Three-dimensional Image Capture and Applications VI (EI07)
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Facial Modeling for Plastic Surgery Using Magnetic Resonance Imagery and 3D Surface Data

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ABSTRACT

We describe a novel facial modeling and real-time pre-surgery planning + visualization tool for surgical and esthetic plastic surgery. The modeling pipeline accepts geometry both in the form of Magnetic Resonance Imagery (MRI) and/or 3D facial surface scans. The MRI data is first used to segment the skin surface as well as the underlying tissues of interest. Textures taken with a digital camera are mapped on the 3D model for display purposes. The facial scanner, when available, provides an alternate means for doctors to obtain high quality 3D skin information and texture at the same time. Multiple facial expressions can be recorded to study tissue deformation. Our solution allows for using the two types of sensors separately or in conjunction with one another. The resulting models and additional information, such as the animated MRI slides, provide doctors with better means of surgical planning. Currently, we are further developing the system to integrate finite element calculations (FEM) that help better planning and understanding of the possible outcomes of a surgery and thereby reduce the risk for any given patient. The presentation reviews the methodologies, algorithms and tools in the context of a real-life application.

Keywords: digital human, virtual plastic surgery, real-time visualization, 3D rendering, MRI, 3D scanning, cyber therapy

1. INTRODUCTION

Recent advances in Digital Human Technology (DHT)[1,2,3] combined with the broad availability of portable, high performance computer graphics hardware have created a unique opportunity to develop a novel set of applications meeting the demands of reconstructive and aesthetic plastic surgery[4]. During the past decades high resolution detailed imaging of the human body using MRI and surface scanners has become more and more cost effective and widely available. However, the real-time tools needed to process and visualize these vast amounts of information have thus far turned out to be a limiting factor for introducing these applications in clinical practice.

The purpose of DHT is to turn an unstructured 3D data sets obtained from a specific patient into a 3D standardized model-based representation thereby creating a domain that can be analyzed and transformed using exact mathematical formulation. To create this mathematical domain one first needs to normalize the data sets and derive an internal data representation whereas each object of interest is mapped onto the same topology. Clinical plastic surgery is one of the key application areas that may benefit from using tools developed for DHT. Specifically, using these tools one can create 3D photo-realistic head models of patients and visualize - as well as simulate - the effects of an operation in a virtual space.

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2. METHODOLOGY

To meet the technical demands of creating a real-time pre-surgery planning + visualization tool we developed a facial modeling pipeline that comprises of i) an MRI segmentation module that provides subsequent processing stages with skin surface and optional tissue data, ii) a 3D surface modeler that turns a single or multiple 3D reference scans into a standardized high-fidelity facial model in a matter of hours, iii) and a real-time engine capable of visualizing the resulting facial models [sizes up to 400,000 polygons], MRI slice information and additional medical data at speeds of 24-30 frames per second.

The purpose of the *MRI module* is to deliver segmented skin surface and underlying tissue data for the subsequent 3D surface modeler and the visualizing unit. Multiple MRI scans of the same individual may be merged to get a single, high resolution surface. Separate texture images (i.e. digital photographs from multiple angles) are also recorded to be projected later in the 3D modeler. The *3D surface modeling* pipeline was designed to turn a high resolution 3D scan into am animation ready, standardized head geometry with accessories (including the eyes, teeth and skull) in a matter of hours. The semi-automatic unit accepts 3D surface data provided by the MRI module or directly from a 3D facial scanner. Texture information may also be delivered from either sensor. Depending on the actual availability of data any combination of these two sensors can be used to create a photo-realistic, high resolution 3D model of the patient. Finally, the resulting detailed 3D models can subsequently be visualized using the real-time plastic surgery editor. Having discussed the overall methodology, we now turn our attention to describing each module in detail.

3. FACIAL MODELING PIPELINE

A block diagram of our 3D facial modeling pipeline is shown in Figure 1. The modeling process starts by *capturing* an MRI along with high resolution 3D images of a person. Next, a series of *reconstruction* and *facial modeling* steps (such segmentation, labeling and automatic feature tracking) turn the reference 3D data set into a high resolution standardized geometric *mesh model* with a unique, standardized topology. Since all faces in the database use the same standardized mesh designed specifically to meet the demand of high quality facial modeling, mathematical transformations such as statistical shape analysis, shape-based deformations and Finite Element (FEM) computations can be readily carried out.

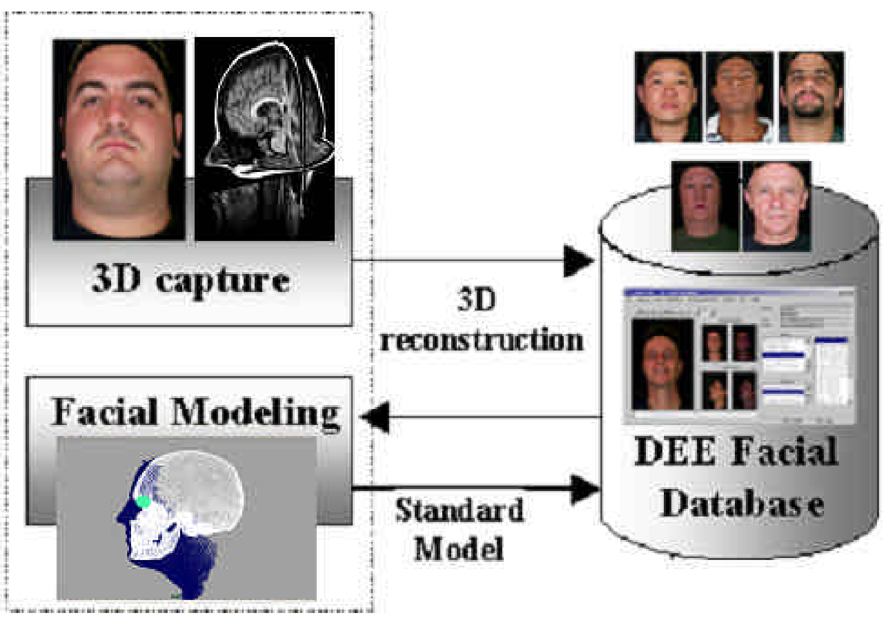

Fig 1. Overall block diagram of the facial modelling process for virtual plastic surgery.

4. PROCESSING MRI DATA

The MRI module is responsible for delivering the segmented skin surface and underlying tissue data for the subsequent 3D surface modeler and the visualizing unit. For initial processing of the raw data set we use an open-source software tool called *Slicer*[5] specifically developed for medical visualization and analysis. It contains advanced registration, segmentation, and quantification algorithms to assess volumetric medical data.

Figure 2. demonstrates the critical steps of how the input MRI data set is processed to obtain the segmented skin surface. The original sliced data set of the patient's head is shown left. Each pixel in the corresponding scans is labeled or classified as one belonging to the skin on the basis of its gray-scale value. Using *voxel* processing (i.e. 3D pixels) to segment all image slices representing different cross sections along the x,y, and z axes, respectively, the spatial location of skin elements can be determined (middle) . the output of this process produces the facial surface shown on the right. Multiple MRI scans of the same individual may be merged to get a single, high resolution surface. Separate texture images (i.e. digital photographs from multiple angles) are also recorded. This latter step serves the purpose of later projecting these photographs on the 3D surface and thereby creating a photo-real rendering of the patient.

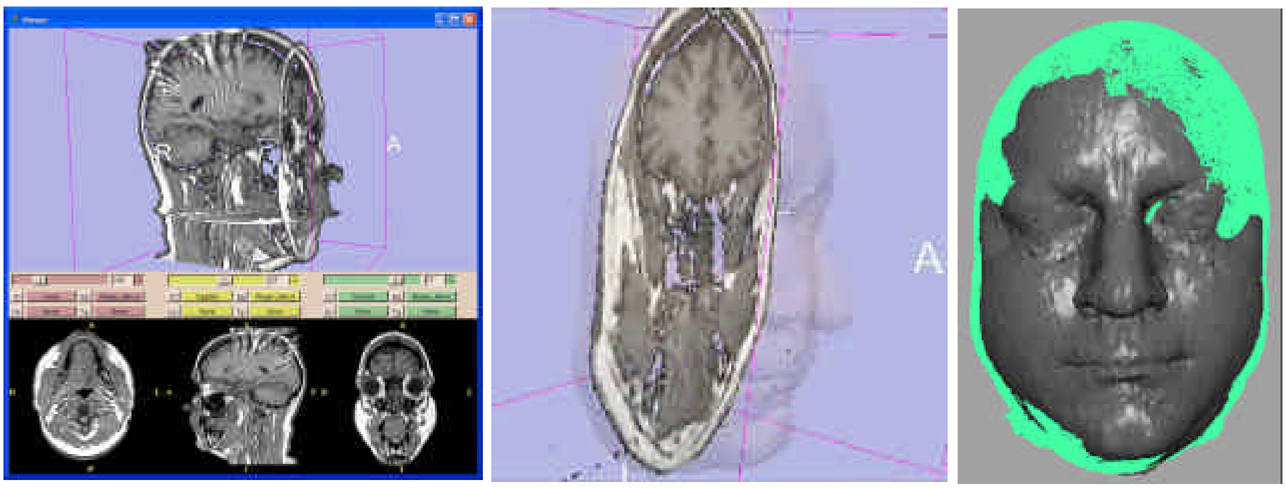

Fig. 2. Steps of segmenting MRI data to obtain a facial skin surface model (see text).

The segmentation technique we employed in this research may be used to obtain 3D surface models of any tissue structure including dermal layers, musculature and bone structure. For the purposes of this research, however, we primarily focused on obtaining only the facial surfaces of patients. At the next stage of processing this initial raw data representation is passed onto the 3D surface modeler unit to create a high resolution, fixed topology model.

5. 3D SURFACE MODELER

Having segmented the skin region from the MRI data set, we next convert this 3D point cloud information into a standardized head geometry. To help modeling and visualization it is during this step when we also place the eyes, teeth and skull into the model. This semi-automatic processing stage accepts the 3D surface data as provided by the MRI module or from an independent 3D facial scanner device. Figures 3 through 5 demonstrate various stages of the modeling process. The first step concerns adapting a low-resolution mask to the general shape of the input data set. Second, the first estimation of the high resolution facial model is generated using the mask points and a large and varied 3D facial database comprising of many head shapes. This iterative step finds an optimal set of deformation parameters that best approximate the mask surface as a combination of surface models. Once the algorithm converges and falls below the threshold of a predefined error rate a final "*snapping*" routine ensures that all points of the high resolution model lie on the facial surface. Finally, the skull, teeth and eyes (that may also be segmented from the MRI data or replaced with generic models) are placed and the photographs of the patient are projected onto the surface for esthetic reasons.

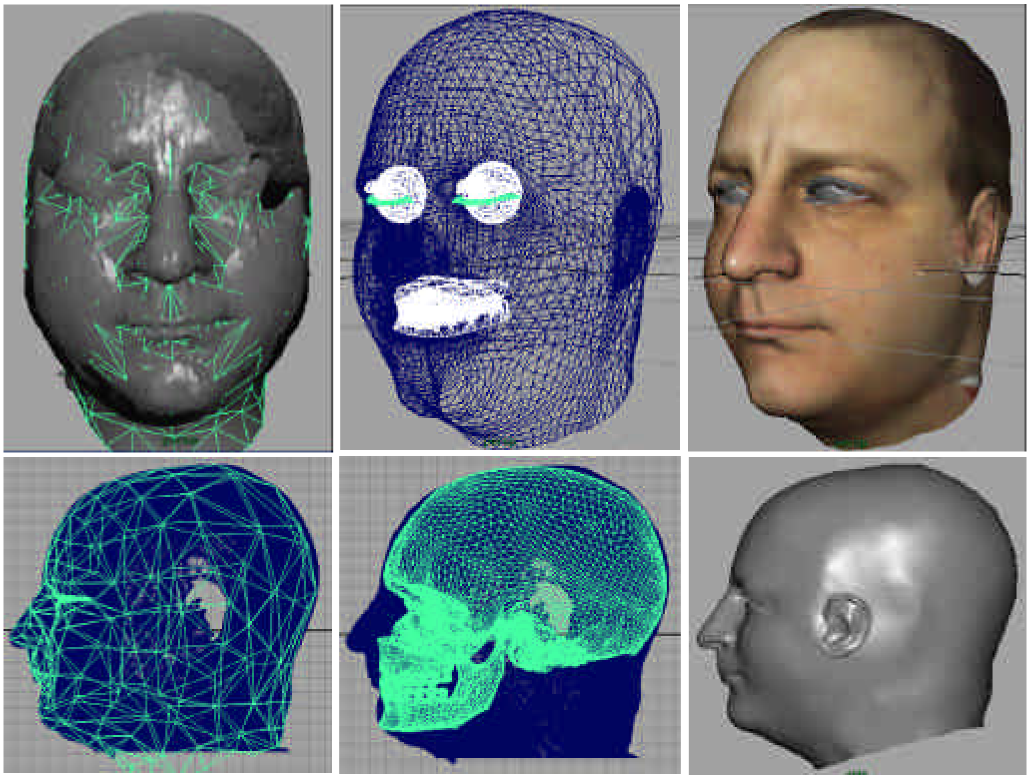

Fig. 3. Creating a high resolution facial model from segmented skin surface data (see text).

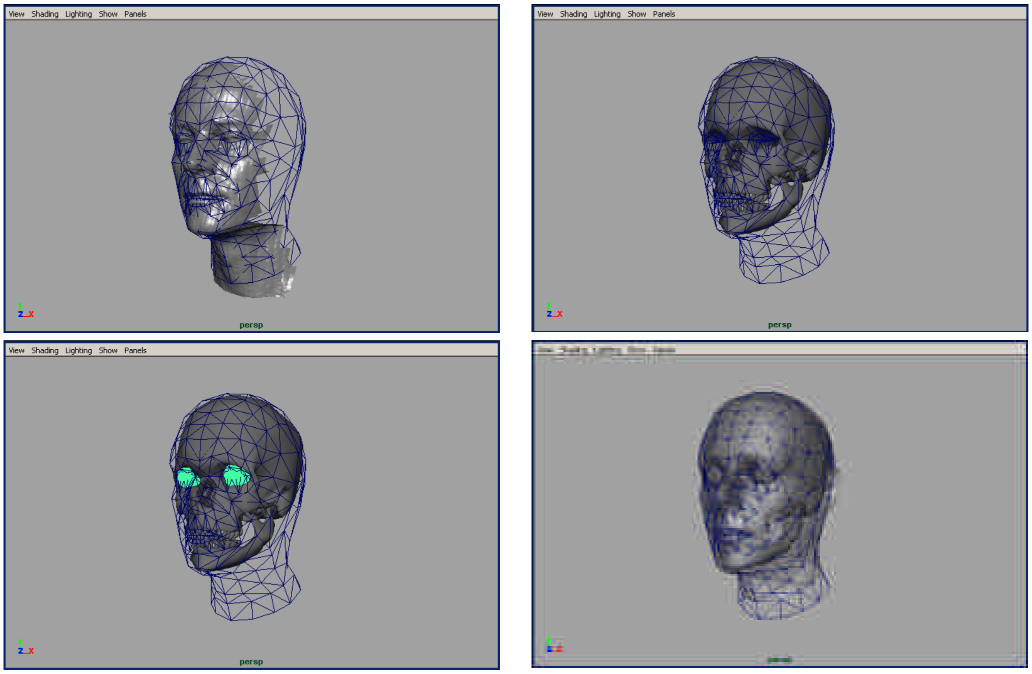

Fig. 4. Building a detailed facial model

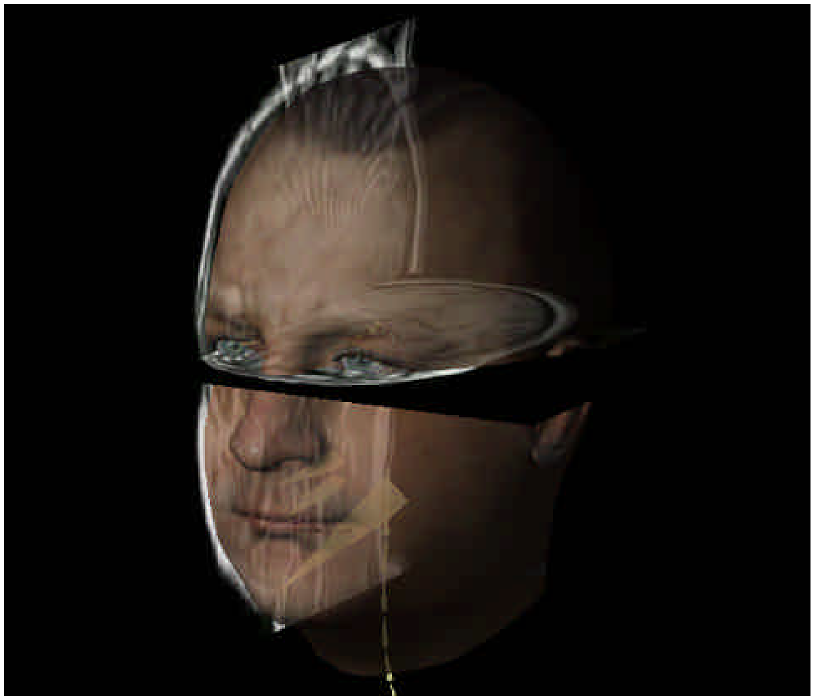

Fig. 5. Final 3D photo-realistic facial model with corresponding MRI scans as shown in the real-time visualization engine.

6. VIRTUAL PLASTIC SURGERY

The final output of the above modeling process is a 3D standardized face mesh that represents the patient's head in a photo-realistic manner. This textured head shape is now ready to be viewed, deformed, operated on and even animated in the real-time pre-surgery planning & visualization system.

One of the main advantages of deriving a standardized mesh geometry as opposed to using only the raw point cloud obtained from the MRI scan, is that it enables changing the shape of certain facial features as a function of the patient population already in the database. In other words, by means of mathematical analysis, one may modify for example the shape of the nose of a new patient using parametric data available from other patients. Specifically, the virtual surface deformations that take place in the real-time environment may be parameterized to reflect tissue properties as function of age, sex demographics, or even the specifics of a given implant. These constraints are used to limit the generic deformation space and consequently provide a better approximation of how the patient will look after the operation than when using other methodologies.

The photo-real quality of the 3D models opens up a unique opportunity for the patient to actively participate in the „design" phase of the operation as well. Using the 3D real-time deformation tools the doctor may interactively change the look of the pateint a feature that may possibly allow him or her to feel better about the operation.

For more complex surgical planning and simulation the standardized facial surface mesh can also be used to build a detailed finite element model (FEM) that capturs the physical characteristics of the underlying tissue deformations[6].

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7. CONCLUSION

In this paper we introduced a novel methodology to create highly realistic and accurate 3D facial models for the purpose of real-time digital plastic surgery, simulation and visualization. These models may be produced from patient specific MRI scans and/or 3D surface capture methods, such as a 3D camera, by means of an efficient modeling pipeline. Our solution employs a standardized generic head mesh to describe head shapes and facial deformations in a mathematical domain. During the past years we have developed a large and varied database of 3D faces that forms the foundation of shape-based facial feature design and transformation. The system we developed maybe used to design evaluate the aesthetics of digital facial modifications prior to plastic surgery, and/or carry out more complex surgical planning via finite element modeling.

8. REFERENCES

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