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Interactive graphic editing tools in bioluminescent imaging simulation

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ABSTRACT

It is a challenging task to accurately describe complicated biological tissues and bioluminescent sources in bioluminescent imaging simulation. Several graphic editing tools have been developed to efficiently model each part of the bioluminescent simulation environment and to interactively correct or improve the initial models of anatomical structures or bioluminescent sources. There are two major types of graphic editing tools: non-interactive tools and interactive tools. Geometric building blocks (i.e. regular geometric graphics and superquadrics) are applied as non-interactive tools. To a certain extent, complicated anatomical structures and bioluminescent sources can be approximately modeled by combining a sufficient large number of geometric building blocks with Boolean operators. However, those models are too simple to describe the local features and fine changes in 2D/3D irregular contours. Therefore, interactive graphic editing tools have been developed to facilitate the local modifications of any initial surface model. With initial models composed of geometric building blocks, interactive spline mode is applied to conveniently perform dragging and compressing operations on 2D/3D local surface of biological tissues and bioluminescent sources inside the region/volume of interest. Several applications of the interactive graphic editing tools will be presented in this article.

Keywords: interactive graphic editing tool, bioluminescent imaging, simulation, Bezier cubic spline

1. INTRODUCTION

With the development of molecular marker technique and optical imaging technique, *in vivo* bioluminescent imaging attracts more and more attention and can be used to non-invasively visualize the physiological and pathological process of biological tissues in real time^[1-2]. As an important part of bioluminescence tomography, bioluminescent simulation environment (BSE) is developed to simulate bioluminescent phenomena in the living small animal (e.g. the mouse) and to predict bioluminescent signals detectable outside the animal. It is a challenging task to build the virtual BSE which accurately describes the complicated biological tissues and bioluminescent sources. The accuracy of the BSE directly influences the precision of the simulated results, so it is crucial to build appropriate graphic editing tools.

Several graphic editing tools (GET) have been developed to efficiently model each biological tissue of the BSE. In general, there are two major types of graphic editing tools, i.e., non-interactive GET and interactive GET. The first type is usually applied in most of optical simulation platforms (e.g. MCNP^[3], EGS4^[4], MCML^[5], and TracePro^[6]). Regular geometric graphics and superquadrics are taken as the geometric building blocks (GBB) of these platforms. With Boolean operators, anatomical structures of biological tissues and bioluminescent sources can be approximately modeled by combining a sufficient large number of GBB. However, because of the complexity of biological tissues and medical images, GBB models are too simple to describe the local features and fine changes in 2D/3D irregular contours. Therefore, the second type - interactive graphic editing tool is developed to facilitate the local modifications of any initial surface model, especially the virtually specific contours. In our bioluminescent imaging simulation software, interactive spline mode is applied to conveniently perform dragging and compressing operations on 2D/3D local surface of biological tissues and bioluminescent sources inside the region/volume of interest (ROI/VOI). The spline mode we

used can be described algebraically by Bezier cubic spline. According to users' requirements and experiences, key surface characters of complicated anatomical structures and bioluminescent sources can be accurately described by shifting the control points of Bezier cubic spline curves.

In this article, we present these graphic editing tools not only for building the virtual biological environment but also for conveniently modifying the shape of the biological tissues and bioluminescent sources. In particular, interactive graphic editing tools are emphasized in the article due to its advantages of describing the complicated biological tissues. These tools have been integrated into our ongoing bioluminescent simulation software (MOSE) which realizes the forward problem of the bioluminescent tomography imaging.

2. NON-INTERACTIVE GRAPHIC EDITING TOOLS

Because of the simpleness and convenience in building a virtual environment, non-interactive graphic editing tools are pervasively used in most of the simulation platforms. Most of the non-interactive GET can be described by mathematic functions with several parameters, so different parameters generate various geometric shapes. As the basic building blocks, regular geometric graphics (e.g. ellipse, rectangle, ellipsoid, and cylinder) and superquadrics (i.e. superellipsoid, supertoroid, and superhyperboloid with one or two sheets) are chosen in our simulation platform. With various parameters of these proposed primitives and Boolean operators (e.g. union, intersection, and subtraction), a large variety of solid building blocks can be modeled into a distinctly irregular structure of biological tissues. Related information of these building blocks can be stored in the graphic database, so that the simulated tissue structures can be quickly input and conveniently modified.

2.1 Regular geometric graphics

2D/3D regular geometric graphics usually involve ellipse, polygon, ellipsoid, cylinder, and so on, which are basic building blocks in many simulation platforms. Functions of these primitives can be easily obtained according to certain geometric parameters (e.g. center coordinates (x_0, y_0) , long axis a , and short axis b of the ellipse). By varying these parameters, shapes of the geometric graphics are conveniently changed. Shown as Figure 1, a 2D thorax phantom model of the mouse has been realized by the combination of 11 ellipses whose geometric parameters are chosen as Table 1. The geometric function of each ellipse in Figure 1 can be expressed as $(x - x_0)^2/a^2 + (y - y_0)^2/b^2 = 1$. In Figure 1, it is easy to see the complicate structures generated by combination operations of different ellipses. For

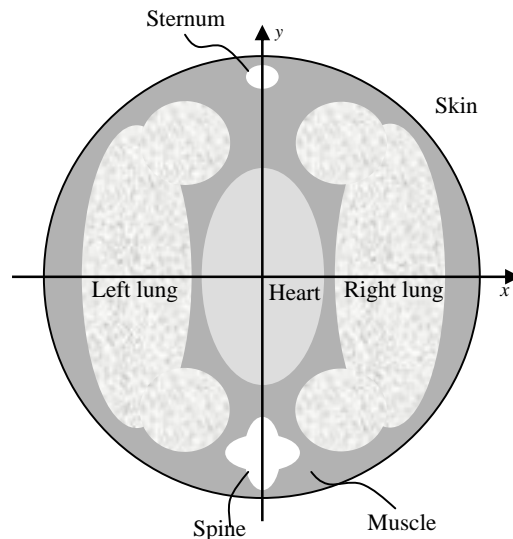


Figure 1 2D thorax phantom model of the mouse with the combination operations of different ellipses

example, the left/right lung tissue is made up of the union of three ellipses; and muscle is described by subtraction between the mouse skin (i.e. the outer ellipse) and all the other tissues (i.e. lung, heart, spine, sternum), which is a typical irregular structure.

Table 1 Geometric parameters of 2D mouse thorax phantom

Parameter	x [mm]	y [mm]	a [mm]	b [mm]
Tissue/Muscle	0.0	0.0	18.0	18.0
Left Lung 1*	- 6.5	1.1	4.0	4.0
Left Lung 2*	- 10.5	0.0	4.5	12.5
Left Lung 3*	- 6.5	- 11.0	4.0	4.0
Right Lung 1 ⁺	6.5	11.0	4.0	4.0
Right Lung 2 ⁺	10.5	0.0	4.5	12.5
Right Lung 3 ⁺	6.5	- 11.0	4.0	4.0
Heart	0.0	0.0	5.0	9.0
Spine 1	0.0	- 14.5	3.0	2.0
Spine 2	0.0	- 14.5	2.0	3.0
Sternum	0.0	16.5	1.5	1.0

* The model of the left lung in mouse chest phantom is made up of three elliptic parts named as Left Lung 1, Left Lung 2 and Left Lung 3.

⁺ The model of the right lung in mouse chest phantom is made up of three elliptic parts named as Right Lung 1, Right Lung 2 and Right Lung 3.

2.2 Superquadrics

The superquadric models were introduced to the computer graphics field in 1981^[7,8]. There are four types of superquadric models: superellipsoid, supertoroid, and superhyperboloid with one or two sheets. Among these four types, only the superellipsoid defines a closed surface without holes, which is always consistent with the condition of real environment. Therefore, the superellipsoid is commonly referred to as the superquadric. In our simulation platform, the superellipsoid is used as a particular geometric primitive.

A superellipsoid surface is defined by an implicit equation:

$$\left(|x/r_x|^{2/\varepsilon_2} + |y/r_y|^{2/\varepsilon_2} \right)^{\varepsilon_2/\varepsilon_1} + |z/r_z|^{2/\varepsilon_1} = 1, \quad (1)$$

where radius parameters r_x, r_y, r_z denote the scaling factors on x, y and z axes, squareness parameters $\varepsilon_1, \varepsilon_2$ are the shape parameters related to the squareness/roundness/pinchedness in the longitudinal and horizontal directions respectively. Another concise definition of the superellipsoid in the sphere coordinate system is described as

$$r(\eta, \omega) = \begin{bmatrix} r_x \operatorname{sgn}(\cos\eta \cos\omega) |\cos\eta|^{\varepsilon_1} |\cos\omega|^{\varepsilon_2} \\ r_y \operatorname{sgn}(\cos\eta \sin\omega) |\cos\eta|^{\varepsilon_1} |\cos\omega|^{\varepsilon_2} \\ r_z \operatorname{sgn}(\sin\eta) |\sin\eta|^{\varepsilon_1} \end{bmatrix}, \quad (2)$$

where η, ω are latitude and longitude angles with $-\pi/2 \leq \eta \leq \pi/2$, $-\pi \leq \omega \leq \pi$, and $\operatorname{sgn}(x)$ is the sign function. By varying the value squareness parameters $\varepsilon_1, \varepsilon_2$, a wide range of shapes can be conveniently generated. Roughly speaking, if a squareness parameter is significantly less than 1, the geometry is somewhat square; if it is close to 1, the object is quite round; if it is close to 2, the shape has a flat bevel; if it is greater than 2, the structure is pinched. Figure 2^[9] presents a series of the shapes that can be obtained from various combinations of squareness parameters. With certain shape parameters $\varepsilon_1, \varepsilon_2$, the superellipsoid can be transferred into regular geometric graphics. For instance, if $\varepsilon_1 = 0, \varepsilon_2 = 1$, the superellipsoid is a cylinder; if $\varepsilon_1 = 1, \varepsilon_2 = 1$, the superellipsoid is an ellipsoid.

When the building blocks are the superellipsoid, it is easy to judge whether a point $p(x, y, z)$ is inside of the shape according to the inside-outside function:

$$F(x, y, z) = (|x/r_x|^{2/\varepsilon_2} + |y/r_y|^{2/\varepsilon_2})^{\varepsilon_2/\varepsilon_1} + |z/r_z|^{2/\varepsilon_1}. \quad (3)$$

If function $F(x, y, z) < 1$, point p is inside the superellipsoid; if $F(x, y, z) = 1$, p is on the boundary of the superellipsoid; if $F(x, y, z) > 1$, p is outside the superellipsoid.

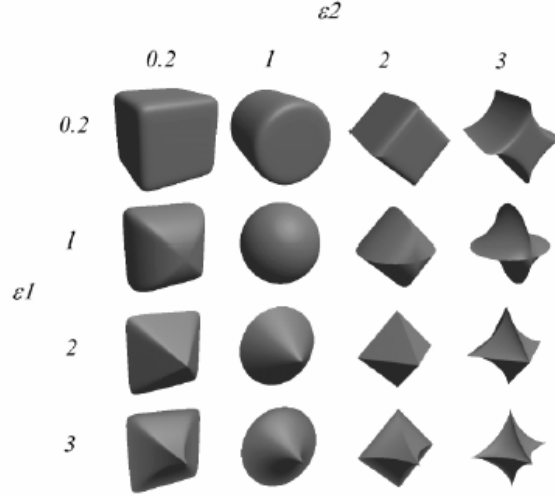


Figure 2 Several superellipsoid shapes with various squareness parameters

3. INTERACTIVE GRAPHIC EDITING TOOLS

The combinations of non-interactive graphic editing tools can describe some relatively complex shapes, but it is hard to describe local features and fine changes in 2D/3D contours of anatomical structures. When parameters of non-interactive graphic editing tools are changed, the whole structures will be modified. Because of the remarkable complexity of biological tissues and bioluminescent sources, interactive GET models are usually chosen to modify local structures of 2D/3D simulated shapes. In our simulation platform, 2D/3D interactive GET were respectively realized and integrated. In the following, our work focuses on the generation and modification of bioluminescent sources for brevity.

3.1 2D interactive graphic editing tool

In 2D simulation environment, any 2D irregular bioluminescent source can be described by 2D interactive GET and can be conveniently modified by interactive operations. Shown as Figure 3, any 2D shape is determined by the position relationship of all vertexes (i.e. small solid circles on the contour). According to the requirements or the prior knowledge of operators, a series of original vertexes are given. Then, original contour (Figure 3 (a)) of the bioluminescent source is formed by smoothly connecting the adjoining vertexes with polynomial curves or arcs. The original contour can be conveniently modified by adding, deleting, and moving vertexes (Figure 3 (b) and (c)). For example, if one part of the local contour is smooth, only a few vertexes are enough to depict its fine features; if it is rough (e.g. sharp protuberances and hollows), more vertexes are needed to describe the details of the local contour, shown as Figure 3 (d). Given a point P , the line \vec{L}_p with certain direction can be easily obtained. The number N of intersections between \vec{L}_p and the contour described by 2D interactive GET is used to determine whether the point P is inside of the contour. If N is odd, the point P is inside the shape; if N is even or zero, the point P is outside

the shape; if the point P satisfies the function of contour formed by polynomial curves or arcs, it is on the boundary of the shape.

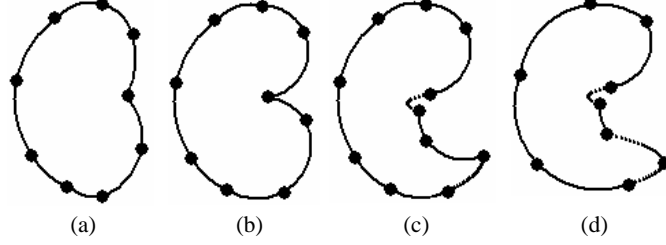


Figure 3 An example of generating a 2D shape with interactive graphic editing tools. (a). The original shape formed by original vertexes with polynomial curves or arcs. (b). Shapes obtained by moving original vertexes to new locations. (c) Local contour was modified by adding vertexes. (d) In smooth contour, only a few vertexes are needed to efficiently describe the contour.

3.2 3D interactive graphic editing tool

The original shape of any 3D irregular object is usually chosen as a sphere or a cylinder whose parameters are determined according to the prior knowledge of operators. In our simulation platform, the default original shape of the 3D bioluminescent source is a sphere, and the Bezier cubic spline mode is applied as the interactive editing tool. First, the volume of interest (VOI) of the original object is selected, which defines the local surface to be modified. Then, the selected local surface of the original 3D object can be dragged via a so-called control point p_c along any direction, which can be repositioned interactively. The position of the original control point p_c is determined by the shape of the local surface S_L which needs to be modified. When the position of the control point is changed, the whole local surface is modified accordingly by a Bezier cubic spline mode.

In 3D simulation environment, multiple Bezier cubic splines are used to describe the modified local surface inside the VOI of the 3D object. To make this 3D interactive mode easier to be understood, we begin with the 2D Bezier cubic spline curve. The 2D Bezier cubic spline curve can be described algebraically by a Bernstein polynomial of degree 3^[10]:

$$p(t) = (1-t)^3 p_0 + 3(1-t)^2 t p_1 + 3(1-t) t^2 p_2 + t^3 p_3, \quad (4)$$

where t varies between 0 and 1. Figure 4 shows the 2D typical Bezier cubic splines. From the equation (4), it is evident that four points p_0 , p_1 , p_2 , and p_3 are needed to determine the shape of the spline curve. The two end points p_0 and p_3 (shown as Figure 4) are fixed, because they are the boundary points of the selected local surface of the original object. However, it is still difficult to interactively operate on the other two points p_1 and p_2 simultaneously. The solution is to search one control point p_c to express two points p_1 and p_2 . In our simulation platform, we chose points p_1 and p_2 are the midpoints of line segments $p_0 p_c$ and $p_3 p_c$ respectively. Then, equation (4) can be rewritten as:

$$p(t) = 1.5[(1-t)^2 t + (1-t) t^2] p_c + [(1-t)^3 + 1.5(1-t)^2 t] p_0 + [t^3 + 1.5(1-t) t^2] p_3. \quad (4)$$

Because the two points p_0 and p_3 are known, the whole Bezier cubic spline can be determined by the control point p_c only. When the control point is moved, the local surface S_L can be conveniently modified accordingly (shown as Figure 4 (b)).

The mechanism of 3D surface modification is the same as that of 2D surface modification. The difference lies in that 3D local surface is made up of many Bezier cubic splines with the same control point p_c . Known the 3D original

local surface to be modified and a series of initial Bezier cubic splines determined by the control point, the 3D local surface of the object is modified by a group of Bezier cubic splines in 3D simulation environment (shown as Figure 5).

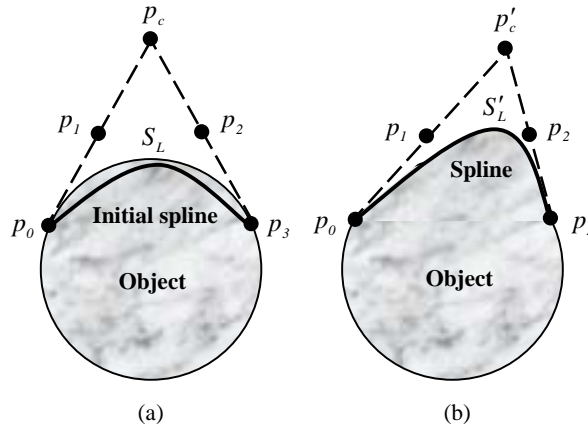


Figure 4 The schematics of the 2D local surface modified by the control point p_c and described by Bezier cubic splines. (a) The surface of the original object with the initial spline determined by the control point p_c . (b) The modified surface of the object with the dragged spline generated by the new control point p'_c .

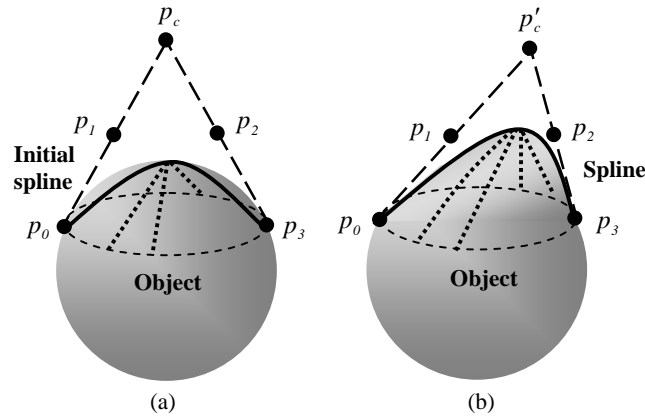


Figure 5 The schematics of 3D local surface modification. (a) The 3D surface of the original object with a series of initial splines determined by the control point p_c . (b) The modified surface with a group of dragged splines generated by the new control point p'_c .

In our 3D simulation platform, all the 3D shape including the biological tissues and bioluminescent sources are described by a series of triangle meshes. It is crucial to judge whether a point is inside a 3D irregular shape. Given a point P and a certain irregular contour, the line \vec{L}_p with certain direction can be easily obtained. The number N of intersections between \vec{L}_p and the contour described by 3D interactive graphic editing tools is used to determine whether the point P is inside of the contour. If N is odd, the point P is inside the shape; if N is even or zero, the point P is outside the shape; if the point P satisfies the function of contour composed of many triangle meshes, it is on the boundary of the 3D shape.

4. RESULTS WITH INTERACTIVE GRAPHIC EDITING TOOLS

All the interactive graphic editing tools presented above have been integrated into our simulation platform, with which the irregular 2D/3D shapes can be conveniently generated and modified according to the interactive operations and prior knowledge of the operator. Take example for the modification of 3D bioluminescent source. The input of our

simulation platform is a series of slices obtained from micro-CT. After segmentation, surface rendering and mesh simplification, the virtual biological environment can be built from the input data. For example, the purple graphics indicates the rib and the heart of mouse thorax with transparent effect in Figure 6. When the virtual biological environment is built, a control panel is used to give the parameters of 3D original bioluminescent source, such as, the coordinates of the center, the scaling factors on x, y and z axes, the original shape and distribution function of the object. With the movement of slides, the position and dimensions of the bioluminescent source can be easily modified. Figure 6 (a) shows the biological tissues and the original shape of 3D bioluminescent sources; Figure 6 (b) presents the movement of the source generated by the modification of the parameters; and Figure 6 (c) denotes the change of source dimensions.

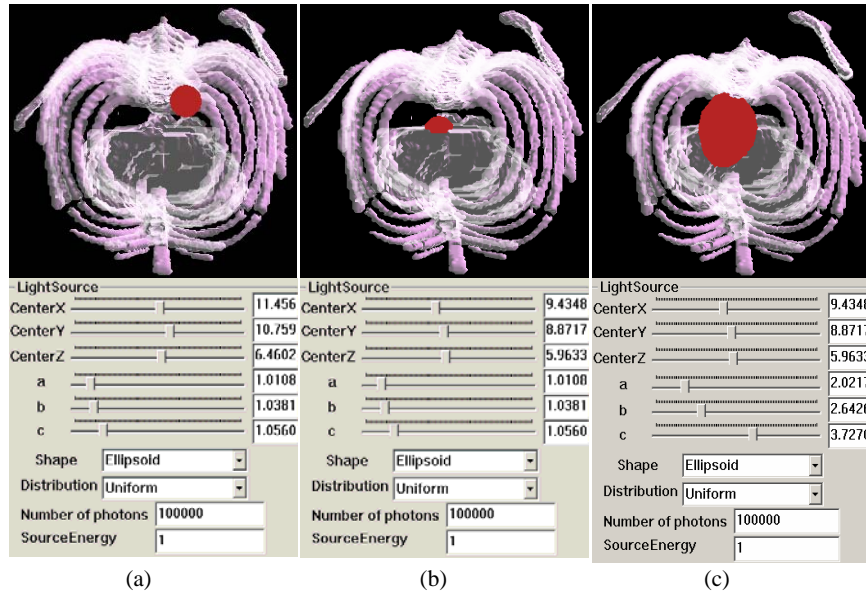


Figure 6 The position and dimensions of a 3D bioluminescent source are conveniently modified by the control panel. (a). The original position and dimensions of the 3D bioluminescent source whose parameters are shown in the control panel; (b). The position of the source is modified by its center coordinates (i.e. *CenterX*, *CenterY*, and *CenterZ* in the control panel); (c). The dimensions of the source are modified by the scaling factors on x, y and z axes (i.e. *a*, *b*, and *c* in the control panel).

The 3D local surface of the bioluminescent source can be easily modified by the Bezier cubic spline mode discussed in Section 3.2. In Figure 7, the solid sphere is the original bioluminescent source and the local convex surfaces are generated by Bezier cubic splines.



Figure 7 Three views of the original bioluminescent sources (the solid sphere) and the local surface modified by the Bezier cubic spline curves (the local convex surfaces)

5. DISCUSSION

Several graphic editing tools have been developed and successfully applied in accurately modeling 2D/3D complicated shapes in the bioluminescent imaging simulation. All computation algorithms have been realized and completely integrated in our bioluminescent imaging simulation platform. Our experiment results indicate that graphic editing tools (especially geometric building blocks and Bezier cubic spline mode) can be used to efficiently model the local surface features and to interactively modify the initial contours of irregular shapes (e.g. the bioluminescent sources) in the bioluminescent environment. Moreover, we proposed efficient algorithms to judge whether a point lies in the modified 2D/3D shape and to calculate the intersection points where the photon hits the boundaries of phantoms, which ensures higher precision of simulation results.

In our simulation environment, the interactive graphic editing tool is efficiently combined with the geometric building blocks, so that 2D/3D irregular contours especially local features can be efficiently modeled by manual corrections of initial GBB models. As a result, the bioluminescent imaging environment can be precisely simulated by the proposed methods.

6. ACKNOWLEDGEMENT

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7. REFERENCE

- [1]. Weissleder R, Mahmood U. "Molecular imaging". *Radiology*, **219**(316~333), 2001.
- [2]. Blasberg RG, Gelovani-Tjuvajev J. "In vivo molecular-genetic imaging". *Journal of Cellular Biochemistry*, **87**(172~183), 2002.
- [3]. Briesmeister JF. MCNP--A General Monte Carlo N-Particle Transport Code, Version 5, Volume 1: Overview and Theory. Los Alamos National Laboratory, 2003.
- [4]. Bielajew AF, Hirayama H, Nelson WR, Rogers DWO. History, overview and recent improvements of EGS4. National Research Council of Canada Report PIRS-0436, 1994.
- [5]. Wang LH, Jacques SL, Zheng LQ. "MCML---Monte Carlo modeling of light transport in multi-layered tissues". *Computer Methods and Programs in Biomedicine*, **47**(131-146), 1995.
- [6]. User's Manual (Release 3.0) of TracePro (Software for Opto-Mechanical Modeling), Lambda Research Corporation, Littleton, MA, USA.
- [7]. Barr AH. "Superquadrics and angle preserving transformation". *IEEE Computer Graphic and Application*, **1**(11-23), 1981.
- [8]. Barr AH. "Global and local deformations of solid primitives". *Computer Graphic*, **18**(21-30), 1984.
- [9]. Sinnott J, Howard T. "SQUIDS: Interactive Deformation of Superquadrics for Model Matching in Virtual Environment". *Eurographics UK Conference Proceedings*, pp. 73-80, 2000.
- [10]. Farin G. *Curves and Surfaces for Computer Aided Geometric Design: A Practical Guide*. 5th chapter. Academic Press, New York, 1990