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A Mobile Augmented Reality Application to Improve Patient Education in Urology

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Abstract In urology, conveying information about pathology and treatment to the patient often proves to be difficult because the concerned organs are not visible. In order to improve the situation, this thesis aims to develop a tool for simple knowledge transfer between physician and patient. By combining an augmented reality (AR) application on a tablet computer with a 3D print of a prostate, details about pathologies and possible treatments are conveyed in a simple to understand manner. The application supports two different interaction paradigms - touch based and with virtual buttons that are printed on paper - that are being compared in a user study (n=11).

The study aimed at evaluating the usability and the intuitive use. Completion of the given tasks was done faster on the display ($\lambda : 120s, \sigma = 33s$) vs. the virtual buttons ($\lambda : 253s, \sigma = 82s$). The touch-display paradigm scored 4.4 out of 5 in the QUESI questionnaire (2.95 for VB) and 86 out of 105 (vs. 74 VB) in the ISONORM questionnaire. One-tailed, paired t-tests were conducted on the mean scores per questionnaire on a per-user with $\alpha = 0.05$. The resulting p-values 0.0045 for ISONORM and 0.003 for QUESI both show a statistically significant difference. The results show that the display based paradigm is less error prone and, due to a more familiar interaction scheme, the preferred solution amongst participants.

Abstrakt In der Urologie erweist sich Wissenstransfer bezüglich Erkrankung und möglicher Therapie als schwierig, da die betroffenen Organe nicht äusserlich sichtbar sind. Um diesen Zustand zu verbessern zielt diese Masterarbeit darauf ab, ein Werkzeug für einfacheren Wissenstransfer zwischen Arzt und Patient zu entwickeln. Durch die Kombination einer Augmented Reality (AR) Applikation auf einem tragbaren Tabletcomputer mit einem 3D-gedruckten Modell einer Prostata, werden Informationen über den Zustand des Patienten und mögliche Therapien auf einfache und verständliche Art und Weise übermittelt. Die Applikation nutzt zweierlei Bedienparadigmen - via Touch-Display bzw. via auf ein Papier gedruckte virtuelle Buttons (VB). Diese Bedienparadigmen werden in einer Nutzerstudie (n=11) verglichen. Die Studie zielt auf die Usability bzw. die intuitive Nutzbarkeit ab. Die gestellten Aufgaben wurden mit dem Touch-Display schneller bearbeitet: $\lambda : 120s, \sigma = 33s$ bzw. $\lambda : 253s, \sigma = 82s$ mit VB. Das Touch-Display Paradigma erzielte 4.4 von 5 Punkten im QUESI Fragebogen (2.95 mit VB) und 86 von 105 (vs 74 VB) im ISONORM Fragebogen. Einseit-

ige, gepaarte t-Tests wurden mit den Mittelwerten der Antworten der Fragebogen pro Teilnehmer durchgeführt. Bei $\alpha = 0.05$ und resultierenden p-Werten von 0.0045 für ISONORM bzw. 0.003 für QUESI zeigen einen statistisch signifikanten Unterschied. Die Resultate zeigen, dass Nutzer aufgrund der weniger fehleranfälligen und bereits bekannten Interaktionsweise die Touch-Display Variante bevorzugen.

Statutory declaration

I hereby declare that this thesis is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used, they have been marked. The work has not been presented in the same or a similar form to any other examination board and has not been made public.

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbstständig und nur unter Verwendung der angegebenen Quellen und Hilfsmittel angefertigt habe. Die aus fremden Quellen direkt oder indirekt übernommenen Stellen sind als solche kenntlich gemacht. Alle weiteren Bilder und Skizzen wurden selbst erstellt und nicht aus anderen Quellen entnommen.

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Magdeburg, 25th October 2016

(Name, Last Name)

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1 Introduction

Modern medical knowledge is a vast field, comprising numerous areas of expertise, each of which has their own specialities and specialists. Providing insight and sharing knowledge about pathologies and illnesses with patients, mostly laymen, thus proves to be difficult. This is worse so if the organ or area of interest is situated within the body. Patient education by the physician or other medical personnel is especially important in serious situations. Understanding the medical status quo, the prognosis and suggested diagnosis is paramount for a patient to participate in care [35]. For patients, an accurate understanding is an important factor to give informed consent and, furthermore, to make an informed choice.. It is a necessary condition for the patient to negotiate effectively about tests or treatments [31]. Kaplan et al. [28] show that patients, who actively take part in the decision finding process of care, are more satisfied. This active role even improves the biological outcome of the administered therapy.

Urology is the medical field of diagnostics and therapy of the urinary tract and the sexual organs of both male and female patients. In this sub field, the current way to approach a patient with information, updates or explanations towards their medical situation, the doctor sits down with them. Using pen and paper or two-dimensional slices from imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), or ultrasound (US) they try to communicate the case to the patient. Reading the information displayed here however, requires years of medical school and training in the urology sub field. Nevertheless, the conversation often fails to make patients fully aware about their state, possible interventions and their risks or safeties. Furthermore, patient education is expensive in terms of money and time. On the other hand, it is one of the most important tasks of the physician as 25% of office time is spent on patient counselling [29].

In recent years, the mobile technology in hand held devices has made big leaps, both in terms of computational power and in user friendliness. Furthermore, a technology known by the term “Augmented Reality” (AR, see chapter 2.1 below) has made its way in the hands of end users. Augmented reality, as the term implies, enhances the world we see by means of a camera, a computing unit, and a display. Combining AR with mobile handsets and applying them to medical issues allows an easy exchange of information, plus a visual representation of not only organs, but - depending on the case - even of the procedure. This is especially helpful for invasive therapies [19]. Augmented reality in healthcare is a bit of a novelty in medical education, but is already being applied in medical training [68]. Research in doctor-patient education vs. computer-patient education by Keulers et al. [29] indicates that computer education by an educational software, without additional doctor counselling might be able to substitute personal education.

1.1 Aim of the Thesis

To improve patient care in urology, a combination of 3D printing and augmented reality is presented. Instead of scrolling through slice after slice in case of imaging modalities, or a really simplified 2D image on a sheet of paper, medical staff can be empowered to explain pathologies utilizing the more modern AR technology. Lesions or tumours, surrounding anatomical structures, and applicable therapies can be shown, explained to and discussed with the patient on a more realistic model. This model can be modified or modify itself through interaction. For instance, a response to a virtual example treatment could be simulated, i.e. a focal ablation, where a tumour slowly disappears when heated by focussed ultrasound.

This thesis project therefore aims to develop an iPad application that utilizes the devices camera, display and touch interaction. The application augments a 3D-printed model of a prostate with the urethra, a lesion / tumour and surrounding anatomical structures. These augmentations can be interacted with by means of touching the display and by interacting with augmented buttons. Additionally, the software is being tested for acceptance and usability by means of questionnaires and interviews.

There are similar solutions where augmented reality aids in patient care. However, those are aimed at assisting physicians or surgeons during a procedure [16, 27, 67].

The overall goal of the project is to aid in the communication between medical personnel and patients by helping them understand the procedures and thus enable them to make a well-informed decision with respect to treatment.

1.2 Structure of the Thesis

This thesis will be structured as follows:

Chapter 2 - Fundamentals The second chapter will explain the fundamentals of augmented reality and the current state of the technology. It includes a definition of the term and conveys the technological requirements and different existing implementations. Furthermore, a short primer of urology and prostate cancer is provided. Different applications of augmented reality towards medicine are presented, as well as other fields in which AR has proven to be helpful.

Chapter 3 - Development Deriving from the requirement analysis at the beginning of chapter three, the application concept is introduced. The concept will be shown and thoroughly explained, including a proposed work space. Additional content in this chapter will be the 3D-printed model, the working prototype and its iterations.

Chapter 4 - Evaluation Here, the software from the previous chapter will be evaluated regarding its user acceptance and usability. Using standardized questionnaires (QUESI, ISO 9241-110), the application is evaluated; in cooperation with the targeted end-users (physicians) at Universitätsklinikum Magdeburg. Results of the user studies are evaluated and discussed.

Chapter 5 - Conclusion and Future Work To conclude the project, the last chapter provides and discusses the gained insights and will further give an outlook on how the project might be continued in terms of features, stability and usability.

2 Fundamentals

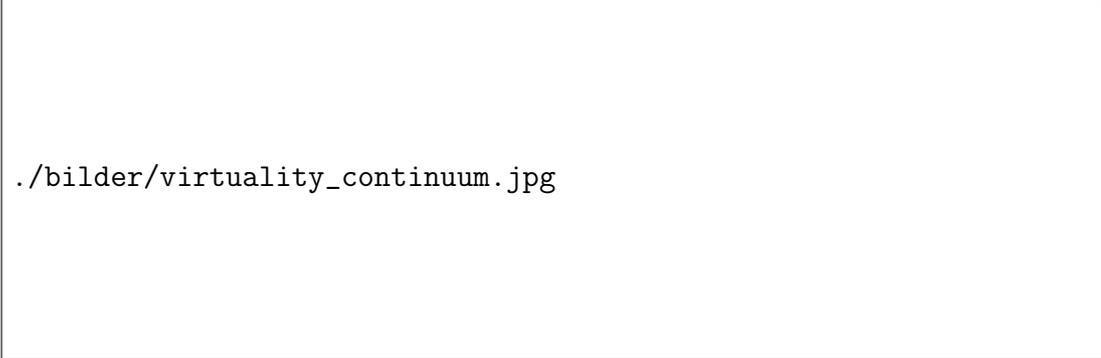
2.1 Augmented Reality

2.1.1 Definition of Augmented Reality

Augmented Reality (to augment, lat. *augmentare*: to improve, to supplement, to enhance) is the enrichment of the perceived reality by means of artificial virtual content [15]. According to Marcus Tönnis [61], Augmented Reality is the logical advance of Virtual Reality (VR). Azuma et al. [4] and Kipper [30] describe AR as more of a variation of VR than a development of it. Whilst immersed in the VR world, the user is not able to see the real world, whereas in AR the actual, surrounding reality of the user is enhanced by three dimensional, virtual elements. The most commonly used paradigm to describe AR was defined by Azuma, who formulated in 1997 that, in AR, added elements or characters are three-dimensionally registered and their superimposition on our reality has to happen in real time [4]. Azuma further states that AR may be defined as “the middle ground” between VR and telepresence (the completely real environment). The statement coincides with the definition of a continuum between reality and virtual world by Milgram et al. [41].

Figure 2.1 shows the virtuality continuum, also known as mixed reality (MR). Although AR and MR are often used as synonyms, MR actually describes the continuum depicted here. It spans between telepresence and VR, and can be read as such: As long as the portion of reality outweighs the augmented parts, one speaks of AR. Otherwise, the environment is referred to as augmented virtuality.

AR is usually used to enhance the visual sense, although it can technically be used to enhance all five senses. Digital information, such as still images, audio,



./bilder/virtuality_continuum.jpg

Figure 2.1: The Virtual Reality Continuum, cmp. [41].

and even haptic sensation is overlaid on the natural environment in real time. Therefore, the environment is rather supplemented (hence: augmented) than replaced, as it would happen in VR. In order for AR to be considered “true”, three characteristics have to be present [4, 30]:

1. Combination of real and virtual information.
2. Interactive, in real time.
3. operated and used in three dimensional environment.

As a combination of several technologies to bring information into perception, AR is a huge field of research and a vision of future computing.

However, even though there are lots of applicable fields (see chapter 2.4) and examples, some seemingly AR applications cannot be considered as AR. For instance, CGI may easily be mistaken as augmented reality.

Augmented Reality may also be confused with “visual searching”, a technique that uses computer vision to identify objects, e.g. using a smart phone’s camera module. Although it may begin with a recognition algorithm of some sort, it does not fulfil Azumas criteria for AR applications.

Alan B. Craig [13] describes AR as a medium. He argues that the type of media must be considered when engaging with it, as different senses may be used during the engagement, even though it is currently a primarily visual medium. Azuma already states that, to be considered AR, the application must be interactive. There is little sense to watching media or listening to it, but one must *engage* with it. As a participant in AR, one must be able to interact with information

that has been added by means of AR. This interaction must take place in the same physical world as one would normally act in. Only with that requirement satisfied, a system may be considered AR.

2.1.2 Common Augmented Reality Techniques

There are a few basic types of AR. One thing they all have in common: they are based on a **perspectively correct** projection of virtual content into the environment (scene).

The for this thesis most important type is the “Magic Lens”, hence the name of the application: UroMagicLens. Magic lenses were first introduced by Bier et al., who describe widgets that can be added on an additional layer between an application and a traditional cursor [6]. These so called widgets may make use of visual filters - the magic lens filters - to modify the way objects are being presented to reveal additional information; and to enhance the data of interest and/or suppress distracting information. 22 years later, the transparent sheet of glass is now a tablet computer with a camera in the back of the device, and the cursor is replaced by the users finger(s). The magic lens is described by Dörner et al. [15] and Tegtmeier [59] as **video see-through AR**. The required constellation, that is, the same viewing direction and angle of camera and view port (the display) to achieve this effect, is already given by the way camera and display are positioned in relation to each other. If that would not be the case, a decoupling between the users real environment and the observed augmented environment would be the consequence. However, as a hand held device, tablet computers offer the required alignment of the position and orientation of the camera and display. This is not true for the actual user, since one may not look directly at the display. Figure 2.2 showcases this.

In addition to video se-through AR, two more pronunciations to AR exist. Since they are not in the scope of this project, they are just presented shortly:

Optical See-Through AR

Optical see-through does not require the environment to be filmed, but superimposes virtual content on a semi-transparent display, through which the user can still observe their surroundings. Typical devices for optical



Figure 2.2: Different viewing angles from user and camera in hand held AR devices / software, cmp. [15].

see-through AR are head mounted displays (HMD) [15, 59]. Prominent examples for this class of devices are Google Glass¹ and Microsoft Hololens², see Fig. 2.3. These wearable displays are sometimes also called video eye wear, video goggles, or personal media viewers. Their design typically features either one or two miniaturized video displays with lenses and semi-transparent mirrors embedded in a pair of glasses [30]. In order to fit the perspective of the real environment with the augmented perspective, the observers point of view in relation to the display must be known.

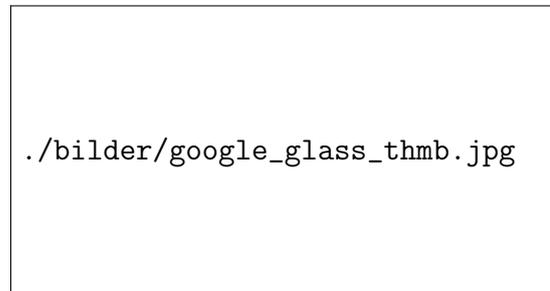
Projection based AR

Projection based augmented reality does not make use of displays. Instead, it uses objects within the real world to project digital content and is thus a form of spatial AR. Projection based AR is limited to manipulation of surfaces in terms of colour or structure. One can imagine the room behind a wall being projected onto that wall, e.g. for planning the merging of two adjacent bedrooms [15]. This kind of augmented reality is called spatial augmented reality (SAR); it utilizes video projectors and holograms

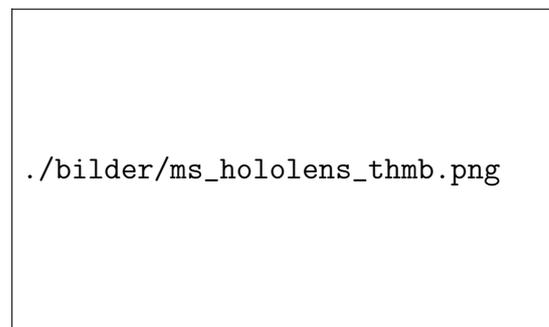
¹<https://www.google.com/glass/start>

²<https://www.microsoft.com/microsoft-hololens/en-us>

to display digital information without requiring the user to carry around a display. The approach described is especially useful in settings where a large amount of viewers needs to see the information, e.g. in museums or in touristic relevant locations [30].



(a) Google Glass



(b) MS Hololens

Figure 2.3: Examples for Optical See-Through displays.

The AR techniques described above differ in their possibilities and capabilities to augment or change reality. In contrast to projection based AR, optical see-through as well as video see-through can overlay 3D objects at arbitrary locations within the field of view (FoV). Nevertheless, the perception of the the surrounding reality as well as the virtual content varies considerably, making a situation-specific selection of the right technology important [15].

2.1.3 Fundamental Concept of Augmented Reality

In order to be able to create an augmented reality, some hard- and software are required. This includes a computing device of some sort (PC, mobile device), an output device (monitor or display), a camera, a tracking system, and some kind of

marker, a physical object or place to stitch the real and the virtual environment together. Software then runs the necessary algorithms to find previously defined structures or features, fuse content and to display data on the screen. This may also be a mobile application (App).

AR technology can come in either mobile or fixed form. Mobile systems are nowadays found in smart phones and tablets, giving the user the flexibility to use the AR system where ever they want to do so. A couple of years ago, similar systems were often head-mounted displays and a backpack [14]. On the contrary, fixed systems have to be used where they have been set up, but those systems might result in a more sophisticated augmentation. However, both systems should rather focus on the AR application rather the device powering it to make the experience more natural to the user [30].

Wolfgang Broll [15] describes the technologies used to build AR in five sub categories:

Video recording

In the beginning, a video stream is used to collect data about the scene which is to be augmented. Any camera (smart phone, web cam) can be used, but that is strongly depending on the technology (cmp. Tracking, see below, and [61]). It is important, that the camera, more exact its intrinsic values, have been calibrated to the AR software.

Tracking

Broll defines tracking as “calculation, more correct the estimation, of position and/or orientation” **of the camera**, because the reality is being surrogated by the video image. Today, these estimations can be done using hybrid 3-DOF sensors (inertial sensors, gyroscopes, and magnetometers). These sensors can be found in about any tablet or smart phone. For example, the iPad used in this project does have inertial and gyroscopic sensors. Tracking is used to transform the cameras coordinate system into the the coordinate system of the virtual environment. For the sake of completeness, the most common used tracking technologies will be introduced. However, the focus is on marker based tracking, as it is the technology used in Uro-MagicLens.

Registration

The geometrical registration fits the artificial, virtual contents into reality. Using the transformed coordinate systems from the previous step, the AR software puts the content and the reality into a relationship so that it can anchor the content to its place in the observed environment. Even if the camera moves, the content stays at its place, so that in the observed reality the content has a seemingly fixed place, independent from the viewpoint of the camera. A photometrical registration - adapting the local light environment - can be done, but will not be discussed in the scope of this thesis, as it is not required in the project.

Display

Based on the registration and the subsequent transformation described above, virtual objects can now be calculated into the scene. The video stream is being superimposed by perspective-correctly fitted virtual objects, which constitutes the actual augmentation.

Output

The video stream with the recorded reality and the virtual objects - this is referred to as the augmented stream - is now rendered onto the screen. The device, in our case is the iPad, but it can be any other device, e.g. phone or data glasses. The output can also be done on a detached device, but this diminishes the effect on an enhanced reality.

Tracking and Registration will be explained in further detail below, because these are important measurements of quality for AR and more so in the medical environment.

2.1.4 Basics of Tracking

Tracking in AR is generally the process of estimating the location and pose of the camera [61] and the viewpoint of the user [15]. There are several possible approaches: the first is to estimate single objects, where a relative transformation between camera coordinate system and object coordinate system is calculated. Another approach is a shared coordinate system for several objects. This requires the transformation between the individual objects to be known, so that only

the transformation between the camera and that coordinate system needs to be estimated [27]. There are also scenarios where some objects are fixed while others can move. One usually deals with a mixture between these two forms [15].

In AR, the most commonly used tracking systems are optical tracking and tracking based on inertial sensors. Optical tracking requires light, visible ($\lambda = 380\text{nm} - 780\text{nm}$) or infra red ($\lambda = 780\text{nm} - \text{ca. } 1400\text{nm}$). Being invisible, infra red light has the advantage that it can be used with additional lighting, without interfering with the human eye. Especially flashes would normally disturb or even hurt the user, but not with infra red wave lengths. However, using visible light allows using the same image for tracking and superimposing, whereas with infra red light one has to work with a special, infra red sensitive camera [61]. Inertial tracking uses measurements of linear and rotational velocity and acceleration. By simple (velocity) or double (acceleration) integration of the measured information, the position of gyroscope can be calculated [59].

Tracking systems are based on one of two principles: inside-out tracking or outside-in tracking. Primarily, these principles describe the composition of the system, which ultimately has an impact on the resulting application. Inside-out tracking systems are those, where the moved object determines its tracking data itself. The ambient room is merely a tool for the object to gain that data. In this case, the marker(s) is/are within the the room, or - in case of marker less tracking - the room itself is used to collect the required information. An advantage of inside-out systems is the ability to use the recorded image for superposition [61]. On the other hand, there are outside-in tracked approaches. Here, the tracked object is clueless regarding its own position. The sensors are fixated at known positions on the object, e.g. the head, so that a system installed in the room can track these, e.g. reflecting markers, while they move [63, 45]. In UroMagicLens, the marker is fixed on the baseplate and can be viewed with a still or moving camera, it thus is based on the outside-in principle. This was also chosen to keep the system mobile. The two components - the 3D printed model and the iPad - can be moved spatially without the requirement of an external tracking set up.

There are other tracking solutions that are, more or less, applicable in AR. There is mobile position tracking, using GPS data, and maybe a compass, to augment the world at a larger scale. Additionally, especially for AR in mobile devices, sensor-based orientation tracking can be employed [15]. Further, magnetic track-

ing and mechanical tracking [61] are viable options. Sensor-based tracking is used in registration, to keep the content fitted in the environment, even when the camera is moved. As well as for the display type (video, optical and spatial), a conscious decision with respect to requirements to the AR system must be made.

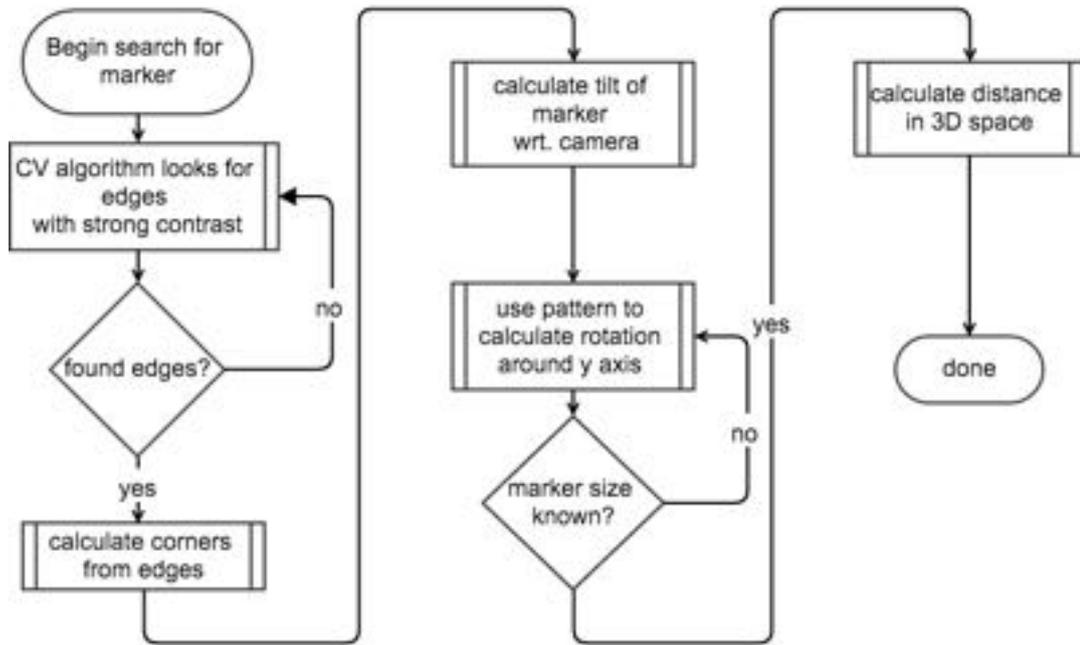
Marker based tracking

The user scenario of UroMagicLens takes place in normal offices, where the infrastructure for invisible light simply is not available. Thus, we opted for marker tracking. In this approach, small images, often patterns, are being attached to the object to be tracked. These two-dimensional markers are mostly rectangular, although they do not have to be. Figure 2.4a describes the general algorithm to find a marker, Fig. 2.4b [30] shows this more graphically.

Generally, there are two kinds of markers: reflecting markers that are used in combination with infra red light, and markers with patterns. The basics of both have already been explained, but as the first one does not have any relevance in UroMagicLens, only marker based tracking will be explained more thoroughly.

Marker based tracking has been done since the late 90's and is nowadays a well-developed, prevalent method. It uses computer vision algorithms to detect markers in a video stream as well as features on that marker. A feature is, in black and white image, a high change in contrast, e.g. corners and edges. These markers are also called flat markers. Although the marker may have many geometrical forms, they are usually rectangular or square. Examples can be found in Figure 2.5. Although it is used as a marker here, it should be noted that the image depicted in Fig. 2.5b is actually a QR code. QR codes are usually used to encode data, such as URLs.

In order for the marker based tracking to work, the pattern and the size of the marker image must be known, so the implementation can recognize the marker (pattern) and adjust the size of the content to the size of the tracker. After an image has been found in the video stream (see chapter 2.4), the relationship between marker and camera is calculated. This is based on the corners of the marker, which is why, as previously mentioned, the marker size must be known.



(a) Algorithm flowchart for marker finding.



(b) Graph for marker finding, cmp. [30]

Figure 2.4: Operational flow for marker tracking.

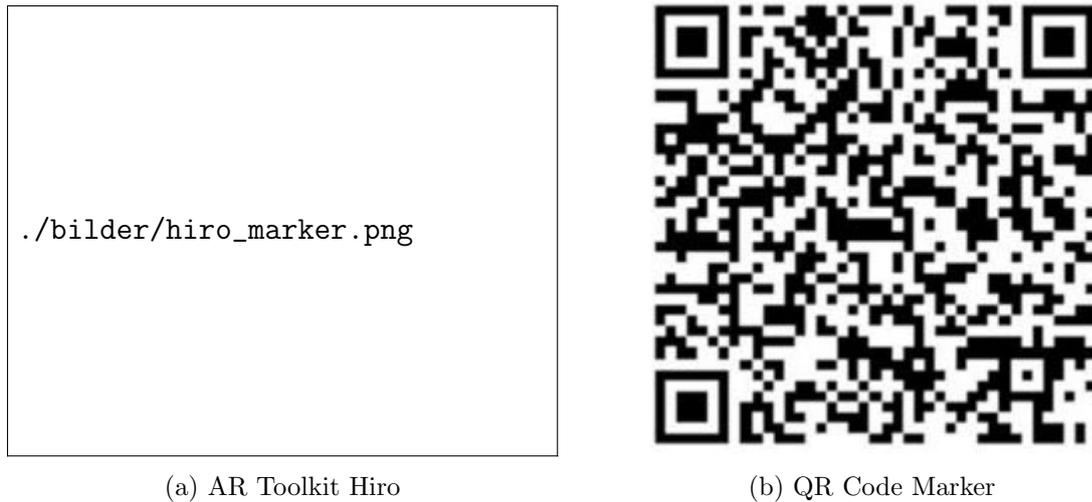


Figure 2.5: Examples of flat markers.

Let TM_{mm-cm} be the transformation matrix from the marker coordinate (mc) system to the cameras coordinate system (cc). To correctly present virtual content on the display, this transformation matrix must be calculated. Geometrically, a (real) camera can be modelled by a pinhole camera. An object point may be transferred into the camera coordinate system by means of an extrinsic transformation. In the cameras coordinate system, the object point is then displayed on a 2D plane, where the distortion, that results from the cameras optics, is also modelled. The outcome is the position of the object point on the cameras sensor. Thus, the projection of an object point onto the image plane of a camera is described by three parameter sets [32]:

- Extrinsic parameters to transfer the world coordinate system into the camera coordinate system.
- Distortion parameter to model the lens distortion of the real camera.
- Intrinsic parameters to depict an object point onto the image plane, in accordance with the pinhole camera model.

The distortion parameters can be used to calculate the intrinsic values by means of camera calibration [15, 32, 58]. Camera calibration also yields the calibration matrix \mathbf{K} which dictates the depiction on the image plane S . In these calculations,

an idealised pinhole camera (without distortion) is assumed. Thus, the relation between a camera coordinate v_c and an image pixel v_s can be described by:

$$V_s = \begin{bmatrix} S_x \\ S_y \\ S_z \\ S_w \end{bmatrix} = \begin{bmatrix} K & 0 \\ 0 & 1 \end{bmatrix} v_c$$

Now, the corner points of the detected marker are put in the formula above, including the calibration matrix K and the **known** distance between the corner points. The calculations yield the 3x3 rotation matrix R and the translation vector \vec{t} of the required transformation matrix TM_{mm-cm} . These are known as the extrinsic camera parameters [15, 32, 58].

Depending on the number of features, even partly concealed markers may be recognized. Depending on the distance between camera and marker, only certain dimensions can be used for the marker, since it may not fit in the FoV of the camera or the amount of marker pixels is too low. Having too few pixels leads to a faulty pattern recognition, which in turn leads highly variable transformations, so that even with fixed markers and an immutable camera FoV e.g. a device mounted on a tripod, a virtual object might start to drift. Additionally, the model scales with the image target, meaning that with increasing size of the marker the model also gains in size. Maybe the biggest advantage of (flat) marker based tracking is the simplicity. Markers can easily be created, reproduced (printed) and then installed on objects, tables, and walls [15, 61]. Disadvantages include a strong dependence on lighting conditions and that markers are usually put directly onto an object. This may often be inappropriate (e.g. on statues [14, 42]) or impractical, since one has to get close to the marker and thereby occlude the augmented object itself. For small objects, it is further aggravating that whilst rotating (interacting with the object in general) one may cover up the marker completely and thereby rendering tracking impossible. For UroMagicLens, it means that a marker with high robustness against rotation in the y-z-plane must be created.

For AR, there exist a number of open source solutions to choose from. Widespread

implementations are ARToolkit³, ARTag⁴, ARToolkit+⁵, and Vuforia⁶.

2.1.5 Basics of Registration

In the context of augmented reality, registration means fitting the virtual content in the ambient room. The content must not only be in its designated place - the geometrical registration - but should also reflect the lighting conditions, i.e. the photo metrical registration.

Based on the previously estimated transformation matrix, the content can be visualised in the correct position and orientation with respect to the current FoV of the camera. Without registration, the content would stay put and would not reflect any changes within the FoV, as shown in Fig. 2.6. In order to achieve correct registration between the virtual and the real environment, accurate measurement of the cameras translation and rotation must be acquired. For the required measurements, sensors (magnetometer, gyroscope) can be deployed. These sensors allow for a stable registration in varying lighting conditions and are especially effective with fast moving cameras. They are ubiquitous in hand held devices [62].

However, not only is the quality of registration of importance, but also the tracking speed. If the camera moves faster than the tracking rate, objects will jitter around in the scene, due to missing tracking information. More frequent updates will benefit a seamless display of digital content. Ideally, the tracking rate should be greater than 60Hz [15, 61]. Another problem is the latency. While the symptoms are similar to a low tracking rate, the problem itself is of different nature. Latency describes the discrepancy between the movement of the camera and the point in time, where the results from the transformation can finally be used to update the scene. The main reason is the relatively complicated calculation. Due to latency, the object has a certain offset to its correct position while the camera moves. The offset is finally corrected when the movement comes to a halt [15, 61]. The described problems can be solved by adjusting the tracking rate to the frame rate in case the tracking rate is not too low, and respectively measuring

³<http://artoolkit.org/>

⁴<http://artag.net>, currently unavailable

⁵<https://github.com/paroj/artoolkitplus>

⁶<http://vuforia.com/>



Figure 2.6: Comparing registered vs. unregistered ambience, cmp [15].

the latency and then buffer the camera stream. With an incoming update of the tracking data, the buffered images are stitched to the content. Even so, now the latency exists for the whole scene, not only between real and virtual world. As long as the latency is not too high, it barely will be noticed [15].

Whilst the geometrical registration is a basic necessity for AR, photo metrical registration is - nowadays - rarely being deployed, according to Groll [15]. It is, however, an important factor of composite images. Relighting techniques are employed to adjust a target objects lighting and shadowing to fit another scene. Such techniques generally require the shape of the object to be displayed, its surface reflectance and the ambient illumination environment of the scene which includes target object and background scene. All of these properties must be obtained before the relighting process [47]. Relighting techniques also include the placement of virtual shadows, thrown by virtual content. However, this change of lighting on real objects can, on principle, only be done with video see-through AR. For a correct photo metrical registration, change in the environment is essential. An incomplete or erroneous registration drastically worsens the illusion, but a well done registration greatly improves the plausibility of AR scenes [15].

2.2 Urology

2.2.1 General Introduction to Urology

The term urology combines the surgical and medical speciality dealing with diagnosis and the treatment of diseases in the urinary tract and the sexual organs of both male and female. It includes treating kidneys, ureters, bladders, the urethra, testes, prostate, penis and the adrenal glands [38]. Urology is considered the smallest self-contained speciality within medicine. At the same time, it is the discipline with the highest amount of technology used. Even the establishment of urology was a technological (German) invention: the endoscope. Statistically surprising, most tumour afflictions (the prostate carcinoma) as well as the most often “correct” intervention (prostate adenom) happen in this small category [23]. Even though all of the mentioned organs can be affected by a wide variety of pathologies, this thesis focuses on the prostate for it is the targeted organ in this project.

2.2.2 Fundamentals of Prostate Cancer

The prostate, in human men, is a pyramid-shaped gland [38], situated deep in the pelvis with an apex (contacting the urethra and directed downwards) and a basis (directed upward, contact to the bladder). It weighs about 20 g, with about $3\text{ cm} \times 4\text{ cm} \times 2\text{ cm}$ in x-y-z-dimensions. The main function of the prostate is to provide nutrition for sperm cells and their motility (spermine). It contributes about 0.5 mL of a thin, slightly acidic (pH 6.4) secretion to the 2 mL to 6 mL of ejaculate. The remaining volume (containing fructose) mostly stems from seminal vesicles (gelatinous consistency, pH 7.4), residing next to the prostate. The (prostatic) urethra passes through the prostate gland, thus separating the prostate into the left and the right lateral lobe [38, 49]. The prostate gland is made up out of about 30 smaller glands with single ducts, all emptying in the prostatic urethra. While natural growth with age is only common, there are four major groups of pathologies men have to pay attention to. These are prostatitis, benign prostate hyperplasia, congenital diseases and prostate cancer [38, 23, 49].



Figure 2.7: Lateral view of the male pelvic area [2].

The prostate carcinoma is the most common urologic tumour in men, and although the incidence rate differs aetiologically from population to population (highest rate to lowest rate: black, caucasian, asian), it generally rises with age. A genetic predisposition is one important factor: patients with first or second grade relatives that had a prostate carcinoma, have a 200-300 % higher risk of developing a malign tumour as well, as well as ten to fifteen years earlier. Additionally, there are hormonal and dietary factors, but even infectious diseases may favour the development of a carcinoma. Commonly, a prostate tumour grows towards the apex, and with advanced stadiums it will start penetrating the prostate capsule. Metastases from lymphogenous scatter will first develop in the lymph nodes in the fossa obturatoria and continue to lymph nodes in the paraortal region. Hematogenous scattering affects the sceleton (osteoblastic metastases), especially the vertebrae lumbales, proximal femur, pelvis, ribs, sternum and even skull.

Early stages of tumour cancers are completely asymptomatic, but later stages may show as obstruction symptoms in the urinating tract. Diagnostic tools include the rectal examination, where existing carcinomas can be felt through palpation. Other forms are the transrectal sonography (sonic heads with 7.5 MHz) that are used to depict the prostate longitudinally and transverse; the PSA value (a value indicating the presence of prostate specific antigen) and also imaging modalities such as NMRI, CT, and bone scintigraphy [23]. Therapeutic procedures depend on the stage and kind of the cancer/tumour, but they range from prostate sectomy, radiation, and ablation to pharmaceutical treatments, e.g. chemotherapy.

2.3 AR in Medicine - State of the Art

Deploying AR in medical environments is by no means a new idea. Other researchers in this field have developed applications to help medical personnel with a variety of tasks in different environments. Augmented Reality is currently used in medical training and education, minimally invasive procedures, instrument guidance and navigation, intervention planning and interventional radiology.

Medical Training and Education Orca Health, Inc. developed a series of iOS applications that make use of augmented reality. As an example, EyeDecide uses the combination of camera and display in the iPhone to simulate the worsening impact of eye conditions to the user, see Fig. 2.8. They, too, use the video see-through approach of AR.

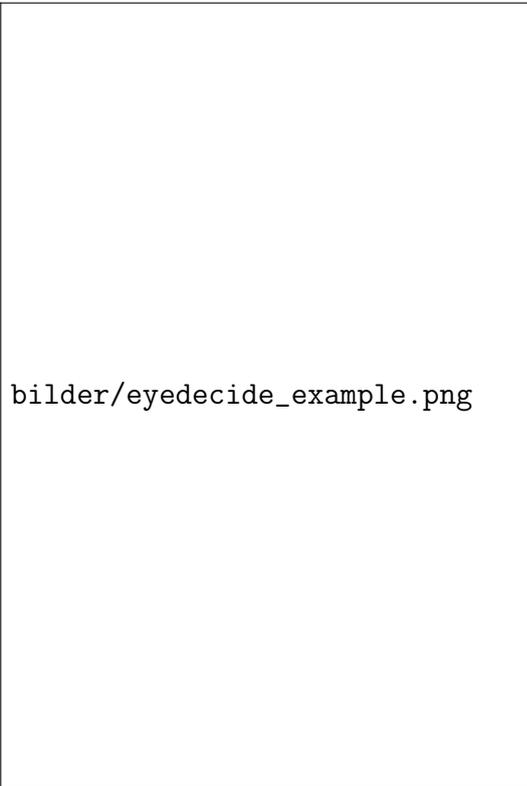


Figure 2.8: Demonstrating the impact of age-related macular degeneration (AMD) through an iPhone [3].

Similarly, nursing lecturers from the Sheffield Hallam University, together with a team of AR researchers at Campus Interactive⁷, introduced an AR application for practising patient scenarios. Usually, trainee nurses train on standard plastic simulation dummies (Fig. 2.9a). While these can simulate breathing and aid in practising taking blood samples, they cannot behave realistically. Thus, the scenario in question must still be explained by a teacher. Using 3D object tracking, the application overlays video data of a real patient with the camera stream as soon as it detects the dummy (Fig. 2.9b) [18].

⁷<http://campus-interactive-media.com/>

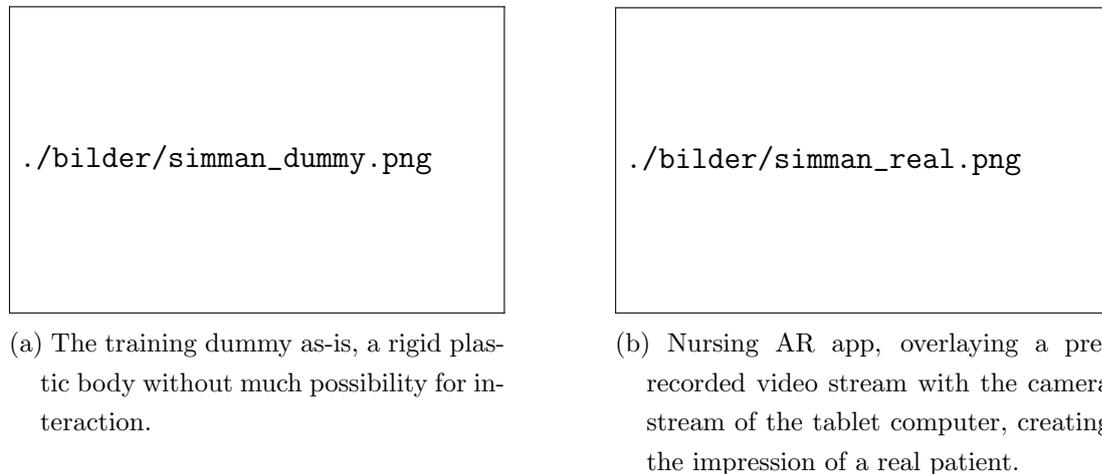


Figure 2.9: The nursing AR app in action, cmp. [18]

Leucht et al. [34] and Loy Rodas et al. [51] independently developed systems to convey radiation exposure to surgeons by means of simulation and augmentation. RGBD cameras are used to obtain the room layout. After calculating a 3D risk map using the position of humans and equipment as well as wireless dosimeters, this map can be shown in AR fashion on a 3D model on a display in the operating theatre.

Blum et al. [8] (see also: [37]) developed “mirracle”, an augmented reality magic mirror to support teaching anatomy. The user, standing in front of a large display, is tracked by a depth-sensing camera, the Microsoft Kinect. On that display, the depth-image of the camera is augmented by an overlay of a CT volume dataset. In doing so, the researchers grant the user the ability to “look into the body”. The system is gesture controlled and can add 3D images of organs as well as text and images regarding that organ to the augmentation. Fig 2.10 shows the system in action.

Felix Hamza-Lup [20] introduced a distributed medical training system to train paramedics, pre-hospital personnel and medical students in practising endotracheal intubations with the help of AR paradigms. Visual feedback gives a better understanding of the procedure and its results, without the risk of harming actual patients. The distributed system allows an instructor to train students remotely and at site. Using an HMD, the trainee sees a virtual 3D model of the internal anatomy superimposed on the human patient simulator (HPS). Remotely, an in-

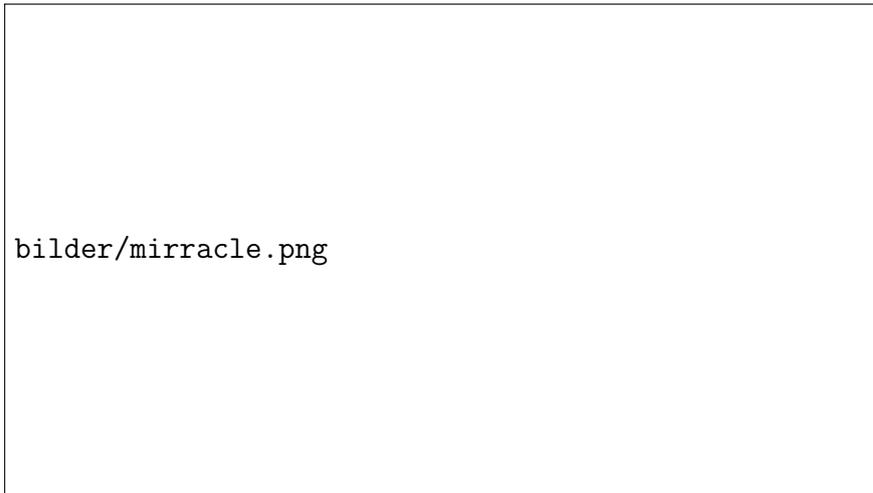


Figure 2.10: The “miracle” magic mirror in use, cmp [37].

structor and other trainee(s) wear similar HMDs and are able to visualize the 3D anatomical models while seeing and interacting with each other in a natural way (see Fig. 2.11). During interaction with the HPS, the relative positions of the 3D models of the endotracheal tube (ETT), the lungs and the trachea are visualized remotely.

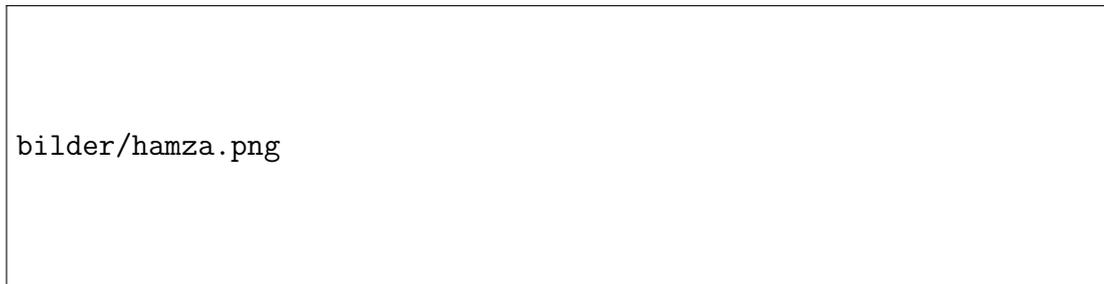


Figure 2.11: Concept of the AR tool for training paramedics on endotracheal tube insertion. A trainee performing a medical procedure remotely supervised by the trainer(s); cmp. [20].

Botden and Jakimowicz [10] review different applications of AR to laparoscopic surgery training. In these training environments, students train certain laparoscopic procedures with the same instruments as used in the OR. Some of the basic recurrent skills are, for example, navigation with the trocars, and touching or grasping of tissue. More advanced recurrent skills that can be trained are transection or cutting, dissection, and suturing. Medical students train on a mannequin on which overlays of anatomical information are projected and the

visual pathways of the laparoscopic instruments are shown. The learning task may be combined with a demonstration video. The ProMIS system, for instance, combines a mannequin with a laptop computer. Inside the mannequin, a tracking system measures position and velocity of the surgical instruments. These data are subsequently visualized on screen. Compared with real training (box trainers) and virtual reality training, AR laparoscopy environments offer realistic haptic feedback, which is essential for the transfer of laparoscopic skills to the work environment.

Invasive Procedures SurgeryPad, an iPad application, aids in computer assisted, targeted tissue needle insertions and therapy by removing some of the limitations associated with 2D imaging methods with the use of AR. Poor image quality and non-existent spatial representation are common in percutaneous needle insertions, yet it is this spatial representation of the patients anatomy that is required for a successful intervention. Preoperative images (X-ray, CT) are used to reconstruct bones, tumours, and risk structures in 3D. During the surgery, the tablet is used to film the patients surface and superimposes video data with the 3D models using five coloured radio-opaque markers. Studies have shown a reduction in operating times and exposure to X-ray radiation. Another benefit of the application is that complications can often be avoided [50, 43].

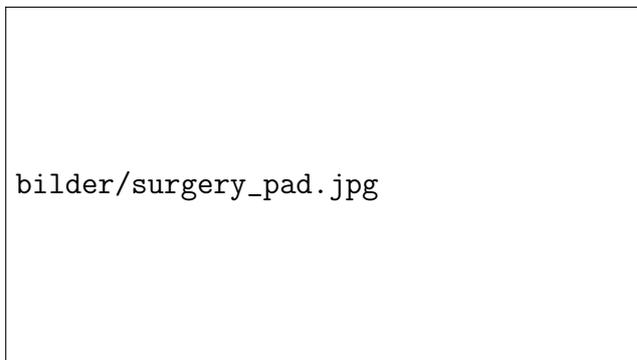


Figure 2.12: SurgeryPad running on an iPad 2, used during navigation of percutaneous access to the kidney [50].

Simpfendörfer et. al and Fuchs et al. [19, 56] both developed an implementation of augmented 3D visualisation to assist surgical procedures with respect to the current FoV of the camera. Simpfendörfers system projects virtual organ models

from ultrasonography onto a real laparoscopic video during the intervention. By adding additional information, albeit on two different screens, the surgeon can make well-informed decisions. On the other hand, Fuchs' prototype deploys 3D visualization, depth extraction, a six DOF head and laparoscope tracking to display a merged real and synthetic image in the surgeons video-see-through head-mounted display. In doing so, the system re-establishes the physicians natural point of view and head motion parallax that they are trained to rely on.

Instrument Guidance and Navigation Behzad Eftekhar [16] introduces SINA (Sina Intraoperative Neurosurgical Assist), a smart phone application that overlaps the semi-transparent computed CT / MRI images on the back camera. SINA was developed to assist surgeons in parts of the world that aren't developed as far and thus standard neuro navigation is not affordable or available. SINA also exploits the MagicLens effect. Because SINA source code does not support magnifying images, alignment with the patients head happens by manually adjusting the distance between the phone and the head. Eftekhar presents SINA as advantageous in terms of availability and simplicity.

Similarly, Soeiro et al. [27] present a smart phone application to visualize the patients brain both in AR and in VR. Their application, developed using the Metaio AR-SDK (software development kit), supports surgeons by simplifying the mental task of integrating and aligning observed images with the patients head by using the MagicLens effect as well. In order to assist in the application of trans cranial magnetic stimulation, the authors developed their application with three different modes. Their application requires the use of fiducial markers, serving similar to QR codes. The use of several markers necessitates an additional XML-file that defines the markers to be tracked. Each marker is associated with a coordinate system, all of which can be configured to coincide at one point inside the head. Further features include stereoscopy and an interactive VR mode.

MEDARPA (Medical Augmented Reality for Patients) [54, 55] combines state-of-the-art technology to provide an HMD-less working space that can aid as a medical AR system for the clinical routine of needle insertion, with the intended scenarios being cardio surgery, bronchoscopic punctures, and assisting in navigating brachytherapie catheters. The authors use fiducial markers that are attached to the patients body, and an electromagnetic marker which is fixed to the medi-

cal instrument. Their tracking system thus combines optical and electromagnetic tracking.

Black et al. [7] and Hansen et al. [21] both introduce auditory navigational support in liver surgery. As per Craigs definition, AR includes the sense of this audible support is also AR. As opposed to the common way of displaying a cross hair on a screen or projecting it onto a patient that has several limitations, such as shifting the operators focus away from the patient or non-existing updates on the navigation progress, auditory support uses a different sensory channel. In the visual as well as in the audible navigation support, the needle is tracked in order to get information about needle position and orientation of the shaft, which allows conclusions about the insertion angle. When both are correct, a progress bar on the screen informs the surgeon about the current insertion depth. However, the audible display conveys the same information without requiring the users eye - instead, the information is encoded in sounds. For example, Black developed a method where two repeated pulses of different pitches are played alternatively. A change in distance to the y axis is mapped to the frequency of pulses, while changes in distance to the x-axis are mapped to the pitch of these alternating pulses. When the distance in y-direction becomes smaller, the frequency of the alterations rises. Smaller distances in the x-direction lead to the convergence of the pitches, until they are identical.

Hansen et al. have developed a method for navigated liver surgery, using an audio resection guide that consists of three different margins (safe, warning, outside) [21]. These margins correspond to a value δ , which describes the distance from instrument tip to the nearest point on the resection line. The safe margin marks an area on both sides of the resection line. Within this margin, resection and marking are safe. The warning margin reaches from the outer border of safe to the warning-range width. The warning margin is close to safe, but resection markings would not be permissible. The outside margin includes all areas except those that are marked by **safe** and **warning**. To signal the position of the instruments tip and thus whether it is safe to resect or not, the authors are using two different tones. The safe tone is played when the instrument is located within the safe margin ($0 < \delta \leq \text{safe width}$). The operator now knows that marking the resection line here results in a safe resection. However, when the tip is in the warning range ($\text{safe width} < \delta \leq \text{warning width}$), the warning tone signals

to the surgeon that a repositioning of the instrument tip into the safe margin is required. When the instrument tip is in the outside margin, no tone is produced. The combination of both warning and confirmation tones provides the user with a way of both locating and remaining on the planned resection line.

Spatial Perception for Medical AR For use in the operating theatre, surgeons have requested solutions to viewing different layers, similar to X-Ray. Commonly used rendering techniques employ classical techniques, which often result in clutter, occlusion and confusion regarding the depth perception [22].

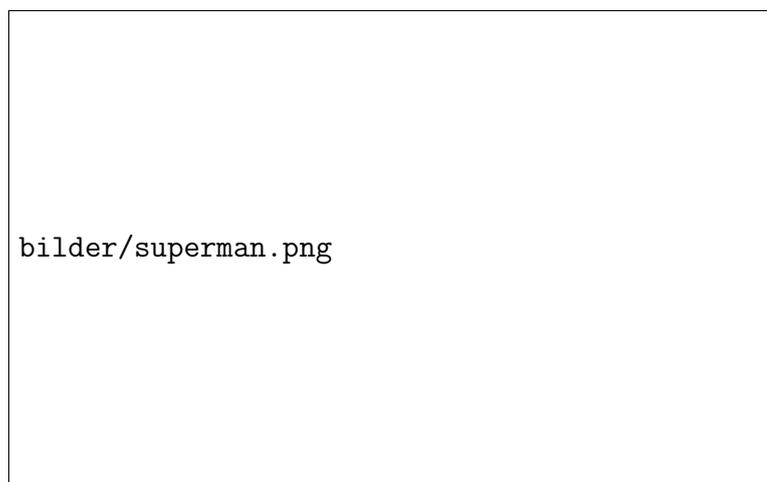


Figure 2.13: Superman-like X-ray Vision: A Brain-Computer Interfaces for Medical Augmented Reality, cmp. [9]

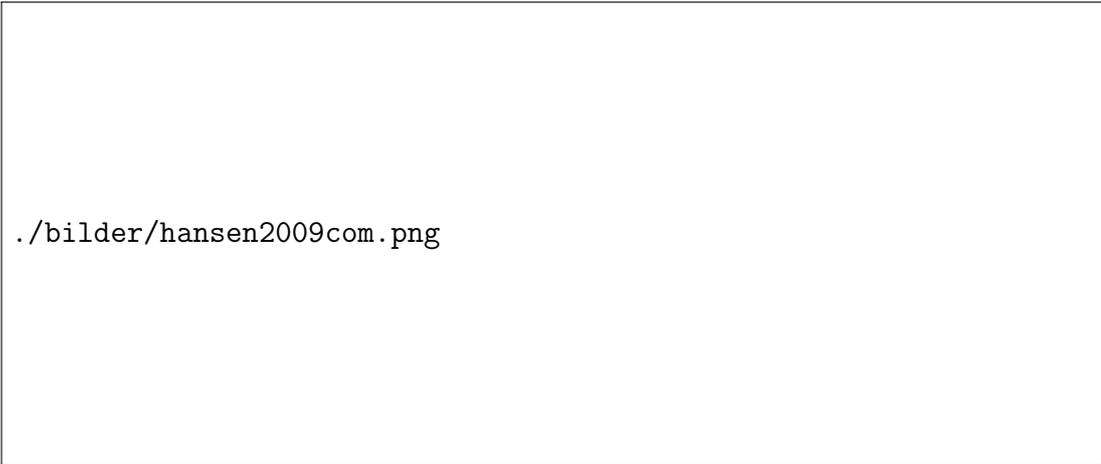
Blum et al. [9] took measurements regarding “Superman-like X-ray vision” using a brain-computer interface (BCI) device and a gaze-tracker to control augmented reality visualization. Surgeons can make use of the “X-ray vision” at will, for sometimes they have to see their hands or their instruments outside of the patients body. In order to switch between standard and “X-ray vision” or to change the parameters of the visualisation, surgeons need a user interface (UI). Appropriate UIs for AR are complicated in their development, for as with medical AR (in the OR), the user has to stay sterile and most surgeries require the surgeon to use both hands. The authors present first steps towards transferring the concept of mind-controlled “X-ray vision” to medical AR by using gaze-tracking in combination with BCI devices. By using a virtual window, a visualization technique that has

already been used by one of the very first medical AR systems [9], anatomical structures that are situated within the body can be made visible. The virtual window improves depth perception but hides real objects.

In order to improve spatial perception, different illustrative visualisation techniques have been employed, as well as auditory displays.

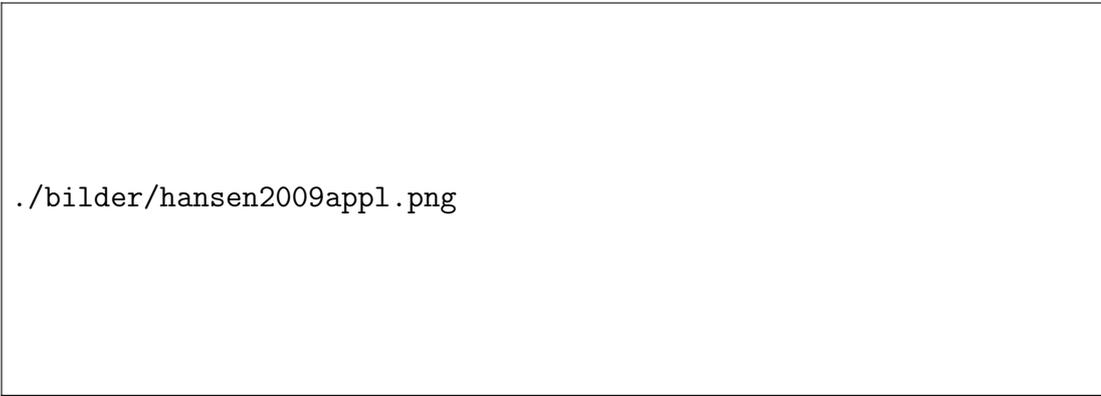
Hansen et al. [22] developed algorithms to improve depth perception by distance encoding for use in intervention planning. Here, it is required that planning data is either being projected directly onto the liver, or that they are superimposed with images from a laparoscopic camera. Using an advanced silhouette algorithm in combination with procedural textures, the authors approach the often criticised problem of depth perception successfully. By varying the stroke thickness and stroke styles in the silhouettes, the depth and the relation between the outlined anatomical structures is encoded. Fig. 2.14a shows a comparison between classical rendering techniques and the combined illustrative technique that has been developed. Fig. 2.14b exemplifies the approach as an augmentation during open liver surgery. Additionally, resection surface lines can be visualised by projecting contour lines on the outer shape of the resection volume. Using a precomputed Euclidian-distance map, the depth perception is improved by the use of equidistant contour lines. Fig. 2.14c shows a comparison between classic rendering techniques and a combination of the three algorithms that the authors contributed.

Wegner et al. [64, 65] approach spatial perception problems via the audio channel. This frees a lot of attention and the surgeon may focus their attention towards the task at hand. This is especially true when considering that humans are able to process both aural channels in parallel, allowing a huge bandwidth of information throughput [65]. The authors introduce a navigation system for biopsy needles that are being tracked electromagnetically. When the surgeon diverts from the previously planned trajectory path of the needle towards a tumour mimic, the system would produce a sound. Sine waves encode the error in one spatial dimension, and by correcting the needle position and alignment the sine waves are brought into harmony. Three-dimensional guidance proves to be difficult, since harmonies of three dimensions might confuse the user. Secondly, an increase of distance between the needle and the starting point is signalled by equidistant sounds. This system was developed for procedures in which anatomical geometry,



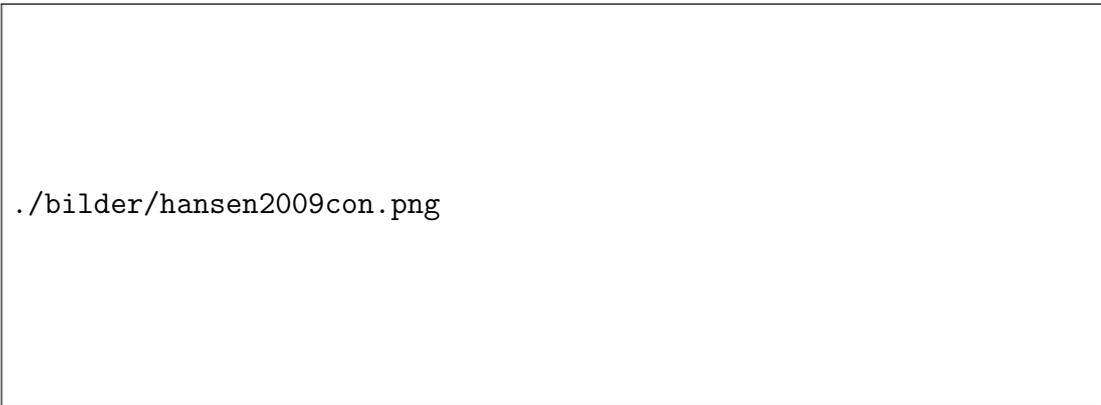
./bilder/hansen2009com.png

- (a) A comparison between classic rendering techniques and the novel illustrative visualisations, cmp. [22].



./bilder/hansen2009appl.png

- (b) Augmenting an open liver surgery with classic rendering techniques vs. distance-encoding silhouettes and surface.



./bilder/hansen2009con.png

- (c) Comparing an augmented open liver surgery with classic rendering techniques vs. a combination of distance-encoding silhouettes, surface and equidistant contour lines. The vessel branches fade wrt. a threshold.

Figure 2.14: Examples of the algorithms in concept and during surgery.

i.e. preoperative data, has been pre-rendered and already been registered to the patient.

More sophisticated - although not smart phone based - applications of AR in medicine are collectively presented by Yaniv and Linte [67], guiding the reader through a diverse array of augmented image-guided surgery including some laboratory prototypes, such as a semi transparent display to aid hand-eye coordination.

2.4 Augmented Reality Applied to Other Industries

Augmented reality is a technology that has a high variety of possible applications. Following, some of them will be introduced by highlighting chosen research paper in the field augmented reality.

Military

The ability to provide information to soldiers on and off the battlefield, for example in jets and helicopters [12] is a big use case. Other fields are support and training for handling military devices, navigating troops and vehicles, and the preparation for combat situations [36, 11]. Livingston et al. developed a Battlefield Augmented Reality System (BARS) to tackle difficulties in processing and handling map data for the dismounted soldier in urban combat environments. Their system employs a wearable computer, a wireless network system, and a tracked see-through HMD. Computer-generated data is then - perspectively correct - overlaid and aligned with the environment on that display, e.g. augmenting a building with floor plans. The system may also report known hostile positions, such as snipers or artillery. Tappert et al. also make a case for HMDs, describing them as valuable tools for device maintenance and repair. Descriptions and instructions can be displayed on the HMD, so a repair can be done without having to shift focus from the device to a wearable computer and back. Furthermore, this technology can potentially be used for communication between unmanned aircrafts (drones) and infantry, e.g. transmitting information about areas that cannot be explored from the ground without giving away your position or risking the soldiers, i.e. when crossing hill tops.

Archeology and Museums

Archeoguide [14] was developed to show tourists how buildings originally looked before they have been destroyed by war and/or time. The system employs laptop and the head mounted display n-Vision VB30. Instead of attaching markers to the historical site, which the authors were forbidden to do, they opted for a collection of view points. In their work, a viewpoint is uniquely described by its longitude and latitude, and the heading of the user. Attached to the viewpoints are imagery, sounds and VRML (Virtual Reality Markup Language) objects, that are being displayed when the carrier of the system closes in on such a viewpoint.

Miyashita et al. [42] show how AR can be used to draw more attention back into the museums. Their system, comprised of two main ideas, provides a more modern way to approach and enjoy art. On the one hand, their AR-interface allows to attach 3D information of an artwork directly in front on the showcase. The second idea evolved as an AR tour guide, seeking to improve simple 2D-maps or pure audio descriptions for art. Not only is the system used to guide visitors, but also to point them towards stations using animations. The authors developed their idea during a three year project with the Louvre-DNP Museum Lab and thus were bound to strict rules. Because they had to work in relatively low light and were strictly forbidden from the use of fiducial markers, they opted for hybrid tracking.

Education

In a survey of AR in education, Wu et al. [66] classify different approaches in three major categories:

Roles emphasize the engaging learner. Because these approaches focus on inter-student group work, they usually deploy a rather playful AR-approach, such as mobile multi player games. As an example, they used the Virus game, where students would exchange information on hand held devices to show how a virus would spread.

Locations Location based approaches deal with interactions between student and location. Here, courses like history or geography are major fields of application.

Task Approaches in the “task” group emphasize on the design of learning. They include game-based, problem-based and studio-based learning. Whilst game-based approaches seem to overlap with the role category, problem-based learning promotes self-directed learning, self-motivation and knowledge application skills. Both game-based and problem-based learning can be included in the same learning module, but in different learning phases. Studio-based learning starts with project-based on open-ended problems, followed by iterations of design evaluation.

Research suggests that deploying AR systems may help learn the skills taught in other (technological) learning environments, but in a more effective way. The authenticity provided in AR increases interest and motivation in students, but also improves the understanding of dynamic models and complex causality [66].

Manufacturing

As AR was originally designed and implemented to serve in industrial purposes [67], several applications can be found here. For example, Tegtmeier developed a system called ARMON (dt. Augmented Reality gestützte Montage/Demontage, engl. Augmented Reality support Assembly/Disassembly) [59]. The system supports technicians by providing blueprints for several devices in a car and thus aids in service and repair. Additionally, Tegtmeier created an authoring tool called ARMON-Autor. The tool creates data (i.e. the required xml file) for new devices, in order to support those as well.

Menk et al. present an SAR system to lower the high cost associated with design iterations in the automotive industries due to the high number of models and model variation [39]. Spatial augmented reality helps cutting development time and cost by showing high-fidelity digital models, i.e. projecting new HUDs on a fitted object. Additionally, SAR is well accepted in the R&D environment, because the virtual data may be assessed better in a familiar environment [15].

3 Development

3.1 User Centered Design Process

Understanding medical procedures as a laymen is difficult. Medical terminology can get complicated and - without a reference - imagining organs and vessels in three dimensional space is a lot to ask from a patient. Thus, UroMagicLens aims to combine a tangible, general model of a prostate with digital, patient specific 3D models to simplify the mental workload. Pointing at the augmenting models, displaying their names whilst explaining their function and purpose eases the patient-doctor communication by providing visual and tangible information, leaving the patient better informed.

The application development follows the general rules of the user centred design (UCD) process [46]:

- Clarification of the software context. This includes the intended user, their use cases and the conditions under which the application has to perform.
- Specification of requirements: by identifying the goals and needs of the consumer, one can decide on hardware and software and make sure the product does not miss its purpose.
- Create the software design: Possibly using iterations, the application design, especially the UI and user experience (UX) is developed from concept to a final stage.
- Evaluation: Evaluation - ideally through usability testing with actual users is integral to find and fix errors in application handling and feature tuning.

3.2 Requirement Analysis

UroMagicLens is supposed to help the patient understand the pathology and possible treatments and procedures. However, it can only aid the doctors explanations by providing a meaningful tool for the demonstration of aforementioned therapeutic measures and, secondly, for patients to discuss therapies with their families at home. An interview with a medical practitioner was conducted to investigate what a possible user of the application expects in terms of functionality, portability and usability.

Software Requirements

The interview resulted in a specification list, which includes the following items:

- The software must show three dimensional models of the locally present key structures. The required models are the prostate, an eventually existing tumour, the urethra, blood vessels and the rectum.
- These models must be interactive (show / hide, adjustable opacity).
- These models must augment a 3D-printed model of prostate with additional information, which is not included in the 3D-print.
- The system must be mobile.
- The operating system of the device must be capable of installing 3rd party applications, so the app can be installed on the device.

Hardware Requirements

The app needs to be running on a mobile device. In order to interact with the models, the screen real estate must suffice. The device requires a back camera in order to utilise the VST method. For elderly patients, a simple to use touch screen and is helpful, as interacting with the fingers is a natural behaviour in humans. Since the program might be used for prolonged time, a lightweight device should be used so not to introduce fatigue in the users arms and fingers, if no holding stand is available. The hardware must be capable of fast processing of image information and it must be able to render the models as quickly as possible. For

later stages, a network connection might be required so new models and updates may be downloaded.

Development Tool-chain

In order to have the code and software editable and usable by anyone, a solution must be found so that both Windows and MacOS users both can access the project. Furthermore, code reusability is an important factor, since the project might later be continued by other developers. In order to build an AR application, some form of framework must be used that already offers AR capabilities and techniques such as feature-finding, extraction, and rendering of models. Furthermore, quick prototyping allows for fast changes, so the tool-chain should offer integration between tools.

3.3 Establishing the Development Environment

After interviewing the intended user group, the requirements have been agreed upon and serve as a base for decisions regarding the hardware and software that have been used in developing the application. After some consideration, the choice was a tablet computer, more specific an iPad mini. Most tablet computers are below 500 g, so they can be held without causing fatigue. The iPad weighs only 331 g and is readily equipped with a back camera, which is needed to find and track the marker. The camera offers a sufficient resolution (5MP). The display offers 7',9" of screen real estate with a resolution of 2048 x 1536 pixels. The screen is touch-controlled. Furthermore, the iPad offers WiFi connectivity for future updates of the application. Running iOS, Apples mobile operating system, the application and its updates can not only be downloaded using the AppStore[®] application on the iPad itself, but also using iTunes on a PC or Mac.

As for the tool-chain, a combination of different tools was employed. On the one hand, Apples security guidelines allow for only Macintosh computers to not only run the in-house integrated development environment (IDE) Xcode, but also the compiling and deployment to the device can only be done on a Mac. However, the application was only compiled and deployed using Xcode 7.3.1. Development and

testing was done using Unity3D⁸, an IDE for game development. Unity3D allows writing software for several platforms by cross-compiling C# or Javascript code for the native, target-platform dependent processors. This is a big advantage, because the application itself does not need to be rewritten to run on an Android or BlackBerry devices, but rather only recompiled and deployed to the respective device. Unity3D did not only serve as the cross-compiling IDE, it also hosted the Vuforia plugin. Vuforia⁹ is an AR framework, which can be downloaded as native libraries for Android and iOS, but also as a Unity3D plugin. Because Unity3D offers cross-compiling, the plugin was chosen over the native libraries. Vuforia also offers a developer centre, where licenses and AR data blobs can be managed. Due to the tight integration of Xcode, Unity3D and Vuforia, it was possible to keep the prototyping cycle quick and concise. However, a drawback is that the iOS app can only be built on a Mac, or by using a compiling service that is hosted in the cloud.

3.4 System Concept: Building Blocks

As described in the basic concepts of the UCD, software may be developed using an iterative approach. In order to fine tune user design and experience, the software was tweaked, deployed and tested often in a fast deploy-test-fix/enhance cycle.

The overall system consists of three major building blocks: First, a 3D printed model of a prostate with a marker item (called image target) that is robust against rotation and bad lighting conditions. Further, three dimensional, digital models of the relevant anatomical structures, the digital content. Lastly, the application itself, that binds the first two building blocks together. Fig. 3.1 shows a proposed usage with the building blocks. Each individual part of that system is explained in more detailed in the following sections.

⁸www.unity3d.com

⁹www.vuforia.com

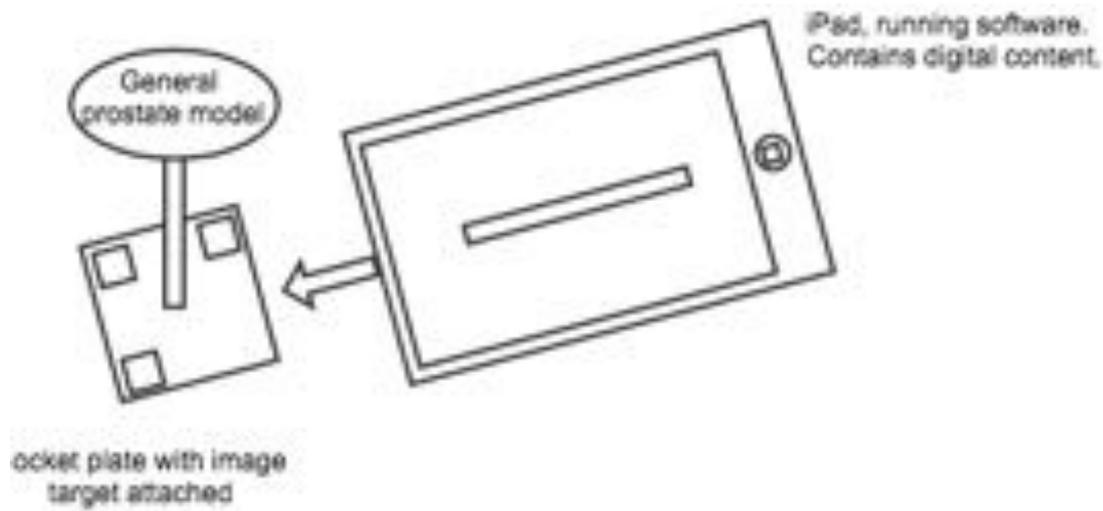


Figure 3.1: Building blocks in proposed usage.

3.4.1 3D Print of the Prostate - The Tangible Model

The 3D model used in this project is based on a prototype model that was already printed for a different purpose. Thus, the exemplary render of it includes the tumour as an actual print instead of an augmentation:



Figure 3.2: A rendered image from the 3D computer-aided design (CAD) tool. It pictures the fundamental version for the 3D model of the prostate. It already includes a tumour. Source: T. Hoffmann, *STIMULATE*¹⁰

The model uses a see-through synthetic material, as transparency aids in visualising the important inner structures. To further improve the visibility of the

¹⁰*STIMULATE* is a research-focused organisation: www.forschungscampus-stimulate.de

digital content, it includes a connector so that the model parts can be separated. The tangible model is a 3D print. The same segmentations that have been used in the digital model came to use in the construction of the print. It has been modified to include a cross-socket, so that it can be propped up on a table. The alterations are depicted in Fig. 3.3. The complete model consists of four parts:

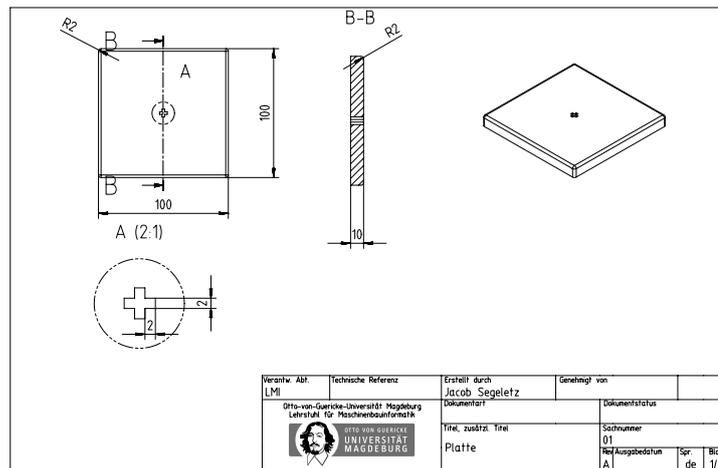


Figure 3.3: The technical drawing for the additional parts of the 3D print.

two for the prostate gland and two for the stand, namely a pillar with 10 cm in length and a base plate, sized 100 cm^2 . The pillar and the base have also been printed using the same see-through plastic. The purpose of the model is to aid in the communication between physician and the patient by giving a deeper insight in the three-dimensional space. Being a tangible device, it gives a better, easier to understand impression of the prostate and its inner and surrounding anatomy. Furthermore, it serves as a carrier for the marker. The marker is attached to the base plate of the 3D model. In doing so, it was ensured that the model could not be rotated in relation to the marker, which would result in a misaligned augmentation. As the socket plate measures 100 cm^2 , so does the marker.

3.4.2 Anatomical Structures - Targets

The digital models are derived from a data set that has been segmented from MRI data by a student research assistant. The segmentations have been validated by a medical professional. The same data set was used to construct the 3D

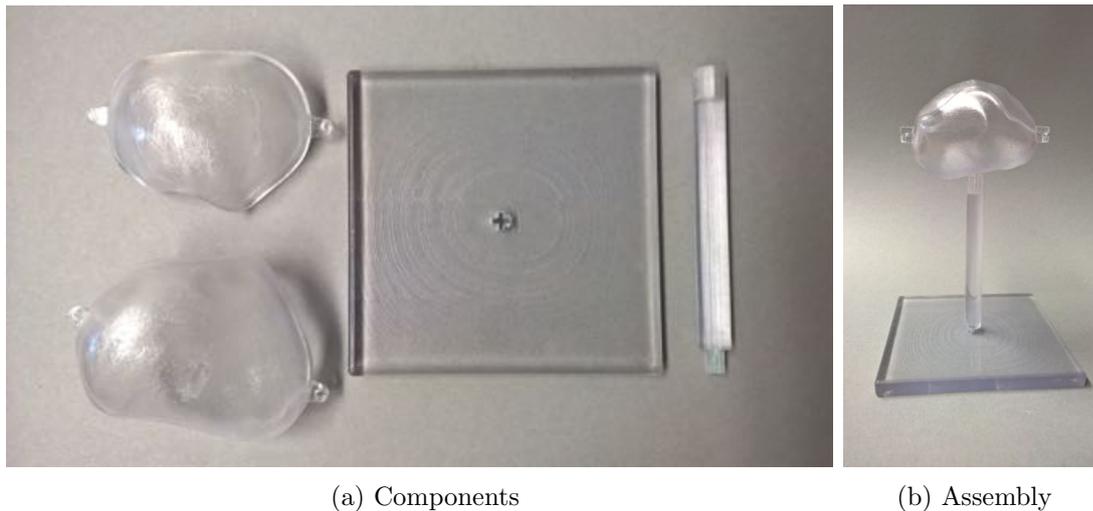


Figure 3.4: 3D print of a general prostate model.

printed prostate model. Using the software tools MeVisLab¹¹ and MeshLab¹², the segmentations were converted into a file format that can be used in Unity3D. The results are illustrated in Fig. 3.5. Models of vessels and rectum have been added at a later stage, see Fig. 3.13. The vas deferens is omitted for it has no value in the general use of the application.

As opposed to what is proposed in the first sketches (see Fig. 3.6b), data sets can not be added during runtime.

During development, the focus for the user interaction changed from a purely display-based input to a 3D-print focused way of controlling the software.

Early on, simple on-display buttons were used. This kind of user interaction is standard on touch screen devices. The application features sliders to change the opacity for each model as well as check boxes to hide them instantaneously.

3.4.3 UI Concept

The first UI concept, that is being altered, prototyped and reiterated later in this chapter, was drawn by hand and turned into a mock-up (refer to Fig. 3.6). The figure shows a so-called table view on the left, and the AR screen with additional

¹¹www.mevislab.de

¹²<http://meshlab.sourceforge.net/>

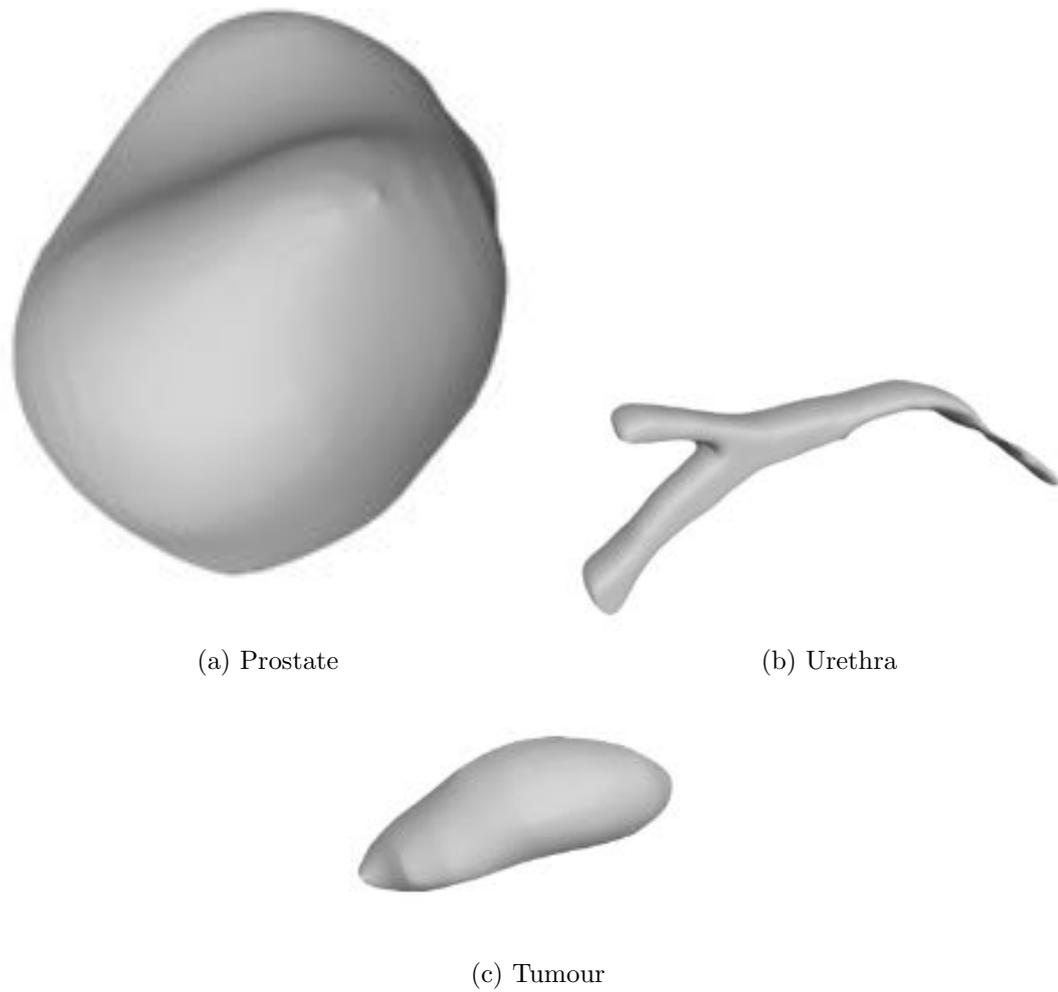
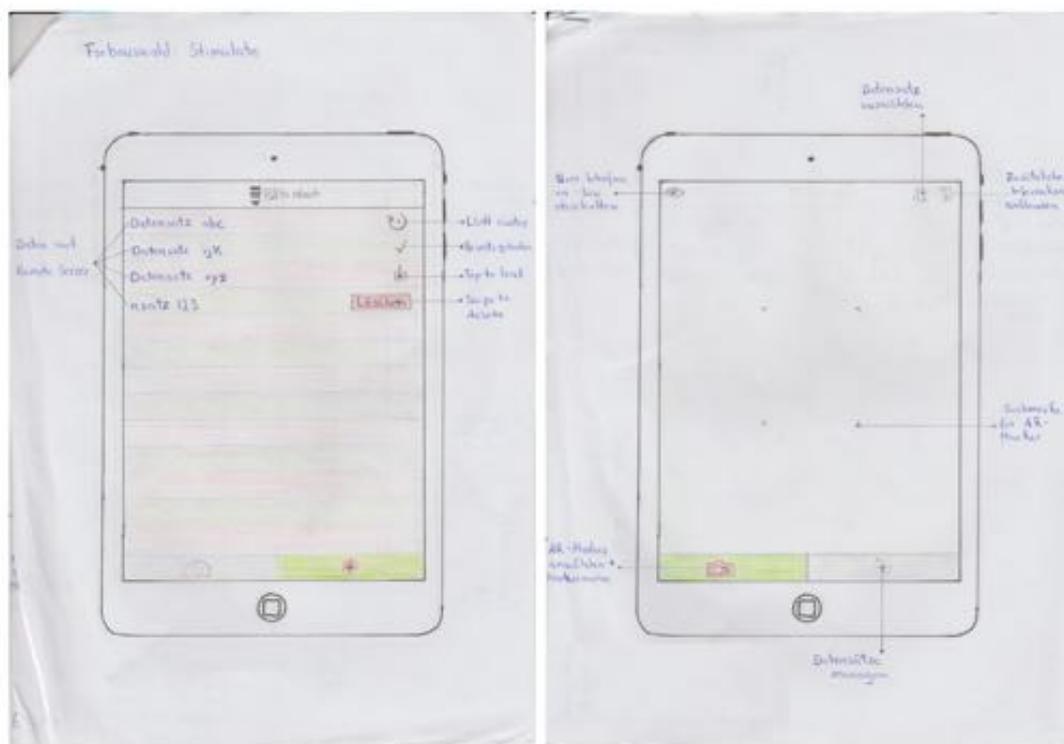


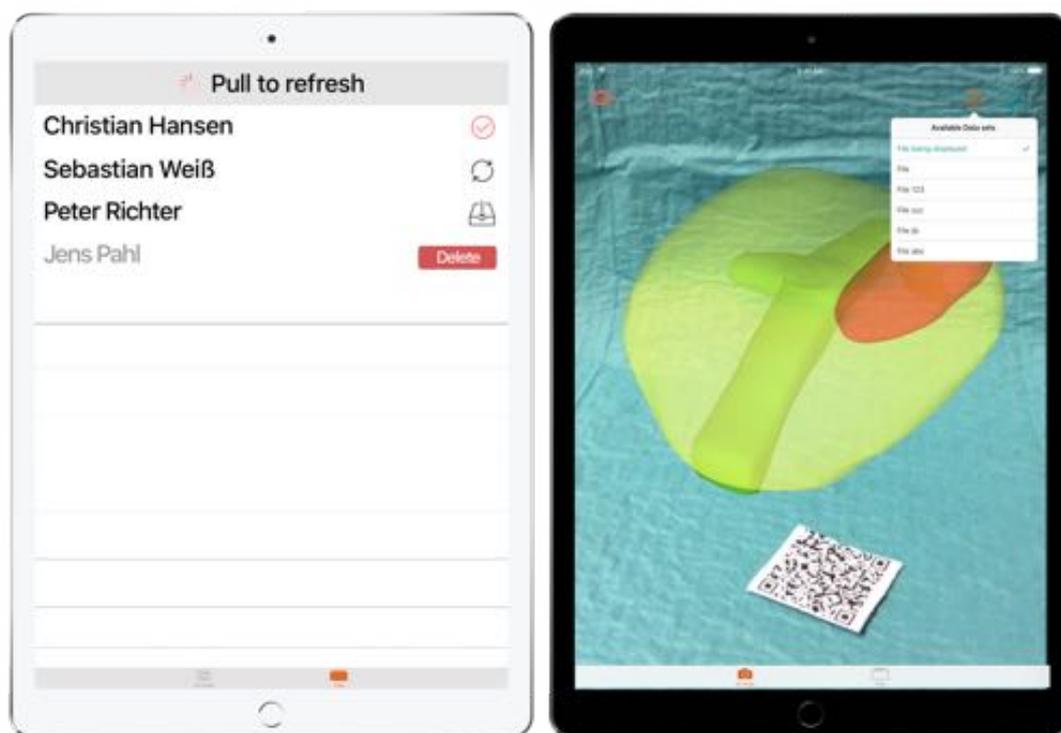
Figure 3.5: Digital representations of anatomical structures. These models are used in in the application.

elements on the right. Table views are commonly used to display several entries of data in a database, or to present a list of options. Here, it was used to show how several target sets can be kept within the application, so to offer the ability to serve in doctor-patient interviews with several patients. The right hand side shows the AR screen. This screen shows the camera stream, superimposed with the digital content when the marker has been found. UI elements for user interaction are shown, even though most of them have been added in the iteration cycle.

The focus of development was then shifted towards the augmentations.



(a) Hand drawn sketches



(b) Software mockups

Figure 3.6: Early design mock ups for the user interface.

3.5 Prototyping Lifecycle

The development for UroMagicLens was conducted according to guidelines described in the user centred design process (see chapter 3.1) and thus began with a rather bare boned prototype. The tangible model had not been built to that time. The prototype used an image of gravel as a marker, and simply visualised the models above that marker. However simple this application was, it served as an important proof of concept: The high amount of features in the gravel allowed for stable tracking, even when the target was folded or crinkled. As an early version, the shader for the prostate object was chosen arbitrarily to something clearly visible. This version did not feature any UI elements, as can be seen in Fig. 3.7.



Figure 3.7: iPad screenshot of an early prototype, featuring a gravel marker image and a mirroring shader.

In the apps first iteration, a less arbitrary marker was chosen. The Vuforia developer website allows for the upload of any image so to use it as marker, and it also conveniently shows a rating of the quality (Augmentable Rating) of the resulting marker. This rating ranges from 0 to 5, where 0 indicates that the image cannot be tracked, whereas an image that was evaluated with a 5 is very easily trackable. According to the developer website, criteria for the evaluation are the number of features, local contrast and distribution of features within the image.

At first, a QR Code (see Fig. 3.8a) was created. The strong contrast between the black and white areas - especially on corners - can easily be detected by a threshold algorithm (see Fig. 3.8b). The high amount of features resulted in a 5 star rating by the Vuforia developer platform, as can be seen in Fig. 3.8c.

Another change was the switch to individually coloured, slightly transparent shaders for the content, so that the relation of the objects to each other became visible. These changes are reflected in Fig. 3.9.

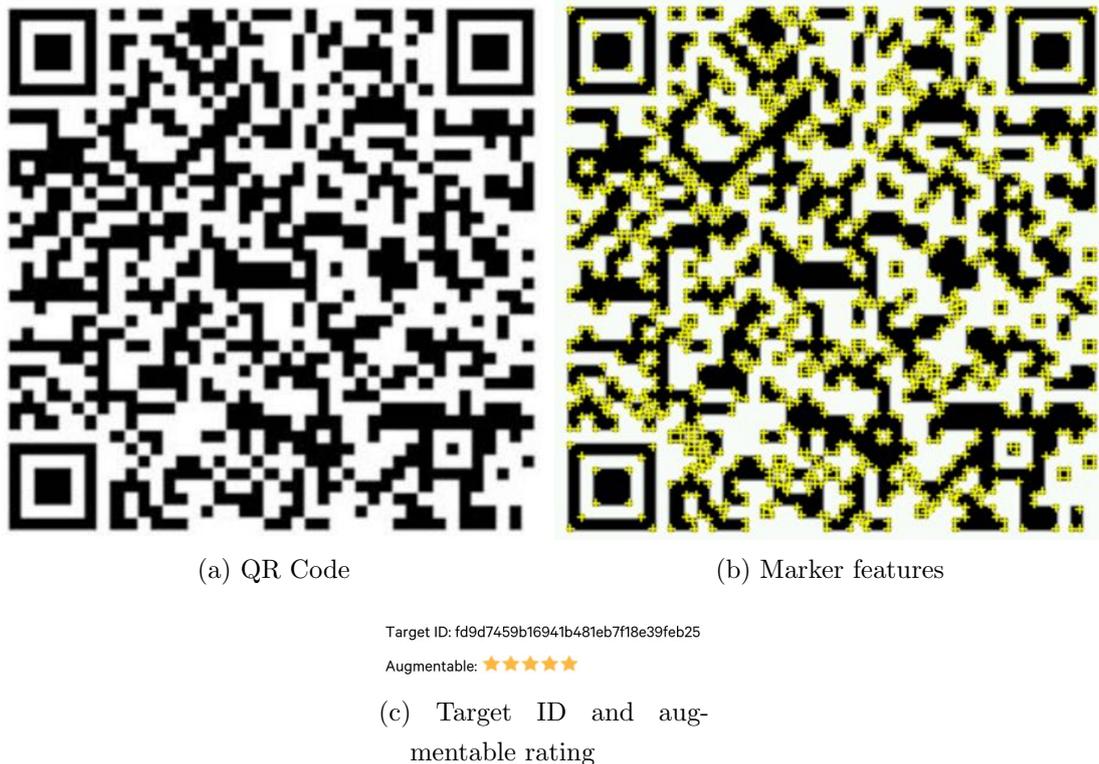


Figure 3.8: QR Code-marker and its augmentable rating.

To add basic interaction, UI elements were added to the application. These allowed changes in opacity of the augmentation by dragging the slider. Moreover, individual models could be made invisible by simply unchecking the related check box. Lastly, the UI could be turned on and off by using another button. Example screen shots outline the user interface in Fig 3.10. Further, it was decided that the QR marker had to be replaced with something less distracting. Instead, the *STIMULATE* logo was employed to serve as a marker.

The UI elements were altered so that the interface would auto rotate with the

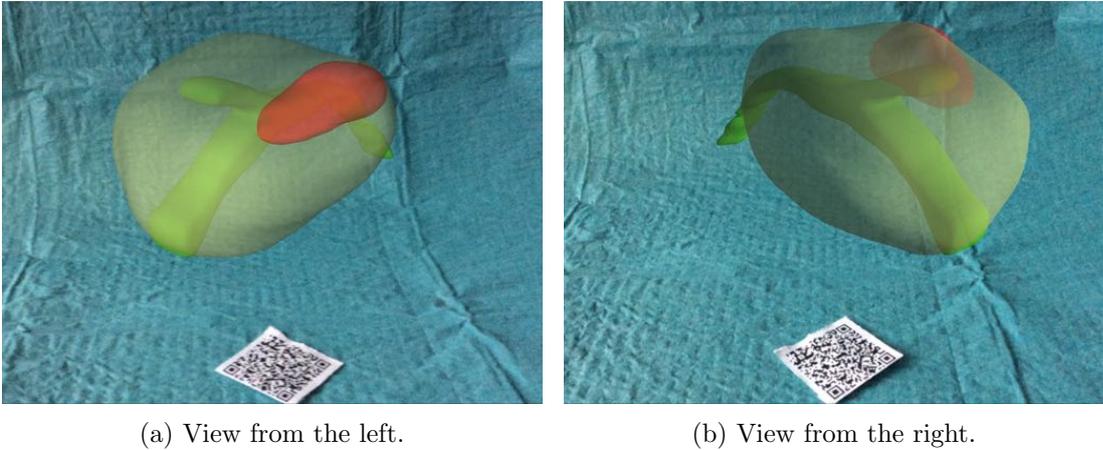


Figure 3.9: First iteration with unique shaders and a QR code as marker.

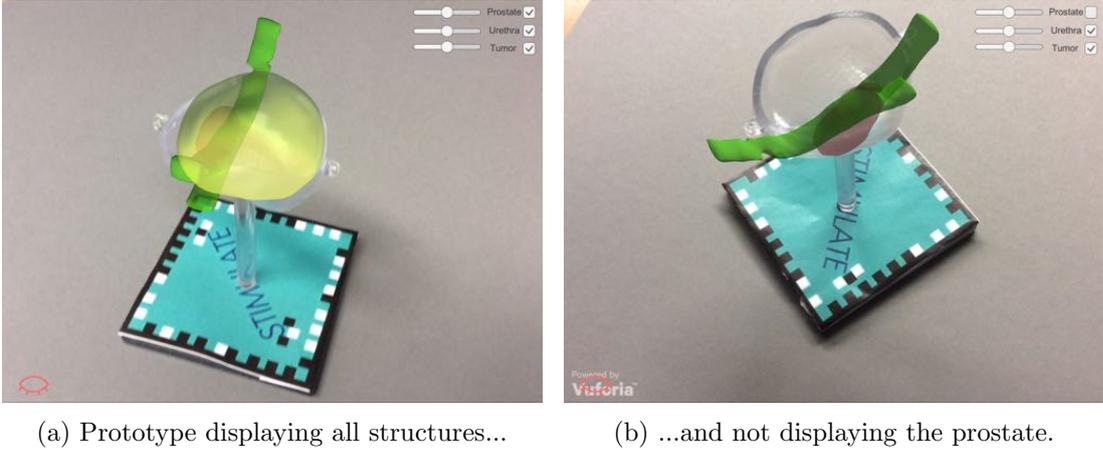


Figure 3.10: Second iteration with UI, *STIMULATE* Marker and basic interaction.

device. Because the 3D print was finished to this point in time, sizes and positions of the digital models had to be adapted.

The Vuforia plugin allows to track objects, given that the object provides enough features, such as changes in colour, edges, and contrasts. Furthermore, the requirements for the interaction now shifted away from the display, towards a more direct manipulation of the model. A promising approach was to simulate the ablation of a tumour by a needle-like object. This idea required the needle to be known so it can be masked with a depth shader for a more sophisticated augmentation by improving the depth perception.

To turn an object into a trackable object - an object with known features - it had to be placed in a known 2D environment. The setup is provided by Vuforia and is depicted in Fig. 3.11. In order for the simulated ablation to work, both - the 3D printed model and the needle - had to be turned into objects, see 3.11a and 3.11b.



(a) Object tracking setup with 3D model.

(b) Object tracking setup with “needle”.

Figure 3.11: Setup to turn objects into trackables.

However, it turned out that software was not able to recognize the objects. Possible reasons are the form of the objects, which in case of the both prostate model and the “needle” is quite homogeneous and thus do not show any features. Additionally, the see-through but also reflecting material of the 3D print aggravates the feature finding even more.

When the object-tracking approach proved to be infeasible, the application was reverted to using a marker image. However, it was discovered that due to a low number of features, the *STIMULATE*-logo based marker had a low tracking

quality. Trading design for tracking accuracy and stability, the QR code-based tracker was used again. Nonetheless, to shift interaction from the iPad to the printed model, another concept was developed. By using virtual buttons, the marker itself was enabled to serve as an interaction surface.

Virtual buttons (VB) allow to control features of the application by occluding marks on a printed sheet of paper. These marks include features, similar to the edges on the QR code. The sheet of paper with the symbols on it serves as an image target. During development, virtual buttons are positioned over the feature-including symbols. When the camera is pointed onto the printed sheet, the user may occlude those symbols and thus render the features invisible to the software. Occluding symbols subsequently fires an action, as the VB is now considered as pressed. Although several buttons can be used on a single marker image, bigger spacing between the buttons simplifies usage. Using digitally visible buttons, i.e. squares that are visible on the display, would result in depth perception irregularities, so instead the graphics are directly printed. This still allows for putting small digital content above the images, for example rotating 3D models. Additionally, using the same marker impedes the possibility of turning the model, while operating the buttons at the same time. For this reason, the use of a secondary image marker was proposed. This second marker, as shown in Fig. 3.12 simply shows the function of each button as a printed representation, as opposed to augmenting it on the iPad.

The images on the right side of the row represent the digital models. A single model can be activated by covering the corresponding graphic. Then, the plus and minus buttons can be used to change the opacity. This way, the interaction offers the same functionalities as on the iPad's display, but the interaction with elements close to the 3D print comes with a deeper connection to the model.

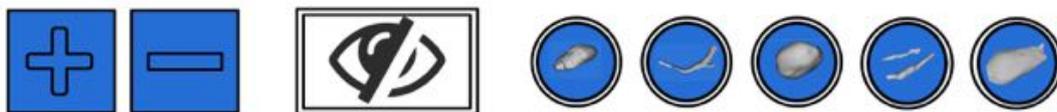


Figure 3.12: Secondary marker, serving as an interaction surface.

With this last iteration of the prototype, the set of anatomical structures of

interest is complete, consisting of prostate, urethra, tumour, (blood) vessels and the rectum. The image target as well as the display-controlled interaction support these new models by allowing interaction.

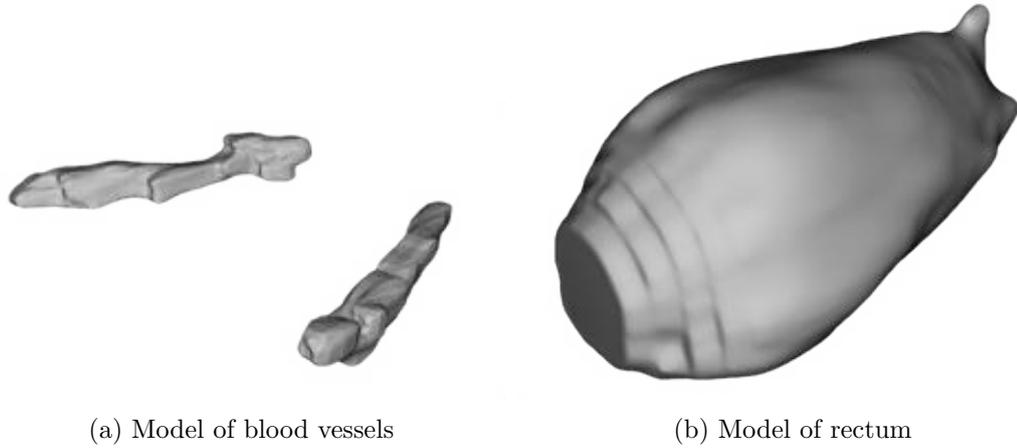


Figure 3.13: Added models of blood vessels and the rectum.

Fig. 3.14 shows the proposed working setup, with the iPad mounted on a flexible holder which is fixed to a desk. The iPads camera is pointed towards the model and the image target which is used for interaction. The user can now interact with the iPad or image target using both hands. This is especially handy when using larger iPads. Here, an iPad mini is used, which is light enough to allow for extended holding without tiring the users arm. The same setup is used during the study, see chapter 4.

In the next chapter, the finished prototype is being evaluated for its intuitive use and its usability. The evaluation is also the last step in a full UCD cycle.



Figure 3.14: Setup for interacting with the prostate model while explaining possible treatment methods to a patient.

4 Evaluation

To evaluate UroMagicLens, different questionnaires are used. Usability and intuitive use are assessed by means of questionnaires. The first questionnaire is called ISONORM. Based on ISO 9241/110, it deals with measuring the usability [48]. Usability is important to give patients and easy-to-use tool. The second questionnaire is QUESI, a standardized questionnaire for intuitive use [25]. Intuitive use will ease the cognitive burden on elderly patients trying the app and give them an easy way of educating themselves. Both questionnaires will be filled out twice, so to compare the touch-interaction on the iPad's display with the interaction using the printed image target.

The null hypothesis H_0 for this experiment is that there are no significant differences in the scores for each questionnaire. The alternative hypothesis (H_a) is that the display based interaction scores significantly better than the paper based paradigm. A significance level of $\alpha = 0.05$ was chosen, as this value is sufficient to determine the outcome of the experiment. Also, this significance level of 0.05 is acceptable for most hypothesis-driven experiments. As we deal with a directed test, a one-tailed, paired t-test is executed. The hypotheses are based on the following assumptions:

- Touch displays are a ubiquitous way of handling a wide array of devices, primarily mobile phones and tablet computers.
- The video see-through paradigm is altered in the paper based interaction. The distortion in the FoV by the device's camera alters results in the user looking past the tablet, not through it.

4.1 Study Design

To test the hypothesis, the questionnaires described above were answered by every user. The experiment sequence is following:

- Each participant is assigned a number 1 or 2. A random number sequence containing ones and twos was obtained from random.org, a website creating random numbers from atmospheric noise instead of pseudo random algorithms found in many programming languages.
- Each participant may play around with the app to familiarize themselves with both kinds of interaction and the features it offers.
- Depending on the assigned number, one of two task blocks must be processed. The blocks differ in task sequence and which way of interaction is evaluated first. The tasks include typical interactions with the software.
- In between the two task blocks, QUESI and ISONORM are answered with respect to the first task block (Q1). After the second block, both questionnaires are answered again, this time regarding the other way of interaction (Q2). In between two task blocks, the application is put in its default settings by restarting it on the iPad.

A graphical representation of the sequence is display in Fig. 4.1.

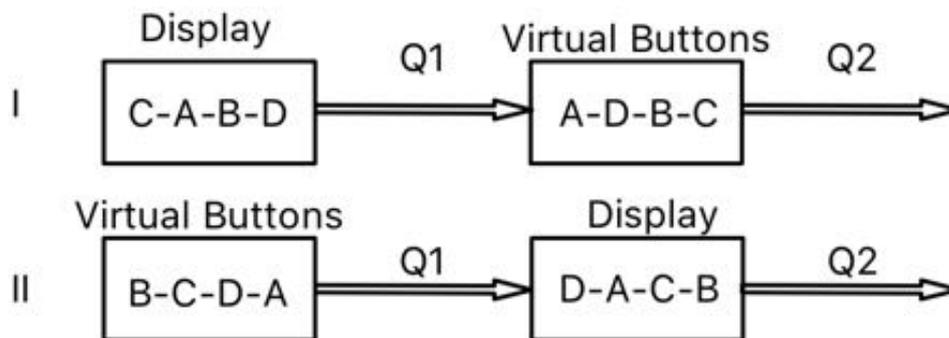


Figure 4.1: Sequence plan for the experiment

The letters A to D refer to the list of these tasks:

- (A) Hide prostate, urethra, rectum.
- (B) Lower the visibility of prostate and increase the visibility of the tumour.
- (C) Hide rectum, vessels, urethra and increase visibility of the prostate.
- (D) Turn the printed model around, holding it at its socket (not the pillar, not the model), so you can view the 3D models from all angles.

The participants were filmed while they were completing the tasks to measure the time taken and to record eventual spoken comments regarding usage or any problems. The set up, from the cameras point of view, is shown in Fig. 4.2.



Figure 4.2: The figure shows the proposed setup, as it was used during the evaluation of the app.

To prevent language-based comprehension mistakes, participants were given either German or English questionnaires, depending on their choice.

To check the feasibility of the study, a small pilot study with one user was conducted. The task sequences were tested and the hardware was checked for functionality. However, it was not realised that simply fixing the sheet of paper with the virtual buttons would greatly improve the handling. This was criticised later. Testers were given as much time as needed to familiarise themselves with the application and the interaction paradigms.

The group of participants ($n=11$, male: 11, female: 0) comprised 5 urologists, 2 Ph.D. candidates, 2 research assistants, 1 student in digital science, and 1 medical student. 10 of the participants had more than 12 months of experience

using mobile devices with touch screens. However, only two had prior contact with augmented reality and only one is using AR on a regular basis (more than 0.5h/week). The average age of the participants was 31.2 years, ranging from 24 to 41.

The t-test has been run on the summed scores of each participant per questionnaire, both with ISONORM and QUESI. This differs from the way the questionnaires are meant to be evaluated. The results of both evaluations per questionnaire will be given further below.

4.2 Evaluation of Usability

To grade and improve usability of a software, it should be evaluated with respect to the seven objectives of software design. Prümper [48] developed a questionnaire that covers these objectives with 21 questions (3 per objective). As it is based on the usability specification of ISO 9241, Part 110, ISONORM was chosen as the tool to measure usability. Its broad language makes it suitable for a lot of different software systems and yet is fine enough to differentiate between specific properties of different interfaces [48]. The questionnaire is standardised and a well-known tool in the literature, for example Hurtienne et al. [26] and Mewes et al. [40]. However, ISONORM is not a substitute for a deeper analysis. Its results give hints as to which aspects developers and designers need to improve.

- Suitability for the task
- Self-descriptiveness
- Controllability
- Conformity with user expectations
- Error tolerance
- Suitability for individualization
- Suitability for learning

Each item can be answered on a 7-step Likert-scale. Scores for each sub scale (objective) are calculated by adding up the mean answers for each question within that objective. For this project, some questions on the questionnaire have been deemed inapplicable, so although they have been answered on paper, they have been excluded from evaluation. The excluded questions deal with switching of menus or masks (question marked as sk2), display of error or error messages (ft1,2) and individualisation (lk1,2,3), since individualisation is not possible at all and thus should have been graded as very low. As a consequence, the objective of customisation has been excluded completely. The resulting maximum score for the ISONORM questionnaire is 105 instead of 147.

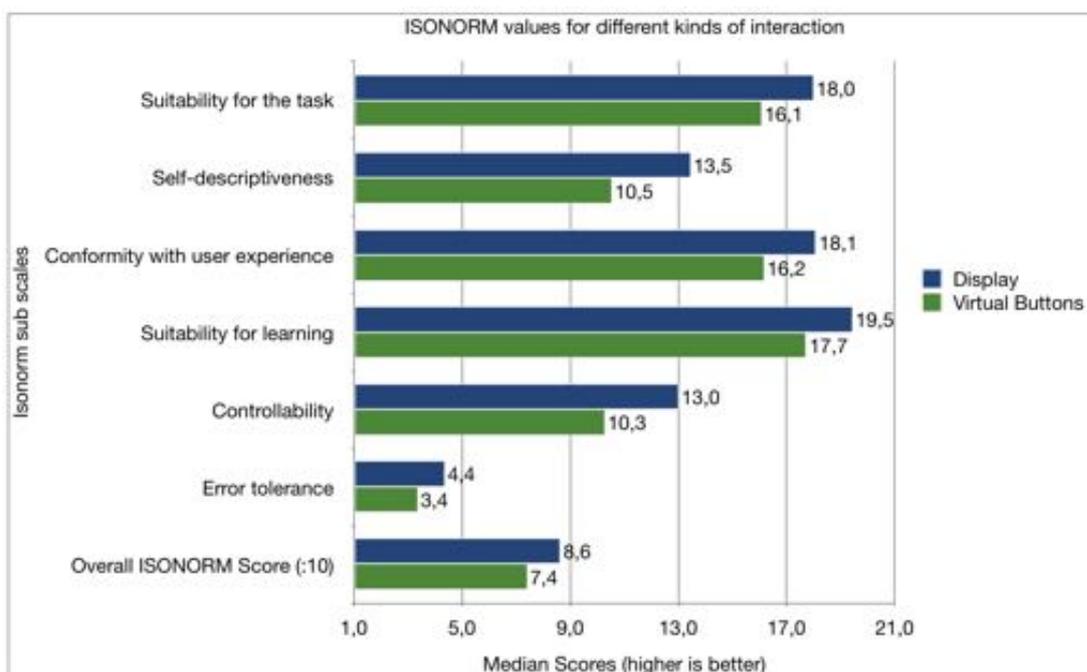


Figure 4.3: Results of the ISONORM scale.

The ISONORM score, the final overall result of the questionnaire, is then calculated by adding up the scores of the sub scales. Since the addition of the sub scales naturally results in a high number, in Fig. 4.3 the actual score was divided by ten to better fit in in the graph - because it would distort the sub scales - and to make it more comparable. For objectives with all questions taken into account, a maximum value per objective is 21, 10.5 is regarded as neutral. Everything below that should be improved.

According to [48], with results of at least 15 in each sub scale, the application is considered to allow for effective and efficient usage.

Both interaction methods have been found suitable for the task (18.0 for display, 16.1 for VB) and for learning (19.5 for display, 17,7 for VB). Taking into account that one question from the relevant sub scale has not been taken into consideration, the display based method scored very high in controllability (13.0 out of 14). The paper based scored above average - here 7 - with 10.3 out of 14. A lot of errors happened due to unintentional activation of buttons next to the intended one, which lead to frustration, resulting in a lower score in error tolerance for the virtual buttons (3.4 out of 7). The display based paradigm scores better than neutral (4.4 and out of 7). For statistical tests, the scores per participant have been noted. Summed up, these were used for a directed paired t-test, comparing mean evaluations of the users in QUESI and ISONORM and to prove or disprove H_0 . Figure 4.4 shows the results of summed scores per questionnaire. The t-test calculations showed a significant superiority ($p = 0.0045$, $t = 3,25$, $df = 10$) of the display based paradigm over the paper based. Thus, it can be concluded that, by the measures the ISONORM questionnaire, the display based paradigm offers statistically significant higher usability. A more detailed output of the statistics software can be found in the appendix.

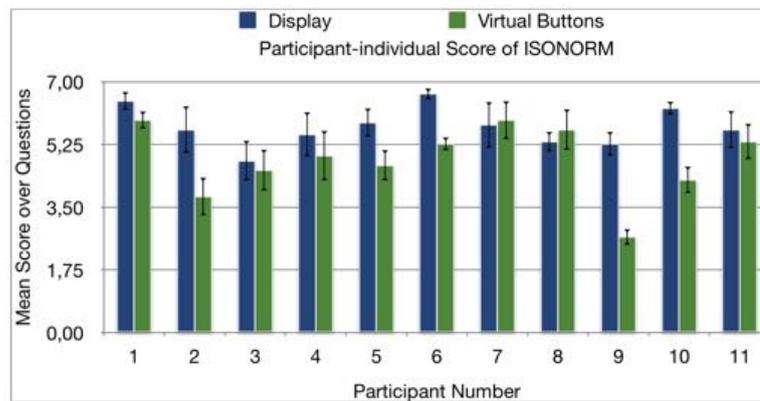


Figure 4.4: ISONORM results on a per-user base with error bars showing standard error of mean score over 18 questionnaire items.

From 11 participants, 6 evaluated both interaction paradigms with a very similar result. Mean scores ranged from 4.8 to 6.67 per item for the display paradigm with standard deviations between 0.9 and 2.16. For the virtual buttons, mean scores between 2.67 and 5.93 were recorded, with standard deviations between

0.59 and 2.28. The generally lower mean score for the virtual buttons paradigm is another indicator for the result of the experiment.

4.3 Evaluation of Intuitive Use

The “Questionnaire for the subjective consequences of intuitive use” (QUESI) is standardised questionnaire, consisting of 14 items. It was chosen because, in contrast to the ISONORM questionnaire, it evaluates the subjective perception of the user. The questionnaire is also standardised and has been used in previous studies, e.g. Saalfeld et al. [52] and Müller [44]. The way the questions are phrased make QUESI suitable for different kinds of software. Answers for each question are given on a 5-step Likert-scale (1 = fully disagree, 5 = fully agree), forcing a decision of the user. The questions are asked so that a higher number means a better result. Every item on the QUESI is assigned to at least 2 of 5 sub scales:

- Subjective mental workload
- Perceived achievement of goals
- Perceived learning effort
- Familiarity
- Perceived error rate

In contrast to the ISO 9241-110 questionnaire, the median over each sub scale is calculated (instead of sum of averages). The final score is then computed by finding the mean over the results of the sub scales [25, 44]. This means the diagram in 4.5 shows the QUESI score as a mean, not as a median.

With 5 being the best possible result, 3 is considered neutral and results below that should be improved.

While the paper based input method rarely scores better than average (neutral) and indeed shows a bad result in the first sub scale (Perceived error rate), the display based interaction outperforms it in every metric. The subjective mental workload was not considered too high (3.82). Participants were quick to achieve their goals (4.64), with little learning effort (4.55) due to the high familiarity

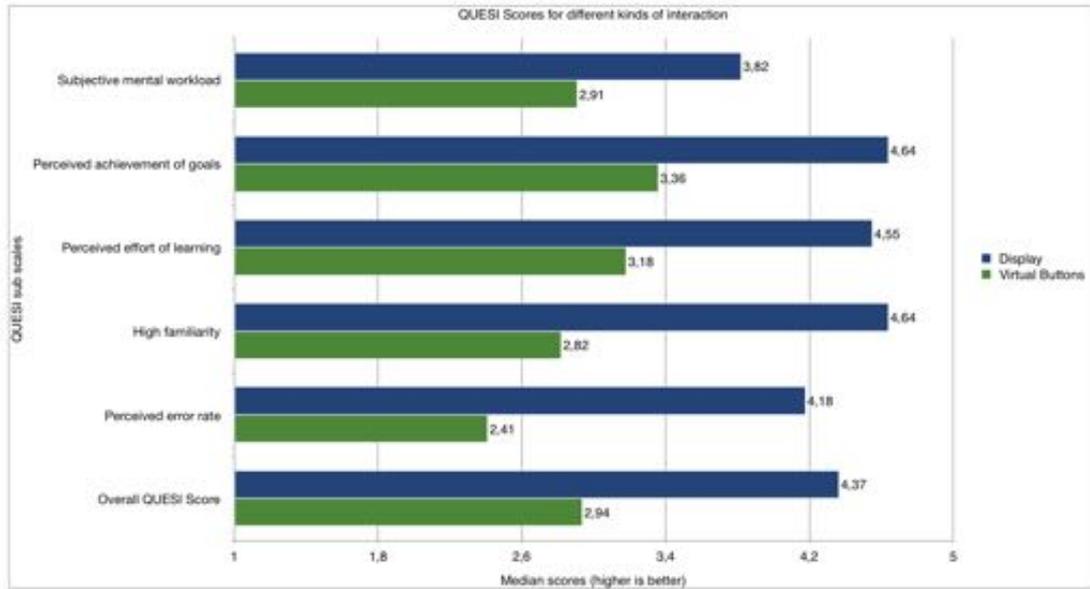


Figure 4.5: Results of the QUESTI questionnaire

(4.64). This high familiarity also explains the low error rate (4.18). However, UroMagicLens can be improved by easing the mental workload, e.g. by improving the interface, making it more self-descriptive (where it scored lowest in the ISONORM questionnaire).

The subjective mental workload in the paper based method is worse than in the touch based interaction (2.91), making an efficient goal achievement harder (3.36). Using the application has a higher learning curve (3.18) due to the uncommon interaction method. This results in less familiarity (2.82) than with its display based counterpart. The high error rate is mostly explained by the unintentional activation of virtual buttons. Another cause is the attempt to use both display and VB based together. Overall, the paper based paradigm scores 4.4 out of 5, vs. a nearly neutral - 3.12 out of 5 - result in the virtual button paradigm. As well as it has been done with the ISONORM questionnaire, the QUESTI results have been summed up on a per-user base and a t-test was performed on the results. The one-tailed t-test shows a significantly better evaluation ($\alpha=0.05$, $p=0.003$, $t=3.503$, $df=10$) with the QUESTI questionnaire as well. More detailed results are attached in the appendix. Figure 4.6 shows the summed results of each evaluation, with error bars showing the standard error of the mean over all questionnaire items.

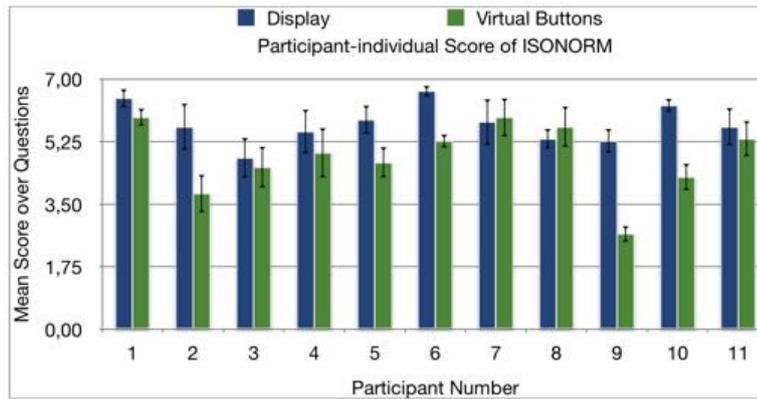


Figure 4.6: QUESI results on a per-user basis with error bars showing standard error of the mean over all 14 questionnaire items.

Similar to the ISONORM questionnaire, mean scores for QUESI were also higher for the touch based paradigm, ranging between 3.5 and 4.93 (out of 5), compared to the lower scoring virtual buttons (1.93 to 4.43). Participants were also less divided in the results for the virtual button paradigm, with standard deviation ranging from 0.47 to 1.36, whereas the touch based interaction is between 0.27 and 1.29. These values show that the participants agreed more on the lesser graded paradigm.

Both questionnaires show, in their own way of evaluation and also statistically by means of a one tailed, paired t-test, that interacting with the application through the display is the favoured paradigm.

In chapter 5 some possible techniques are introduced which can greatly enhance both usability and features of the application.

4.4 Comparison of Evaluation Results

The participants required between 76 and 143 seconds ($m = 120s, SD = 33s$) to finish the tasks using touch-based controls. For the VB-based interaction, it generally took more time for the participants to finish. Minimum required time was 143 seconds, maximum 387 ($m = 253s, SD = 82s$). Total time required was $\Sigma = 1079s$ (17min, 59s) for the touch based interaction and $\Sigma = 2527s$ (42min, 7s) for the virtual buttons, respectively.

As one can see, interacting with the display scores higher throughout each metric. On the one hand, this can be explained by the fact that 10 of 11 participants had more than 12 months of experience with using touch screens. Using virtual buttons, however, was new to all of them. On the other hand, the concept of virtual buttons breaks the focus of the user: while interaction happens on the paper, results are shown on the display. While evaluating the video footage of the experiment, it became clear that people were confused as where to look while working on the given tasks. Since the camera's FoV and the users point of view (PoV) differ in their perspective, users would have a misaligned view, comparable to the effect when watching something in the water from above.

The t-test results emphasize on the results, clearly showing that operating the app through the display is perceived as easier, quicker and less error-prone than by virtual buttons on a printed image target.

4.5 Concluding Remarks

A lot of participants mentioned an inconsistency between the interaction with virtual buttons and the display. Most often, it was criticised that the two methods were not able to be used interchangeably, i.e. a model that was marked active by touching it on the display could not be hidden or altered using virtual buttons. Furthermore, changing the opacity of a model using VB would not update the UI on the display (i.e. changing a slider value correspondingly, when the opacity of a 3D model was changed). This criticism has its grounds, however, the ways of interaction were never meant to be used at the same time. The urologists further mentioned a translation mistake: the german translation mistakenly labelled the urethra "Samenleiter", which is the vas deferens.

It was stated by the participating urologists that the prototype of UroMagicLens, that has been developed in this master project, is a helpful tool, however not without weaknesses that ought to be addressed. One of the specialists further mentioned, that he would not require the 3D print is for himself during the talk with the patient, but might turn out very helpful in understanding three dimensional relations in case the patient takes the print home to discuss possible treatments with their spouse.

While the low number of participants might not give representative results, they give some insight over the current state and future direction of this project. The comments and wishes of the participating medical specialists can be used to turn the prototype into a useful application for everyday use.

5 Conclusion and Future Work

In this thesis, an application for the support of patient education in urology using AR was developed, prototyped and evaluated. After an introduction into the underlying topics - patient education, urology, mobile technology and AR - the fundamentals of augmented reality are explained and discussed. These chapters are followed by the development and prototyping cycle of an iOS-based AR application using Unity3D. The applications interaction paradigms that have been described within the last chapters have then been evaluated and compared regarding usability and intuitive use.

The application was developed as a tool to help medical specialists convey information to patients, mostly laymen. The prototyping phase proved that the tool chain used allows for quick reiterations and fast and simple changes.

Digital Models The digital models used to augment the 3D printed model were arbitrarily coloured, making it more abstract as opposed to a more realistic colour scheme, which can and should be implemented. On the other hand, the digital models have been found as being too detail-rich: edges and dents, often artefacts stemming from the processing pipeline from the imaging modality to the modelling software, can easily confuse patients. These artefacts might lead to questions regarding the health of the patient. Depending on the form of the object, e.g. compact for the rectum, or elongated for the vessels and the urethra, other smoothing algorithms may be employed. However, based on the comparison of smoothing algorithms by Bade and Preim [5], a low pass filter seems suitable for all structures. Also, adding models of different patient should be enabled. This feature was previously planned but were not implemented in the prototype. An example UI for switching between model was shown in Fig. 3.6. The feature would, for example, allow a more seamless loading of models to enable physicians

to readily have data of those patients available, who all have an appointment at the same day.

Usability and intuitive use The findings of the research conducted clearly show that using the display as a primary interaction and manipulation tool is favoured by many participants due to its more natural and less error-prone handling.

When using the paper based interaction paradigm, the arrangement of the virtual button should be reconsidered in order to fix the double activation issue that has been criticised. One should further take into consideration to either combine or completely separate the two interaction paradigms. In the current state, they cannot be used in combination.

Further evaluation The application has only undergone evaluation with respect to its usability. However, it must be evaluated regarding its usefulness, too, i.e. how well a patient understands the information provided. This can be done similar to Breulers et al. [29], where some patients had undergone purely computer-based training. Similar work was presented by Strömberg et al. [57], Heikinnen et al. [24], and Enzenhofer et al. [17]. All these groups compared patient knowledge after some form of computer-aided patient information with traditional, face-to-face doctor-patient interviews.

Room for improvement To improve the application in other ways, one might include labels for the anatomical structures that keep their orientation towards the view port for simple reading, see Oeltze et al. [1], possibly using the front camera and to use gaze based annotations, similar to Saalfeld et al. [53]. As has been noted before, realistic textures instead of arbitrary colouring is another step towards higher realism. However, these textures might turn out as a complicated endeavour since they would have to fit the patient-specific forms and sizes of the prostate gland as well as other displayed structures. A better depth visualisation may be conferred using similar visualisation techniques as [22] and [33]. Using an HMD instead of a tablet computer for the VST paradigm, implementation of stereoscopic rendering is also possible, as presented by Kutter et al. [60].

Based on the findings, but more importantly the comments from medical experts in chapter 4, one can safely presume that the resulting application has the potential to support patient education in urology and thus improve the situation for all parties involved. Coming through with the proposed changes and additions above, UroMagicLens might be able to support the doctor-patient interview and to aid in decision making when planning therapies.

6 List of Acronyms

AMD	Age-related Macular Degeneration
API	Application Programming Interface
App	Piece of software for mobile devices, also: Application
AR	Augmented Reality
BARS	Battlefield Augmented Reality System
BCI	Computer-Brain-Interface
CAD	Computer Aided Design
CAS	Computer Assisted Surgery
CT	Computed Tomography
ETT	Endotracheal Tube
FoV	Field of View
HMD	Head-mounted Display
HPS	Human Patient Simulator
iOS	Operating System for mobile Apple devices
IDE	Integrated Development Environment
MR	Mixed Reality
MRI	Magnetic Resonance Imaging
NMRI	Nuclear Magnetic Resonance Imaging
OR	Operating Room
PoV	Point of View

SAR	Spatial Augmented Reality
SDK	Software Development Kit - a collection of classes, methods, and APIs to develop software
SINA	Sina Intraoperative Neurosurgical Assist
UCD	User Centered Design
UI	User Interface
US	Ultra Sonic
UX	User Experience
VB	Virtual buttons - augmenting buttons on a paper surface
VR	Virtual Reality
VRML	Virtual Reality Markup Language
VST	Video-see-through

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A Appendix

All appendices can be found on the accompanying DVD.

A.1 Native Unity Project

To see the Unity project, please open “UroMagicLens/native_unity_build/” using Unity3D. This folder also includes the 3D models of the anatomical structures.

A.2 Xcode Project

To see the iOS build (Xcode project), please open ‘UroMagicLens_iOS/Unity-iPhone.xcodeproj’. You will need a Macintosh computer with Xcode installed.

A.3 Questionnaire Sheets

The questionnaires have been combined into a single .pdf document and can be found in the ‘Questionnaire sheets’ folder on the DVD.

A.4 Thesis

The latex files and all images have been included in the “Latex” folder.

A.5 Results for t-test Calculations

T-TEST PAIRS=Display_ISONORM_Sum_of_Scores WITH VB_ISONORM_Sum_of_Scores (PAIRED)
 /CRITERIA=CI(.9500)
 /MISSING=ANALYSIS.

T-Test

Notes

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Comments		
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	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	11
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax	T-TEST PAIRS=Display_ISONORM_Sum_of_Scores WITH VB_ISONORM_Sum_of_Scores (PAIRED) /CRITERIA=CI(.9500) /MISSING=ANALYSIS.	
Resources	Processor Time	00:00:00.01
	Elapsed Time	00:00:00.00

[DataSet1] /Users/sebweiss/Desktop/master.sav

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Display_ISONORM_Sum_of_Scores	117.3636	11	10.63271	3.20588
	VB_ISONORM_Sum_of_Scores	98.7273	11	19.01626	5.73362

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Display_ISONORM_Sum_of_Scores & VB_ISONORM_Sum_of_Scores	11	.279	.405

Paired Samples Test

		Paired Differences					t
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		
					Lower	Upper	
Pair 1	Display_I SONORM_Sum_of_Scores - VB_I SONORM_Sum_of_Scores	18.63636	19.01722	5.73391	5.86042	31.41230	3.250

Paired Samples Test

		df	Sig. (2-tailed)
Pair 1	Display_I SONORM_Sum_of_Scores - VB_I SONORM_Sum_of_Scores	10	.009

T-TEST PAIRS=Display_QUESTI_Sum_of_Scores WITH VB_QUESTI_Sum_of_Scores (PAIRED)
 /CRITERIA=CI(.9500)
 /MISSING=ANALYSIS.

T-Test

Notes

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	Weight	<none>
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	N of Rows in Working Data File	11
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax	T-TEST PAIRS=Display_QUESTI_Sum_of_Scores WITH VB_QUESTI_Sum_of_Scores (PAIRED) /CRITERIA=CI(.9500) /MISSING=ANALYSIS.	
Resources	Processor Time	00:00:00.01
	Elapsed Time	00:00:00.00

[DataSet1] /Users/sebweiss/Desktop/master.sav

Paired Samples Statistics

	Mean	N	Std. Deviation	Std. Error Mean
Pair 1 Display_QUESTI_Sum_of_Scores	61.6364	11	7.44678	2.24529
VB_QUESTI_Sum_of_Scores	44.1818	11	14.44866	4.35643

Paired Samples Correlations

	N	Correlation	Sig.
Pair 1 Display_QUESTI_Sum_of_Scores & VB_QUESTI_Sum_of_Scores	11	-.041	.904

Paired Samples Test

	Paired Differences					t
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		
				Lower	Upper	
Pair 1 Display_QUESI_Sum_of_Scores - VB_QUESI_Sum_of_Scores	17.45455	16.52491	4.98245	6.35296	28.55613	3.503

Paired Samples Test

	df	Sig. (2-tailed)
Pair 1 Display_QUESI_Sum_of_Scores - VB_QUESI_Sum_of_Scores	10	.006