parametric form. In this form, each of the coordinates of the points on the curve is represented separately as an explicit function of an independent parameter:

$$\mathbf{C}(u) = (x(u), y(u)) \qquad a \le u \le b \tag{1}$$

There are several advantages of using parametric curves:

- the parametric method can easily be extended to represent arbitrary curve in three–dimensional space
- the parametric curves feature a natural direction of traversal – can be generated an ordered sequences of points along a parametric curve
- the parametric form is more natural for designing and representing shape in a computer. The coefficients of many parametric form feature considerable geometric significance.
- the parametric form can represent a surface by introduction a second parameter[3][4]

2.2 TYPES OF THE CURVES

The are a several types of curves used in computer graphics. Curves consisting of just one polynomial segment are often inadequate. They require a high degree of order to satisfy a large number of constrains. For example n–order is needed to pass a polynomial Bezier curve through n data points. Also they are not well-suited to interactive shape design. As a solution we can use curves which are piece polynomial. This curve consists of nth order polynomial segments:

$$\mathbf{C}_i(u) = (x(u), y(u)) \qquad 1 \le i \le m \tag{2}$$

The curve **C**(u) is defined in u € [0,1]. The parameter values: $u_0=0 < u_1 < u_2 < u_3=1$ are called breakpoints. The segments are constructed so that they join with some level of continuity. The type of continuity does not need be the same at every breakpoint. Any of the standard polynomial forms can be used to represent $\mathbf{C}_i(u)$. Order of the curve a high degree is required to accurately fit some complex shape, but high order curves are inefficient to process and are numerically unstable. In practice most common is fourth order – the curves are called cubic curves. As regard of form of the curve B-spline function is used:

$$\mathbf{C}(u) = \sum_{i=0}^{n} N_i(u) P_i \tag{3}$$

where: Ni – are basis B-spline functions and Pi are the control points. In every segment of piecewise polynomial curve only of order n basis spline function are not vanishing – this is called local support. The continuity is determined by the basis functions, hence the control point can be modified without alerting the curve's continuity [3].

2.3 TYPES OF THE SURFACES

In the current study the tensor product surface is used. A B-spline surfaces is obtained by taking a bidirectional net of control points, two knots vectors, and the products of univariate B-spline functions [5]:

$$\mathbf{S}(u,v) = \sum_{i=0}^{m}\sum_{j=0}^{n} N_{i,p}(u)N_{j,q}(v)P_{i,j} \quad (4)$$

The cubic B-spline function $N_{i,p} = N_{i,4}$ and $N_{j,q} = N_{j,4}$ is used in each u and v direction. Fig. 1 shows an example of B-spline surface: cubic in u direction and quadratic in v direction

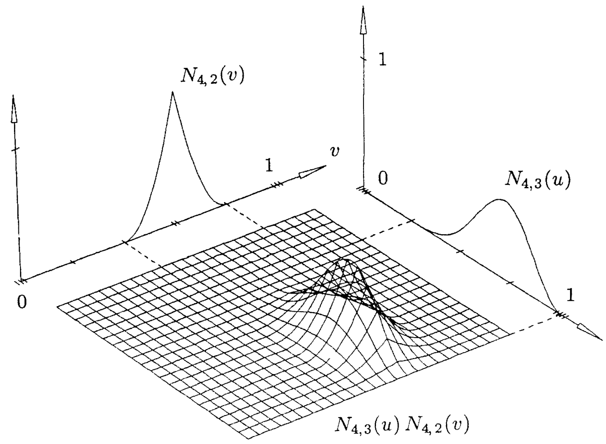

Fig. 1 Example of B-spline surface – cubic × quadratic basis functions [3]

2.4 SURFACE FITTING ALGORITHM

There are two types of fitting surface: approximation and interpolation. In interpolation a surface which satisfies the given data precisely is constructed – the surfaces passes through the given points. In approximation, surfaces do not necessarily satisfy the given data precisely. In our research interpolation fitting and global interpolation algorithm are employed. Similar to the curve case, we have data points and degrees *p* and *q* as input. To define an interpolating a B-spline surface, we need two knot vectors *U* and *V*, one for each direction, and a set of control points.

Suppose the B-spline surface is given :

$$\mathbf{S}(u,v) = \sum_{i=0}^{m}\sum_{j=0}^{n} N_{i,p}(u)N_{j,q}(v)P_{i,j} \quad (4)$$

Since it contains all data points and since parameters s_c and t_d correspond to a data point $\mathbf{D}_{cd}$, plugging u=s_c and v=t_d into the surface equation yields:

$$\mathbf{D}_{cd} = \mathbf{S}(s_c, t_d) = \sum_{i=0}^{m}\sum_{j=0}^{n} N_{i,p}(s_c) N_{j,q}(t_d) P_{i,j} \tag{5}$$

Since it contains all data points and since parameters s_c and t_d correspond to data point $\mathbf{D}_{cd}$, plugging u=s_c and v=t_d into the surface equation yields:

$$\mathbf{D}_{cd} = \mathbf{S}(s_c, t_d) = \sum_{i=0}^{m}\sum_{j=0}^{n} N_{i,p}(s_c) N_{j,q}(t_d) P_{i,j} = \sum_{i=0}^{m} N_{i,p}(s_c)\left(\sum_{j=0}^{n} N_{j,q}(t_d) P_{i,j}\right) = \sum_{i=0}^{m} N_{i,p}(s_c)\mathbf{Q}_{id} \tag{6}$$

Thus, data point $\mathbf{D}_{cd}$ is the point, evaluated at s_c, of a B-spline curve of degree p defined by m+1 "unknown" control points on column d of the $\mathbf{Q}$'s. Repeating this for every c ($0 <= c <= m$), the d-th column of data points (*i.e.*, $\mathbf{D}_{0d}$, $\mathbf{D}_{1d}$, ..., $\mathbf{D}_{md}$) is obtained from the d-th column of $\mathbf{Q}$'s [6].

3. INTERACTIVE SURFACE EDITOR

We have developed an interactive surface editor, which allows to modelling surface interactively. At the beginning of modeling process user chooses new study (patient) from a work list (Fig. 2). The input data are CT chest images. On each slice user can interactively indicates the place of interpolation's knots, what is shown on Fig. 3

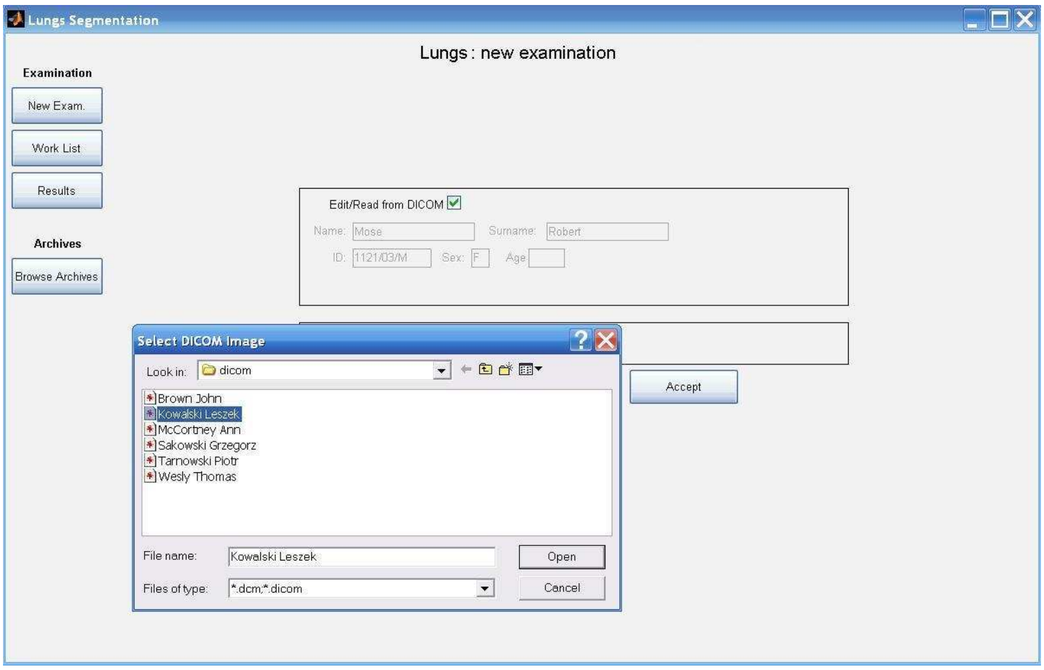

Fig. 2 Starting window in interactive editor

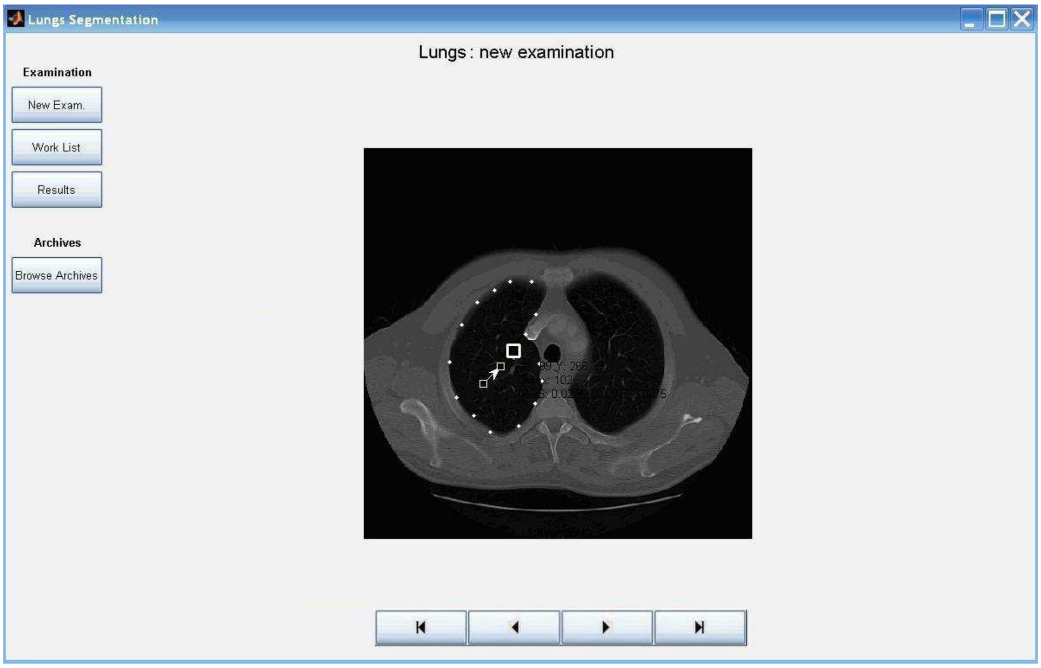

Fig. 3 Starting window in interactive editor

Afterwards the global interpolation algorithm is performed in order to find the surface of the lung. The example results of the right lung can be viewed in Fig. 4.

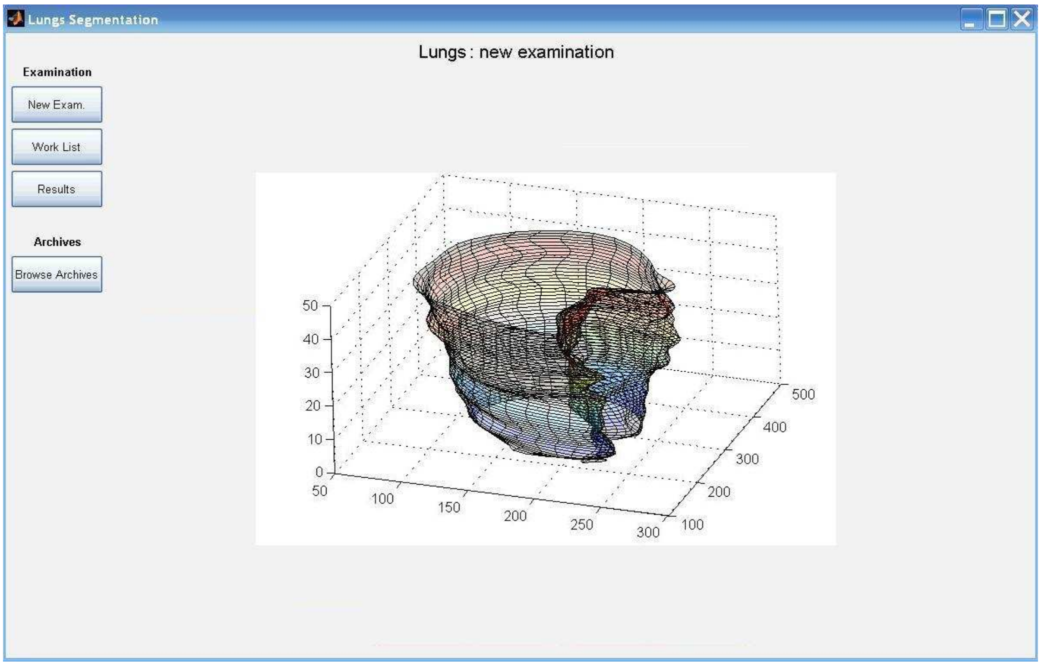

Fig. 4 Example surface of the right lung

4. RESULTS AND CONCLUSION

The presented approach has been subjected to 10 CT chest studies. Three independent users have marked the interpolation knots. The difference in field for the lungs is shown in Tab. 1.

CT chest Data	Average field [pixels]	User 1 [%]	User 2 [%]	User 3 [%]
Patient 1	596 314	8,9	3,1	5,8

Tab.1 Example results for the right lung

The next step of this project will be finding the statistical shape distribution of the lungs and use this knowledge in segmentation algorithm.

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