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Chapter 1

Introduction

This master thesis is in context of a cooperation between the Visual Computing Institute at RWTH Aachen University and the Department of Oral and Maxillofacial Surgery (OMFS) at University Hospital RWTH Aachen. The main goal of this thesis is to create a pre-operative assistance software for oral and maxillofacial surgery. Additionaly, results of the pre-operative planning will be used intra-operatively to provide assistance via Augmented Reality (AR). Dies wird im rahmen einer weiter master thesis entwickelt

This thesis simulates a virtual operating room for maxillofacial surgeons in Virtual Reality (VR). Workflows and procedures will be strongly oriented by clinical practices of the oral and maxillofacial department in UHA.

Through the well established field of medical imaging, surgeons can get a very detailed view of patient's specific anatomy and pathology today. It is an essential part of preparing for surgery. Most common medical 3D image acquisition techniques (not exlusive) are computed tomography (CT), cone-beam computed tomography (CBCT) and magnetic resonance imaging (MRI). CT / CBCT makes use of x-ray measurements from different angles to produce cross-sectional (tomographic) "slices" of the scanned site. With this technique, bone structure and soft tissue can be displayed in medical imaging. The disadvantage of these techniques is the exposure to carcinogenic x-rays. In MRI, strong magnetic fields, magnetic field gradients and ultrasound are used to create tomography of the patients soft tissue. Since this technique makes use of hydrogen atoms, which is predominantly present in patient's soft tissue, this bone structure is imaged not as good. However, when studying mandibular joints for example, MRI is able to outperform CT (TODO zitat). The most recent one, CBCT, lowers radiation dosage of traditional CT and continually contributes to the accuracy of diagnostic tasks of the maxillofacial region. It is able to produce images with isotropic submillimeter spatial resolution, which is ideally suited for dedicated maxillofacial CT scans. The radiation dosage of CBCT is less than traditional CT and thus helps optimize health-to-risk ratio [1].

As discussed, there are a variety of ways to acquire medical imaging. However, the displaying methods of 3D medical imaging data is very limited for clinicians. After acquiring raw data via mentioned techniques, volume images are generated. Generally, data is reconstruced in three planes (axial, sagittal and coronal). Each plane is represented in ”slices” which are .

Even though three-dimensional objects are being analysed and also generated, they are viewed in a two-dimensional format on conventional computer screens. The generated slices from medical imaging are viewed in the mentioned planes to get volumentric understanding of patient’s underlying anatomy and pathalogy. Because of the two-dimensional nature of slices, the spatial perception of the viewed image is solely based on the resolution of slices in combination with the viewers experience. Another problem with slices is that they are generally unsegmented and it is up to the viewer of the medical imaging to interpret them correctly. Generally, this will not be a problem for trained clinicians. Planned procedures are hard to visualize and discuss with patients.

Before medical procedures, there are a number of ways in which surgeons can prepare. We will discuss each of them based on how well it is suited for the individuality of patients, the realism and the cost (time and resources) associated in preparing for the operation.

- Simulation based on the surgeons imagination
  - Depends on the experience and spatial imagination of the surgeon
  - Can be very patient specific
  - Low realism
  - Cost based on experience and skill of surgeon
- Modeloperation on 3D-printed models
  - Very patient specific
  - High realism
  - Very costly
- Papersimulation
  - Little patient specific
  - Low realism
  - Low cost
- Operational textbooks / videos
  - Not patient specific
  - Low to medium realism

- Low cost

Each of theses techniques (except simulation based on 3D models, which is very costly) has major disadvantages. They all cannot reflect the underlying specific anatomy and pathology of the patient and lack spatial perception. The process of preparing for the operation is based solely on the experience of the surgeon, and hence can take a lot of time to properly prepare, especially for first time operations. Also, the 3D medical imaging, which gets viewed on 2D computer screens, has to be translated back onto the patient via the surgeons imaginative power. As discussed, there does not seem to be a trivial technique which all surgeons should use. Surgeons will often use a combination of mentioned techniques to get the best results. In the preparation stage, it is crucial that the operator gets a well defined mental image by medical imaging data of the patient's anatomy and pathology.

This thesis aims to improve medical imaging and pre operational planning by using a modern approach with virtual reality. By using acquired 3D medical imaging in a virtual reality application, we hope to provide a very patient specific, highly realistic and only moderately costly technique with which surgeons can prepare for operations.

We aim to achieve the following advantages over conventional methods:

- Important procedures can be simulated
- Faster preparation
- Patient anatomy and pathology specific
- X-ray vision through tissue for 3D spatial perception
- Assign structures to each other

Especially the imaging of voluminous objects is demanding mentally and this thesis hopes to eliminate this problem completely by providing realistic medical imaging in virtual reality. To provide a useful preparational tool, it is critical that we can simulate individual operation steps. Planned steps will be storable in a format in which they can be loaded and viewed in both the virtual and augmented reality applications bi-directionally. By planning the operational steps in virtual reality, planned procedures can easily be shown to other staff involved. Naturally, it will be of uttermost importance that we have medical equipment and an appropriate virtual environment recreated as close to reality as possible.

Chapter 2

Related Work

A key part of this thesis is to advance the area of visualisation of medical imaging. Even though techniques exist, operations are still planned on two-dimensional images of three-dimensional surgical sites. Since 3D imaging is still an unconventional area, there does not exist much research in the oral and maxillofacial surgery. In 2.1, we will take a look at efforts made in the area of three-dimensional treatment planning in orthognathic surgery. Differences and possible advantages and disadvantages towards the conventional techniques will be thoroughly discussed.

2.1 Three-Dimensional Treatment Planning of Orthognathic Surgery

To get a first insight into effectiveness of three-dimensional treatment planning, we will discuss an approach for orthognatic surgery. Medical imaging was aquired by cone-beam computed tomography (CBCT), which is one of the techniques used in UHA. In this thesis hoewever, a number of different techniques are combined to give best results.

Swennen et al. discuss several improvements for three-dimensional treatment planning over conventional methods. The main benefits occur in the following areas:

- Diagnosis of Patient
- Treatment Planning
- Treatment Planning Communication

- Treatment Outcome Evaluation

A combined approach of clincal examination together with 3D inspection of the patient has an unprecedented potential toward the diagnosis of the patient with a maxillofacial deformity [2] by providing a virtual inspection of the patient's anatomy. Both volume (bone) and surface (skin) rendering were used for an in-depth inspection. The main benefit of the 3D approach for treatment planning is that the cinician has more information about the patients underlying anatomy. The routine clinical use of 3D virtual planning also showed that the used 3D soft-tissue simulation was unreliable. In spite of some disadvantages and problems with 3D virtual planning, a number of major advantages were experienced using 3D virtual planning compared to conventional orthognathic surgery treatment planning. 3D virtual planning solves one of the major disadvantages of conventional treatment planning. Conventionally, treatment planning is a complicated procedure involving a number of steps which are difficult to communicate to the patient. Three-dimensional treatment planning however can be a powerful communication tool since treatment plans can be visualized and shown to the patient:

- Send plan via electronic mail to orthodontist to discuss the patient's treatment
- Discuss with patient, optimize and individualize to patient's needs
- Excellent communication tool to teach contemporary treatment of maxillofacial deformity to residents in orthodontics and oral and maxillofacial surgery
- Easily communicate the 3D virtual treatment plan of a difficult case to another colleague worldwide with more experience
- Electronic learning and electronic teaching

Swennen et al. mention how one of the biggest disadvantage of this technology, having a powerful enough workstation to power the software, will soon be eliminated. They also mention how the soft tissue similation has to be improved a lot. Finally, the treatment outcome evaluation can easily be done by comparing the 3D treatment plan to CBCT scans after the procedure was done. It is however important to wait an appropriate amount of time (3 to 6 weeks) after the procedure was done. The first two weeks should be avoided because of post operative swelling and buccal mucosa, which can cause occlusion. In contrast, bony consolidation appears at 6 weeks postoperatively and will no longer allow for proper virtual identification of the osteotomy lines. CBCT should also be done 6 to 12 months and 2 years after the procedure to evaluate soft-tissue response and the long term treatment outcome.

Overall, it appears to be the natural conclusion that 3D virtual treatment planning has major advantages over conventional methods, visualisation and communication being the most beneficial for pre- and post-operative procedures. In his thesis, Swennen et al. mentions how both image acquisition systems and 3D virtual planning software must become user-friendly, easily accessible, and available at a relatively low cost [2] to enable a major paradigm shift in clincal surgery. The technology could be extremely beneficial for all clinics if the adoption rate is high enough. In this thesis, we will use commercially available hard- and software which is relatively low cost and highly available. Even though three-dimensional treatment planning has benefits over conventional methods, models are still viewed on a non stereoscopic two-dimensional computer screen. By moving from computer screens to virtual reality displays, we hope to improve the mentioned benefits of three-dimensional planning even more, while giving an easily adoptable interface to plan treatments.

CHAPTER 3

SCOPE OF THE THESIS

This chapter outlines the requirements of this thesis based on the challenges mentioned in Chapter 1. It will also outline a broad monthly schedule of the thesis at the end. As this thesis is a cooperation between two endeveours we will also clarify in which way those applications need to communicate and how we are planning to achieve this.

3.1 Features of the Virtual Reality Application

As this thesis is a completely new project we will need to build an architecture from the ground up. Since the main focus of this thesis is visualisation and planning, we aim to provide a realistic feeling experience without being unnecessarily complex. This means that while our main goal is surgery simulation, we do not focus on realistic physical behaviour of tissue. The following data will be kindly provided by the OMFS in UHA:

- Imaging acquisition
  - CT/CBCT scans, MRI scans...
  - provided by the UHA
- Image processing
  - Apply techniques to segment tissue from scans
  - Create three-dimensional objects from segmented data
  - Export data into conventional three-dimensional objects which can be used in the application

Furthermore, following key components will be designed and developed for this thesis to give an immersive experience:

- Virtual operating room
  - Based on real locations in the UHA
  - If possible, designed via photogrammetry
- Provide an interaction system where the user can:
  - Freely move around
  - Interact with virtual model of patient:
    * Magnify and reset to original
    * Project another copy of the initial model for comparison
    * Set cutting planes
    * Mirror at symmetry line
    * Simulate cuts including depth by drawing
    * Measuring of the following attributes:
      · distance between two points
      · surface / volume area
      · angle
    * Transparancy slider for segmented tissue
    * Select which tissue to view
  - Grab surgical instruments
  - Use instruments for intended operational procedures (drilling, sawing. . .)
  - Start, undo, save recording movements of currently selected instrument
  - Start screen capture (Photo, Video)
- Surgical Instruments and materials
  - Create realistic virtual objects from real physical instruments and materials which are used in the oral and maxillofacial department of the UHA
  - Mechanism to plan and view procedures in relation to the patient including:
    * Angle of the instrument
    * Movements including direction of the instrument
    * Depth of the instrument if patient was penetrated
    * Markings on the patient
    * Inform if critical tissue was penetrated
  - Mechanism to start, stop, redo recordings of procedures for each instrument
- Provide an interface to the augmented reality application:
  - The user should be able to view all necessary patient data
  - The user should be able to view screen captures
  - The user should be able to load planned procedures in both applications by using an agreed format

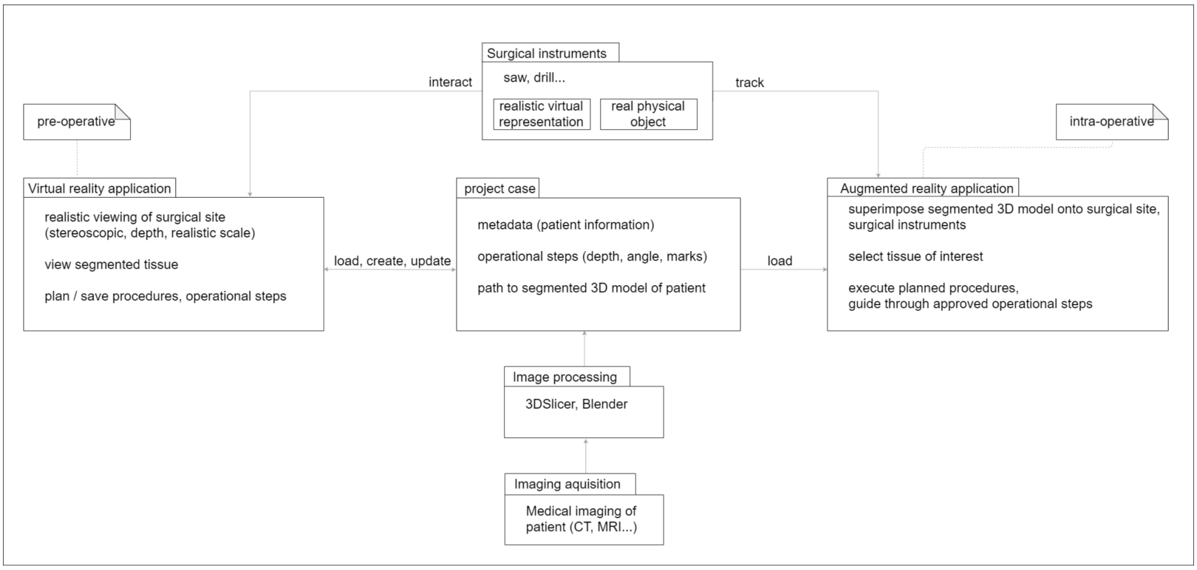

Figure 3.1: A simplistic view of the architecture.

The first step in realizing these requirements is to develop a software architecture with an interface to the augmented reality application in mind. Since this is a bi-directional data exchange which does not need to be real time, one obvious approach would be to use a simple object notation language such as JSON. Different options will be explored and decided upon in the beginning phase of the thesis. However, it is import that we do not have to rely on each other to develop an interface. To accomplish this, we will agree upon a simple interface before starting the projects. Hence, we will be able to develop the applications completely independant of each other, even though the applications are linked.

After deciding on a software architecture, the next step is to create a virtual operating room and first surgical instruments. The operation room will be designed after real operation rooms inside of the UHA. A photogrammetry approach will be evaluated in the hope to give the most realistic experience as possible for surgeons. Virtual objects will be combined with a scan of the real world to give an interactive and immersive experience. After the operating room, the focus will be on developing a traversing mechanism which allows for free exploration of the operating room. Since operating rooms are not too large in general, it should be possible to traverse them in room-scale VR. However, a teleport function will be added for convenience. The surgical instruments will either be created in a 3D modelling software or exported in a similar way to how we obtain the segmented patient models from medical imaging. The full functionality of the instruments will be developed in a later stage, since we will first work on the more important planning tools.

The planning tools will be the most critical part of the thesis, since they have to behave as expected. There will be a mix of planning tools which are represented by virtual surgical instruments and basic features which will be mostly visualisation assistance. At this stage, it will be crucial that the UI is as intuitive as possible and does not distract in any way. Improving the UI however will be a continious effort throughout the thesis, and will hopefully become as intuitive and assisting as possible.

Each of the surgical instruments will have its own planning operations which can be recorded and saved. Since at this stage, the architecture and format will already be decided, there should not be too much to worry about when implementing this feature.

There are currently no plans to hold a user study, however an expert review by working surgeons is planned to evaluate the usability and percieved realism of the tool. Additionally, a small questionnaire will be used after surgery to determine if the new tool is prefered over conventional methods.

There are also possible optional features, such as an additional tool to view dicom data directly, which can be included in the scope of the thesis but will be decided upon during the development phase of the thesis and will be dependent on the progression of the core features of the tool.

As of now, a basic prototype is already developed to showcase some of the planned functionality of the application.

3.2 Schedule

The written part of the thesis will be worked on continuously throughout the whole six months period of the thesis, either in form of notes or directly written passages. What follows is a broad monthly schedule for the thesis:

December: Designing a software architecture to allow the implementation of the requirements mentioned in section 3.1 and designing the structure of the ”project cases” to save and load planned procedues.

January: Start of the development phase of the thesis, beginning with implementing the a basic interaction system in which users can navigate and interact with objects. This is important as a first step so that we can fully concentrate on the planning tools and the realistic operating room afterwards.

February: Designing and implementing the virtual operating room and surgical instruments. Since an interaction system is already in place, the tools will already be interactable and base functionality provided.

March / April: Implement planning operations (and save/load) and functionality for intended use of the surgical instruments (drill, saw...). As mentioned in section 3.1, it will be not important to have complex physics, but the necessary functionality of the instruments has to be implemented so that they are useful as planning tools.

May: Finish the written part of the thesis as well as giving the final presentation.

Bibliography

[1] S. C. White and M. J. Pharoah, “The evolution and application of dental maxillofacial imaging modalities,” *Dental Clinics of North America*, vol. 52, no. 4, pp. 689 – 705, 2008. Contemporary Dental and Maxillofacial Imaging.

[2] G. R. Swennen, W. Mollemans, and F. Schutyser, “Three-dimensional treatment planning of orthognathic surgery in the era of virtual imaging,” *Journal of oral and maxillofacial surgery*, vol. 67, no. 10, pp. 2080–2092, 2009.