3D facial reconstruction,
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dowels

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SYSTEM FOR FACIAL TISSUE RECONSTRUCTION BASED ON DOWEL METHOD

The paper presents the ideas of a system of soft tissue reconstruction which uses the method of dowels. The list of functionalities which should be included into such a system is described. The system enables the user to edit the thickness of dowels and their directions, which results in building an editable model of the surface of the skin. The set of dowels called the "Rhine configuration" [1,2] is used by default , but there is a possibility to make new statistics for the population being analysed. Further processing is required and the paper shows the ideas of an algorithm of surface splitting taking into consideration the curvature of the skull or, for example, the use of morphing techniques.

1. INTRODUCTION

Traditional orthodontic diagnosis puts emphasis on the analysis of the bones of the skull [3] . For a long time, soft tissue analysis has been treated as an auxiliary method, and not very precise. This was resulted from the difficulty of finding a good model of the behaviour of soft tissues. The importance of soft tissues was appreciated with the development of programs supporting surgical intervention and aimed at visualizing the patient's postoperative appearance. Improper modelling of tissue properties leads to many misunderstandings and patient's claims in a situation when his appearance differs from that predicted by the system. Therefore proper models of soft tissues are still being sought.

2. SOFT TISSUE RECONSTRUCTION

2.1. TRADITIONAL METHOD

Modelling of soft tissue can proceed in different ways. In a traditional method modelling is a precise, manual action, which involves putting layers of plastic substances (such as clay) on a model of the skull. When layers corresponding to muscles and fat tissue have been added, a skin layer is stretched on the model [2]. Eyes, mouth, ears and nose are also modelled from plastic substance. This method is

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used in forensic science and in archaeology studies, to show what the deceased person may have looked like, and has good results in these disciplines. The nontrivial process of preparing a physical model of the skull and the manual character of the work involved in shaping the clay (which can contain imprecision) made it nearly impossible to be used in orthodontics. However, the idea of using dowels as a representation of tissue thickness is applied in the system of facial tissue reconstruction which is described below.

2.2. AUTOMATIC METHODS

The development of computer graphics and vision, connected with multimedia and the entertainment industry, forced a development of simplified models, which can animate the appearance and behaviour of the human face in the process of talking. Such a model is adapted by a method called ‘talking-heads’ [4]. This model considers the knowledge of the way facial muscles participate in the process of expressing emotions and talking. The ‘talking-heads’ method must be very quick in order to manage with real time animation of the process of talking. For this reason, the results need not be very accurate.

There is also method called FEM: finite-element method. It can be used in systems in which time limitations aren’t critical. This method is based on advanced mathematical calculations. The surface is divided into small regions, and each region is represented by a node. Accurate values of properties are known only at the node, elsewhere the properties are estimated. Calculations are also carried out only at the nodes and at other points the results are averaged. This method is very exact, but has several properties which make it difficult to use in orthodontics. The main one is the lack of a good system to measure the properties of facial tissues. While thickness and density are known, it is difficult to measure the reaction to pressure or tensions in human tissues.

3. SYSTEM OF RECONSTRUCTION

3.1 THE IDEA AND THE APPLICATION OF THE DOWEL METHOD

The dowel method is based on landmarks, well-defined feature points of the head. Each dowel [1] is a distance between a pair of landmarks: one localized on the skin, and the matching landmark on the skull. The use of dowels is then close to landmark-based analysis, which is so popular in orthodontic diagnosis[3], and shares all of its advantages. Landmark representation solves the problem of correspondence in temporal and inter-patient studies, and dowels additionally bind the skin and skull landmarks; the correspondence of dowels can therefore also be established. Finally, estimating the average values of thickness of soft tissues, for many different populations, was the subject of many long-term research endeavors [1, 2], which yielded a number of sets of dowels.

These advantages of the method of dowels, as well as its simplicity, were the main reasons why it became the basis of our system of facial tissue reconstruction. The system uses the set of dowels called the “Rhine configuration” [1, 2], extended with several landmarks on the back and top of the head, which enable the reconstruction of the surface of the skin in those regions.

Determination of dowels requires proper landmark localization, which is a task both for the user and the authors of the system (the database must be filled with proper data before releasing the program). Representing thickness as a scalar value (without direction), dowels are insufficient to generate the surface of the skin. Therefore, a normal vector has to be determined for each landmark. The direction of the vector is calculated as a weighted sum of normal vectors of polygonal faces of the mesh having a common vertex at this landmark.

3.2 READING AND STORING DATA, DATA STRUCTURES

The use of dowels requires the system to be able to handle and store not only the representation of 3D surfaces, but also additional information connected with soft tissue thickness. Therefore there are two types of data sources, which can be used by a system:

- The database, which contains the information about model properties (e.g. thickness of dowels) files, connections between them, etc.,
- VRML files which contain the 3D representation of shape of skulls

Information from VRML files is stored in appropriate data structures in the program and is sufficient to visualize the appearance of the skull. The representation of soft tissue thickness can be additionally provided by normal vectors. Calculation purposes, however, require another structure to be created, based on graph representations. This representation is useful in the algorithm of finding a path between two points and also in modelling a new shell over the skull.

3.3 INTERACTION BETWEEN USER AND PROGRAM

The program has a simple interface, which allows the user to choose suitable data, localize the landmarks and create connections between landmarks on the skull and on the template, modify and delete and store them, and finally save the result of reconstruction in VRML files. The functions like 'zoom', 'rotate' and 'move' make the system more comfortable to use.

3.4 CALCULATIONS BASED ON DOWEL METHOD

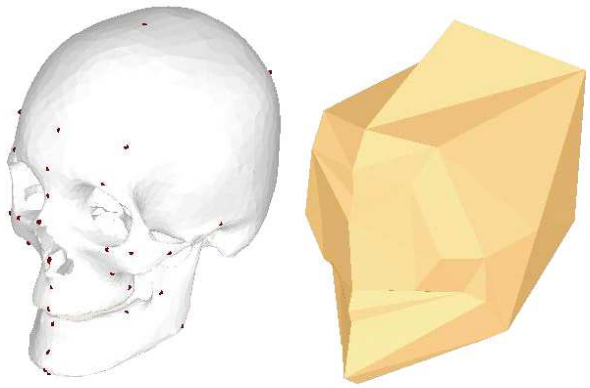

Fig.1 Skull with landmarks, simple mesh based on dowels

Calculations in the program are divided into a few parts. The first part is based on the dowel method. A simplified mesh is spread over the landmarks. Vertex coordinates are calculated using landmarks, and thickness at each landmark is added to the landmark as a dowel-length vector in the normal direction. The program should have the possibility to parameterise the length of dowels in case human faces aren't identical. One person is slimmer than the other and this fact should be represented by weighted thickness. The program provides this possibility because dowels are stored not as single values, but as ranges.

An exemplary skull with landmarks and reconstructed simplified mesh is shown on fig.1.

3.4 FURTHER PROCESSING

The simplified mesh is not a good reconstruction of soft tissues, but it can be used as a starting point for further processing. One of the approaches can be the division of large triangles into smaller (idea of this algorithm was drawn from [5]). The algorithm divides each triangle into 4 smaller ones. In the first step it calculates the coordinates of the new points as placed in the middle of each side of a triangle. In the second step, the coordinates of the new points are modified, taking into account the curvature of the surface of the skull (fig. 2). In this step, several algorithms are applied: finding a path between two points (at this moment graph structures are needed), fixing the central point on the path, calculating the angle between points in 3D space, calculating the coordinates of a point on the basis of knowledge about the location of other points and their interdependencies.

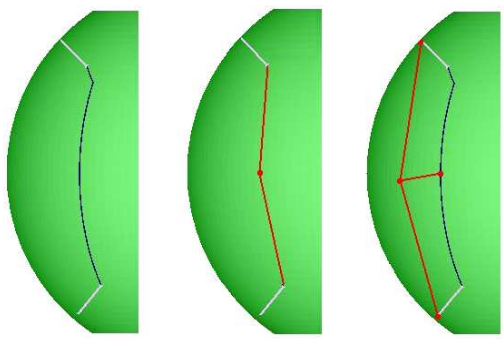

Fig. 2. Adapting coordinates of new point to the curvature of the surface

When the coordinates of new points are calculated, they are added to the structure of the shell, graph structures are changed as well and this completes one iteration of division. (fig. 3 shows the result of one iteration done on a simple shape).

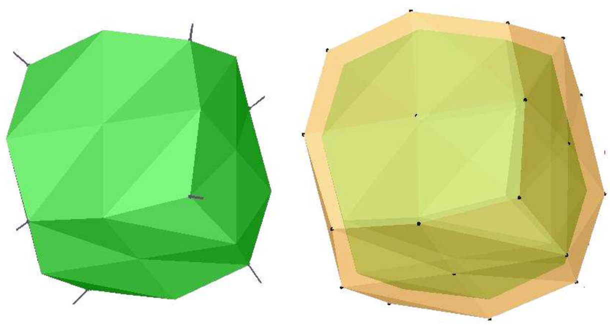

Fig. 3. Results after one iteration of reconstruction

The number of iterations influences the output data size (described by number of points and triangles) and its accuracy. Output data size, however, doesn't depend on input data size. Input data is of course very important and the quality of output data directly depends on input data. The program should give the user a possibility to specify his or her requiements (number of iterations, accuracy, data size), directly as a number of iterations, or indirectly, by indicating the desired accuracy or output data size.

There is one more problem involved in generating a surface which will look like a face – it is impossible to reconstruct structures like eyes, mouth or ears using only the dowel method and bone surface, because these features are not defined by the shape of bones. At present, work in the project is focused on making the generated surface more similar to a human face. It has not yet been determined if it will be done by a program written specifically for that purpose as part of our project, or by using existing software (like RapidForm or 3DsMAX) and its algorithms of morphing. The former would require the shape of those structures to be defined and made editable (e.g. by adding parameters to them); the latter, a wider set of pattern skulls with skin surface.

Exemplary results of morphing are shown on figure 4 and 5. Morphing was done using RapidForm. Figure 4 shows a skull of an Asian woman (from a RapidForm tutorial) and the result of morphing her face to the simplified mesh obtained for dowels of the male skull.. Figure 5 shows a European face scan obtained by authors from 3D laser scanner and also the result of morphing to the simplified mesh.

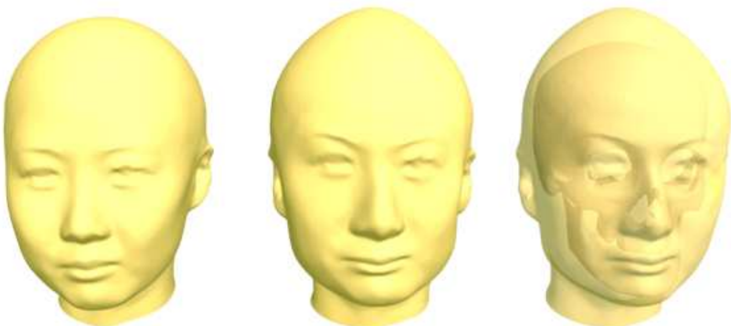

Fig. 4 Model of Asian woman's face, morphed face, morphed face with skull

Fig. 5.European woman face received obtained from 3D scanner, morphed face, morphed face with skull

4. CONCLUSIONS

This paper describes a system of soft tissue reconstruction which uses the method of dowels. The list of functionalities which should be included into such a system is described. The advantages of the program are: the possibility to edit the thickness of dowels and their direction. The system uses existing normal dowel sets known as the “Rhine configuration” and can make new statistics for a population. It is possible to use another type of modelling in the further steps, based on anatomical knowledge about muscles as well as the idea of interpolation under restrictions imposed by the (given or average) curvature of the skull, or based on the principles of morphing.

This kind of program could be developed in different ways. It could be useful to develop another reconstruction system with appropriate dowels and set of rules. If editing of bone structure is implemented, the system will help in the planning of operations. If a set of VRML files with pattern skulls (of different age) will be larger it can be useful to predict the growth of tissues on a given skull.

Now, the next thing to add to the system is generating structures like eyes, mouth, ears and reconstructing from incomplete input data, which means estimating the positions of missing feature points and the shapes of unknown regions.

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