CT SLICE RETRIEVAL BY SHAPE ELLIPSES DESCRIPTORS FOR SKULL REPAIRING

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ABSTRACT

This paper addresses the problem of automated prosthesis modelling and manufacturing, whose machining parameters are based on images extracted from different medical databases. The specific case of 3D surface restoration of a defective skull was used as study case. A method based on adjusted ellipses on skull bone curvature performs the symbolic representation of searching parameters. The superellipse concept permits to define geometric parameters to fit an ellipse on each Computed Tomography slice. Those ellipse descriptors can be used as a template for the retrieval of similar images from databases whose parameters match the sampled image. The similarity is measured according to the best fitness values through an optimization algorithm. The slices found by similarity are retrieved from all databases in order to build the 3D model. Experiments show that the proposed method is a promising technique for content based image retrieval.

\textit{Index Terms}— Prosthesis Modelling, Image Retrieval, Ellipse, 3D, Medical Imaging

1. INTRODUCTION

An important challenge in medical image retrieval is the reduction of the large amount of data for the evaluation. In general purpose databases we can find an image using textual information \cite{1} or in medical databases by describing a specific situation or problem through semantic ontologies \cite{2}. Also, content-based image retrieval systems as \cite{3,4,5} are applied where the content of an image such as colour, shapes and textures are used to retrieve images that are similar to a query image. The perception of significance of an image is a natural characteristic intrinsic to humans, and choosing of search parameters depends of doctor’s experience and previously knowing of a specific problem. So, in the most database system a human need to provide the searching information as text, images, or a combination of both.

A wide range of retrieval methods based on shapes of objects is widely presented in literature and fully reviewed by \cite{4}. There is special interest in content based retrieval algorithms, because the shape characterization automates database image retrieval. Due the actual integration between mechanical systems and medical applications, we need to provide machines with resources in order to automatically retrieve information for the database without any human interaction. The question addressed here is: How a machine, for instance a CNC (Computer Numeric Control), can define a content based search by itself in order to manufacture an anatomic prosthesis?

Content based retrieval is a key point of this problem. As presented by \cite{6,7,8} the basic principle of the feature reduction process is through selecting a subset of informative features for each image.

In this paper we are addressing the problem of 3D surface restoration of defective skulls which has a hole due congenital malformation or accident. The prosthesis modelling from the 3D reconstructed image as in \cite{9} and the bone modelling to rapid prototyping applications as in \cite{10} illustrated that the geometric definition is still a complex task. An alternative method proposed by \cite{11} is based on ellipse adjustment on CT (Computed Tomography) slices. In that case the ellipses adjusted in each defective slice define arcs that can be superimposed to create a CAD model of a 3D piece and respective data can be used in machining.

The proposal here is based on modified approach of the previous work of \cite{11} that suggests the use of elliptical approximation to recover its shape’s characteristics. We are assuming that the physics characteristics of skull shapes are similar among humans (equivalent ages and gender). Due skull anatomy, the bone’s curvature is different among all CT (Computed Tomography) slices, but part of them seems ellipses. Natural rounded shapes can be described by the concept of \textit{superellipse} and \textit{superformula} as defined by \cite{13}. These concepts permit the creation of geometric shapes as commonly found in nature. An ellipse might describe the shape of a CT image using their own parameters as centre coordinates and axes sizes. Instead processing entire image pixels, some geometric attributes are used in order to describe each CT. Then a reduced set of information can be applied to find the wanted information in the database.

A hole in the skull produces CT slices with unclosed edges. The searching images are all CTs with open borders, and the solution must be a closed border CT image stored in database with equivalent parameters to each slice inputted.
This signifies that for each “defective slice” of same patient, the method looks for a corresponding “good slice” from different patients in database. The information that links these two kinds of images is the corresponding ellipse that fit both CTs with the same geometrical characteristics.

2. PROPOSED METHOD

In machining process of the skull failure repairing, the main problem is modelling of the defective area. We need to generate the geometric representation without enough information. The work of [11] suggested to use ellipses virtually created to build a new surface. Here, we are overtaking its approach by finding a similar shape retrieved from databases. In the proposed method the kernel is the creation of the CT descriptor based on the Ellipse Adjustment Algorithm (EAA) as highlighted in figure 1. The method is compound by tree main parts:

II) Database retrieval:

First, using the information of the patient (age and gender) from DICOM header [12] the system can select an initial set of possible images with the same anatomic characteristics from different patients. We get a reduced group of images with better chance to be “the answer image”. Next, from this set of images the system executes once more the EAA among images in this sub group. We obtained another new subset of selected possible images whose respective ellipse parameters (axes dimensions, borders thickness, orientation, etc) correspond to the respective ellipse from each “search image”.

III) 3D modelling and manufacturing:

After all compatible images have been selected from the database (one to each CT slice of defective region), the pixels positions that corresponds the lack in border are applied in order to build the 3D CAD model. The machining parameters are extracted from this model.

3. ELLIPSE ADJUSTING ALGORITHM (EAA)

The image of a segmented skull bone contains a relativity simple object, which is a skull border presented as an oval shape. The concept of superellipse defined by [13] can be applied to image selection, because it permits to find a mathematical description to a natural shape.

3.1. Superellipse definition

The bone in each CT image can be modelled as an ellipse with slightly different shapes and the system needs adjust their parameters. The mathematical formulation of the superellipse is presented in equation 1 as defined in [13].

\[
r(\varphi) = \frac{1}{\left(\left(\frac{1}{a}\cos \left(\frac{m}{4} \varphi\right)\right)^{n_1} + \left(\frac{1}{b}\sin \left(\frac{m}{4} \varphi\right)\right)^{n_2}\right)^{\frac{1}{n_3}}} \tag{1}
\]

From equation (1) the parameters \(a\) and \(b\) represents the minor and major axis of the ellipse. The \(\varphi\) is the angle and the \(m\) value represents the rotational symmetry, which is the number of fixed arguments on the unitary circle. The obtained shape is a rounded polygon and \(m\) describes the number of sides of this polygon. For example, for \(m = 3\) we obtain a triangular shape and for \(m = 0\) we obtain a circle. An ellipse can be obtained if \(n_1 = n_2 = n_3 = 2\) and \(m \neq 0\), and in this case we have the canonical ellipses’ equation.

By observation, some slices in the middle of the skull looks like as a normal ellipse (by the equality of parameters \(n\)). When the shape turns more oval, on the skull top for instance, the superellipse can self-adjust better than the normal ellipse by adjusting the values of \(n\). The \(r\) value is the generated parameter from equation 1 to estimate the

Figure 1. The Proposed Method.

I) Identification of CT slices’ failure:

The machining preparing starts with the extraction of CT images from patient DICOM files [12]. Those with open borders must be selected, and the EAA searches the best ellipse that fits each defective slice. Here it is created a selected set of CT images to be applied as “searching images”.
The ellipse found by the superellipse formula, as the example in figure 2, is one whose parameters represents a possible curvature around bone (in this example only represented the external border). The arc that fills the ROI is the expected solution but there are slight differences between generated ellipse $E(i,j)$ and the real bone edge $I(i,j)$.

In this approach, the main problem is that many arcs can be found with similar information to the same CT slice to external and inner borders. Among a lot of possible arcs created for each slice, the decision to be taken is to decide what the best solution is. The question is about what superellipse parameters will permit to create the best piece of curved shape for this uncompleted bone. This search for parameters might be optimized to find the best set of them. The amount of this difference, i.e. the error can be measured by a fitness function.

### 3.2 Fitness Function

Evolutionary Algorithms (EA) are capable of efficiently finding an optimal solution without necessitating reformulation for the evaluation of individual solution candidates. The research in [13] shows a comparative study of some algorithms as GA (Genetic Algorithm), PSO (Particle Swarm Optimization) and Harmony Search (HS) as tools to find the best ellipse parameters to skull border adjustment by an automatic way. A fitness function $F(X)$ evaluated by PSO optimization proposed in [10] was used in order to evaluate the ellipse adjustment and it is given by equation 3.

$$ F(X) = \frac{\sum_{i=1}^{l} \sum_{j=1}^{n} [I(i,j) \cdot E(i,j)]}{\sum_{i=1}^{l} \sum_{j=1}^{n} I(i,j)} $$

The image $I$ is a black & white segmented CT slice. Each point $I(i,j)$ is the position of one pixel in the image where its binary value is 1. The $l$ and $c$ values are respectively the total of lines and columns in the image $I$. The value that maximize the fitness function depends of the values of $a$, $b$, $m$, $n_1$, $n_2$, $n_3$ estimated to equation 1, and the values of the centre of coordinates $(x_0, y_0)$ estimated to equation 2. The both bone borders from external and internal skull walls must be evaluated.

### 4. RESULTS AND DISCUSSION

The searching image is an open border CT from the patient, and the solution must be a closed border CT from the database. The information that links these two kinds of images is the ellipse, which fit both CT with the same geometrical characteristics. The figure 3 shows as example a real 3D set of reconstructed slices and a selected searching image.

![Figure 3](image-url)
image. The image of figure 4.a is the volumetric representation of a human head generated by Fiji software [15] and respective slice of interest found in database whose ellipse parameters match the searching image.

![Figure 4. (a) 3D volume CT image retrieval from the database. (b) A possible solution to fill the open border in the original CT.](image)

The image of figure 4.b is a good CT slice (i.e. no border failure) from respective human head. The arc that fills a hole can be recovered from this image, and it can be used to fill the missing bone part as demonstrated in figure 4.b. This recovered piece is used to fill that specific slice in the original defective skull, as presented in figure 5.

![Figure 5. 3D skull model and respective recovered piece.](image)

5. CONCLUSION

This paper presented the progress of studies applied to anatomic prosthesis modelling. The main idea is to change a defective slice by another good slice with similar shape. This research address the method based on the creation of adjusted ellipses as image descriptors. That descriptor can be used by a machine (CNC) by itself look for a similar image in database. Thus we have a content retrieval tool based on the shape of each evaluated CT slice without human interaction. The result show that the method is feasible and promising, but it is a complex task and there are still some open points. The next two stages of research are: (i) Evaluate a modified approach executing a prior off-line indexing of all images in databases extracting previously the ellipses parameters; or extracting them when the images were collected from X-Ray device, in order to improve the response time. (ii) Medical analysis of functionality aspects of the method, and evaluation of the measurement accuracy before and after manufacturing.

6. REFERENCES


