

# A Haptic System for Simulation and Planning of Plastic Surgeries

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## Abstract

In plastic surgery, there is a high need for preoperative visualisation of the surgical results. This is used for planning purposes and to show the patient what he or she will look like after the surgery. In plastic surgery, the last point is more important than in other surgical fields, because the aim of the intervention is to optimise the visual appearance of the patient.

There are existing simulation systems which are able to perform the task described above. Now it would be useful to have a planning system which gives the surgeon the possibility to manipulate a 3D-model of the patient interactively and adapt it to the wishes of the patient. This system should contain realistic tissue parameters like stiffness to allow the surgeon to interact with a virtual face as he does with a real one. It should be possible to feel bone structures and move the skin in a realistic manner. The deformed model should be usable for surgical planning, therefore the main tissue structures like skin, fat, muscle and bones should behave realistic. This paper will present a framework for such a surgical simulation system.

The focus of our work lies in the facial area. A patient is scanned using a spiral-CT with a slice thickness of 1.5 mm. After several image processing steps, we are generating surface models for the main structures like skin and bones. These surface models are the basis for our deformation system.

We are using the haptic device PHANToM™ for the haptic interaction with our surface model. The surgeon can use the stencil-like endeffector called “stylus” of the PHANToM™ to deform the surface structure of the model. By applying pressure, the surface is deformed by taking in account, that no underlying bone structure may be deformed. The tissue between bone and skin is marked as “to be removed” by the planing system. The other way around, the surgeon can pull the skin with the stylus and the planing system is inserting “tissue to be added” in the resulting gap. This tissue can be taken from other parts of the face, this is performed when moving fat from one space to another. It is also possible to add solid material to the bone structure, which will result in a different behaviour of the soft tissue model of the face. The different tissue structures are simulated using a fast spring-damper-model. The resulting “ADD”- and “REMOVE”-regions can be displayed separately.

By using this system, it's possible for the surgeon to plan his operation on a realistic 3D-model and to gather information about the surgical procedure. It is planned to add even more realistic tissue models to the system and add a second PHANToM™ for two handed manipulation of the surface model. Furthermore the “ADD”- and “REMOVE”-regions should be integrated in the original CT images for intraoperative fast access.

## **Introduction**

In plastic surgery, there is a high need for preoperative visualisation of the surgical results. Nowadays, the surgeon plans it's surgical procedures by touching and moving the skin in the affected regions. This is done before and during the surgery. Another tool are CT and MRI scans of the affected regions. The outcoming result of the surgery is not completely predictable, especially for the patient, and furthermore the times needed for a surgical intervention are lengthened because of the "online"-planning process.

A three dimensional planning system would be useful in several ways:

1. Planing of a surgery will not only depend on the experience of the surgeon.
2. A 3D-Visualisation will help in finding topological important body structures like bones and nerves.
3. Implants can be produced before the surgery.
4. Additional information, like risk regions, can be superimposed.
5. The patient can decide, whether he or she likes the predicted outcome of the intervention.

Point 1 is obvious: It is very difficult to predict the visible appearance of soft tissue structures because there are long term deformations of soft tissue which must be included in the planning process. This information about the long term behaviour of soft tissue is only implicit knowledge of the surgeon and good surgeons need many years of experience. It would be helpful to inexperienced surgeons to have the implicit knowledge implemented in the planning system.

A three dimensional visualisation of the regions of interest is helpful and many references can be found, for example in [Fujino 1998, Weingärtner 1998, Höhne 1999, Schiemann 1998].

The third point, the preoperative production of implants seems to be obvious, but it's not found in many surgical procedures. In plastic surgery, an implant, which is too big for the desired application, is moved under the skin, the visual appearance is checked by the surgeon and after this the implant will be removed and modified. This step will be

performed several times and is very time consuming.

The superimposition of additional information is an important point in computer based surgical planning. For example, it is possible to visualise risk regions of a body area, for example blood vessels or nerves, to plan the best access-path to an area of interest. A simulation system which includes risk potentials can be found in [Salb 1999a].

In plastic surgery, the last point is more important than in other surgical fields, because the aim of the intervention is to optimise the visual appearance of the patient. In most cases, the patient would like to know what he or she will look like after the intervention. In some cases there are different possible ways to achieve the functional result of the surgery (like optimal occlusion), which are resulting in different visual appearances of the patient.

Our concept for the planning system will not only include 3D visualisation, it will also be able to let the surgeon touch the virtual model and apply forces to it. This gives the surgeon the impression to touch and manipulate a real tissue structure. It will also be possible to feel the risk potential of an certain area to avoid damage to it when performing the real intervention [Salb 1999b]. This haptic interaction with 3D data sets gives the surgeon new ways for surgical planning.

In our work, we are concentrating on facial applications. Most of the concepts described in this paper should work in other surgical fields, too.

The paper is organised as follows. Section 2 presents an overview over the state of the art. In section 3 the methods used for the simulation system are described. Section 4 presents special topics for this system. Section 5 describes the sequent of a planing procedure. First results of this project will be described in section 6. A conclusion, and an overview over the future work is given in Section 7.

## **State of the art**

During the last years many simulation concepts have been presented which are partly developed to take over educational and training functions. Other systems are

dedicated to planning tasks but can be easily used for medical training as well as educational systems can be used for planning purposes.

A visualisation and simulation concept for interactive planning of cranio-facial operations is presented in [Keeve 1997]. The system enables the surgeon to specify manipulations interactively in patient-specific models based on radiographic image data. In [Weingärtner 1998] a system for pre-operative planning and education of surgeons is introduced. The scope of this work is a simulation of the temporomandibular joint based on a kinematic model. Functional and graphical models of the mastication muscles have been included in the model as well. Both systems are concentrating on the deformation of bone structures, the soft tissue will not be manipulated.

A training system for endoscopic surgery in the laparoscopic region is described in [Kuhn et. al. 1996]. This system, called the "Karlsruhe Endoscopic Surgery Trainer" is dedicated to indoctrinate medical students in minimal invasive surgery. A second approach for a virtual reality based simulation in the abdominal area is presented in [Bro-Nielsen et. al. 1998]. This simulation concept offers various virtual reality techniques to optimise the human-machine-interface. Both are interesting because of their soft tissue simulation systems.

In the knee area a simulation for arthroscopic knee surgery is being developed [Gibson et. al. 1997]. The system will combine real-time volume rendering with volumetric object representation and an haptic feedback.

Another area of interest for surgical simulation are eye diseases. In [Schill et. al. 1998] a biomechanical simulation concept is presented which is dedicated to indoctrinate eye surgeons to the removal of vitreous humour in the eye under pathological conditions. This publication also introduces the ChainMail-algorithm which can be used for soft tissue simulation.

Other planing systems, like the Perceptometer presented in [Coleman 1999] are based on 2D morphing systems which are applied to 2D photographs of the patient. A sample image of the Perceptometer is shown in figure 1.



Figure 1: Perceptometer: A 2D planing system

These systems can not show the 3D appearance and they are not considering the inner structures of the body.

## System Concept

Each surgical simulation system consists of several parts. Figure 2 shows an universal approach for the creation of medical simulations systems like it's presented in [Burgert 1998].

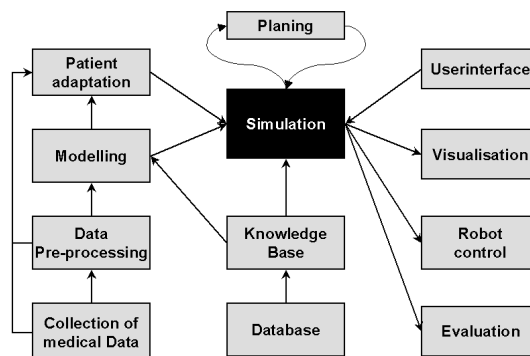


Figure 2: A general approach for medical simulation systems

In the system presented in this paper, the robot control will not be used. Furthermore, the tasks "patient adaptation" and "modelling" are done in one single step.

The collection of medical data is done using CT scans with a resolution of approximately [0.5 x 0.5 x 1.5] mm in [x, y, z]. It is also possible to use MR-images, the main goal is to extract the relevant body structures. For the following steps we need the possibility to see skin, bone, implants and soft tissue. In our first prototype we are working with just one class of soft tissue. The system should be enhanced to work with several different soft tissue structures like fat, skin and

muscle. The imaging techniques have to provide this information. To achieve this, we have to combine the advantages of the different imaging techniques by matching MRI and CT datasets. This can be done using the tools described in [Pokrandt 1996].

These images will undergo several image pre-processing steps to allow a segmentation of the relevant structures. Figure 3 shows the bone structures of a deformed face which is segmented using a simple threshold method. Other image pre-processing steps will include low level operations like filtering and higher level operations like the watershed algorithm, or 3D-region growing.



Figure 3: Bone structure of a real patient

The knowledge base contains the parameters of the soft tissue structures like stiffness and elasticity. Furthermore, the risk potentials which should be included in the haptic model are stored here, too. This concept allows a fast and patient specific storage of and access to the relevant datasets. In addition, it would be possible to store reference models like the "Visible Human" [NLM 1999] in the knowledge base because there are some body structures, e.g. nerves, which can't be seen in medical images.

The information in the knowledge base together with the pre-processed medical images are used for the modelling process. We have to distinguish between geometric modelling and functional modelling.

Geometric modelling means the 3D construction of models. These models are the ones to be visualised. For fast visualisation surface models are used. We are using a variation of the marching cubes algorithm [Cline et al., 1988] for surface generation. Because of the high number of triangles created we are applying triangle reducing algorithms to these models.

The functional modelling of the tissue structures depends on the material: Bone structures are considered as rigid bodies which can not be deformed. In special cases this assumption might be false but in our studies we haven't found any relevant occurrences of such cases. Soft tissue will be modelled in several ways: We will build a Finite Element Model of the soft tissue behaviour. This model will be used as reference model for the evaluation of the other tissue models. The aim of soft tissue modelling is to achieve a realistic and real-time capable model of skin, fat and muscle. None of the existing models like standart mass-spring-damper systems or FEM can provide this. Therefore we have to find a compromise between our real-time requirement and the realistic "touch and feel" of the surface. Several algorithms, like fast mass-spring systems or the ChainMail-algorithm [Gibson 1996] will be investigated and modified for this task. These models will need a parameterisation which will depend on patient specific data like his or her age.

The visualisation of the models will be performed by SGI workstations. These machines allow different presentation techniques: 2D-visualisation using a conventional display, stereoscopic display using shutter glasses and stereoscopic display using a head mounted display. In our system, all methods are used. The advantage of the conventional 2D presentation lies in the higher resolution and most users are used to it. The 3D-presentation techniques are giving a better impression of the models displayed. The visualisation system used in this project is part of a surgical training and simulation system [Salb et al. 2000]. For special purposes it might be useful to apply a texture to the geometric model. Several algorithms for this are presented in [Thalmann et al. 1998]

For the general user interface for our whole simulation system we decided to combine traditional devices like a keyboard or a mouse with 3D interface techniques given by

a space mouse or haptic interface devices. In this special case most of the interaction will be done using the PHANToM™-device. In our system we are using a “PHANToM Desktop” and up to two PHANToM 1.5 for two handed manipulation. Pictures of both devices can be seen in figure 4.



Figure 4: PHANToM™ 1.5 (left) and PHANToM™ Desktop (right)

Both devices have 6 degrees of freedom. The PHANToM™ 1.5 offers a bigger workspace, the Desktop version is much cheaper. Both allow exact measurement of the position of the stylus and they can give force feedback if a virtual object is touched. More information about the devices can be found in [SensAble 1999a, SensAble 1999b].

### Symmetry Consideration

The main goal of the presented system is the achievement of a “good looking” face. Therefore we have a need to define the term “good looking”.

With our system, we will plan “hard” cases for plastic surgery, e.g. people which had a major accident or illness. In such cases it is sufficient to achieve a symmetrical face. This is not true for cosmetic surgery because an “interesting” face has always little unsymmetrical areas. Figure 5 shows an image of a case to which our methods are applied. Only the symmetry calculations are concerned by this restriction to non-cosmetic plastic surgery, the haptic interaction will work in cosmetic surgery, too.

There are several levels on which symmetry calculations can be performed:

1. Single CT / MRI slices
2. Volumetric models (Stacks of slices)
3. Surface models
4. Based on high-level information (landmarks) in 2D and 3D



Figure 5: An unsymmetrical face

In single slices it is possible to apply simple mirroring techniques and subtract the left side of the face from the right side. The difficulty in this case is to find the correct mirroring axis. This simple approach can be used for a quick overview. It’s been used in one real surgery and has proved itself as being helpful.

The same calculations can be performed in volumetric datasets. In that case it is possible to correct errors which might come from a slope position of the patient in the CT scanner.

Surface models allow the consideration of additional information like curvature of the surface.

The consideration of high level information like landmarks is widely known in plastic surgery. [Grayson et al. 1988] are presenting a 3D enhancement of the widely used cephalogram. In that technique, several important points of the face are connected by lines. There are standard lengths for these lines and therefore it’s possible to compare the patient’s face with the normal values. Figure 6 shows a standart cephalogram of a 16 years old and the cephalogram of a patient.

The disadvantage of the cepahlogram is its restriction to surface points. Many interesting structure are inside the head and should be taken in account, too.

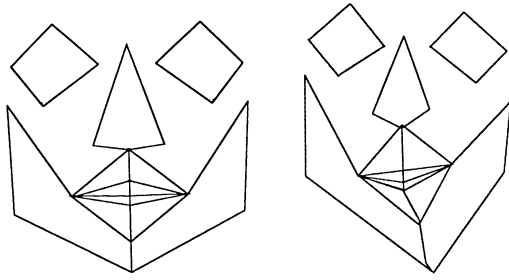


Figure 6: Cephalogram of a normal and a deformed face, from [Grayson et al. 1988]

## **The planing process**

As a first step the surgeon will start the automatic detection of unsymmetrical formed areas. These areas will be displayed together with the geometric model of the face. After the visual inspection of these areas, the surgeon starts the planning process by using the stencil like endeffector of the PHANToM™ to deform the surface structure of the model. Figure 7 shows the use of the system.

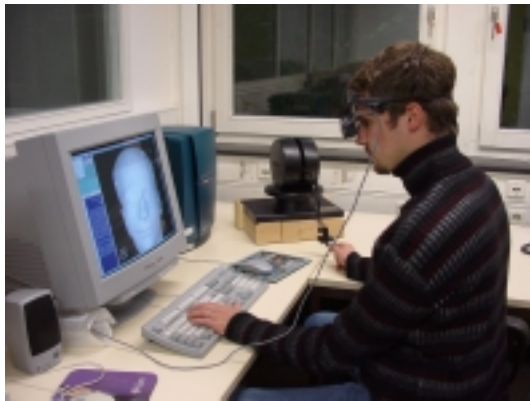


Figure 7: Example usage of the simulation system with PHANToM™

By applying pressure, the surface is deformed by taking in account, that no underlying bone structure may be deformed. The tissue between bone and skin is marked as “to be removed” by the planing system. The other way around the surgeon can pull the skin with the stylus and the planing system is inserting “tissue to be added” in the resulting gap. This tissue can be taken from other parts of the face. Both tasks can be guided by the system by applying forces according to the result of the symmetry calculations. Furthermore, risk regions, for example critical nerves, can apply counter-forces so that the surgeon is not allowed to touch this regions.

It is also possible to add solid material to the bone structure, which will result in a different behaviour of the soft tissue model of the face. The resulting “ADD”- and “REMOVE”-regions can be displayed separately. These information has to be provided at the surgical table to allow an intraoperative implementation of the planing process.

## **Results**

First results of this project are very promising:

The naive symmetry calculations described in the chapter above have been successfully used in a clinical example. The user interface has to be simplified so that these algorithms can be used in the clinical routine.

Our first tests on the haptic interaction with the soft tissue fields are showing the principle feasibility of our approach. The most difficult problem is the interaction with big volumetric datasets which require much computing power for visualisation and haptic feedback. We have to work on faster algorithms to perform this task.

## **Conclusion and future work**

In this paper we presented our existing approach for pre-operative simulation of plastic surgeries.

The general framework presented in this paper is used in many simulation systems. Our first results in the special topics of plastic surgery have been promising.

The scope of our future work will be on the realisation of the missing parts of our approach. The most important task is to find the best algorithm for real time simulation of soft tissue. The simulation of different tissue structures is a further goal of our future work. The risk regions and potentials have to be included in the system. Also the existing simulation system has to be improved in the fields of real-time performance and visualisation techniques. Therefore it would be helpful to use adaptive approximation techniques for the surface models and the haptic models, too.

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