Mobile Augmented Reality and 3D Printing to Involve Patients in Treatment Decisions for Prostate Cancer

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Abstract *For prostate therapy, the involvement of patients in the decision process is of increasing importance. However, transferring knowledge to the patient often proves to be difficult because the concerned organ is not visible and the available image data is too complex to interpret for non-physicians. To improve the situation, our work aims to developing 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 the status quo are conveyed in a simple to understand manner. Our AR application supports two different interaction paradigms that are compared in a user study with 11 participants. The study aimed at evaluating usability (ISONORM) and intuitive use (QUESI). Our results show, that completion of the given tasks was done faster on the touch display (mean = 120s, s = 33s) compared to virtual buttons (mean = 253s, s = 82s). In addition, the data collected from the questionnaires revealed that display-based interaction is better suited for the defined task.*

Keywords: Medical Visualization, Augmented Reality, Urology, Prostate, 3D Printing, Patient Education

1 Introduction

The unambiguous communication between physician and patient is one of the most important factors when explaining pathologies. Two dimensional scans from imaging modalities or printed images are too abstract for laymen to fully comprehend and thus decision making is difficult. However, understanding the medical status quo, the prognosis and possible therapies is paramount for a patient to participate in care [1]. The situation can be improved by employing suitable models of the affected organs as well as computer support and thus empower medical staff to explain pathologies in an easy to grasp fashion. Studies have shown that patients who have been educated with media (leaflets, software) at their own pace often know better about their situation than classically, face to face educated patients [2, 3, 4]. In the following, the technical implementation process for a software prototype that employs 3D printed models of a patient-specific prostate will be presented.

AR in medicine and medical education is already in use and gains more importance. For example, in ophthalmology, the EyeDecide software [5] distorts the video stream on the iPhone's display to simulate the effect of age-related muscular degeneration. The Sheffield University uses an iPad application to augment training phantom, turning them into digital patients which describe the situation and their symptoms, creating a more realistic training experience. Blum et al. [6] developed 'mirracle', an AR system comprising a screen and a Kinect depth sensing camera. Their application overlays volume data from computed tomography (CT) on the video stream, granting the user a look inside the body. Additional information can be added to the 'visible' organs on demand. Hamza-Lup et al. introduced a distributed medical training system for paramedics, pre-hospital personnel and medical students. The system uses AR paradigms for the practice of endotracheal intubations [7].

2 Material and Methods

For our trials we used magnetic resonance imaging (MRI) data, which originates from necessary clinical examination scans. In order to process the data a software prototype was developed, which allows the manual segmentation of prostate, urethra and tumor. The segmentation was handled by an experienced urologist. The surface models were then converted into real organ models using rapid-prototyping. This process took less then a day. The digital information in combination with the 3D printed prostate model can be used in the tablet application.

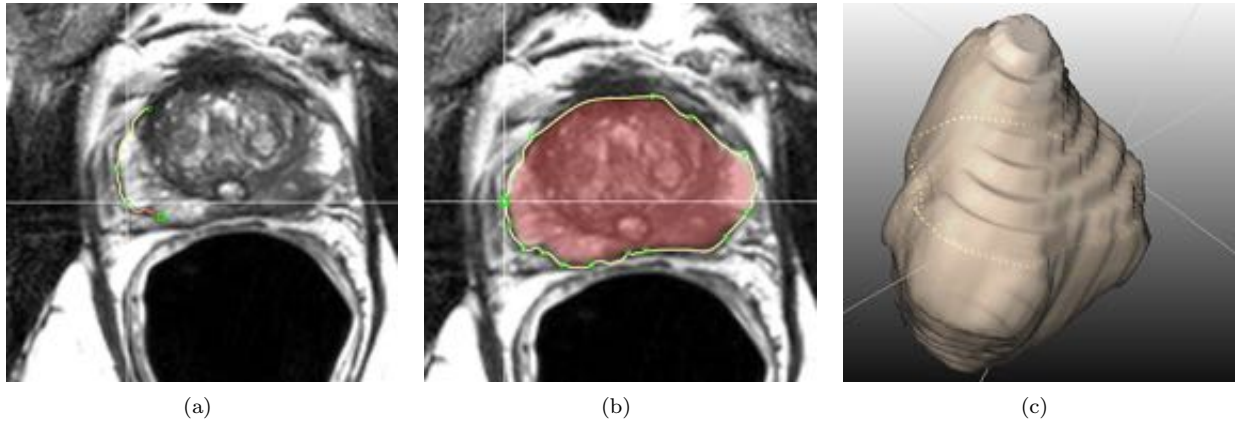|		
(a)	(b)	(c)

Figure 1: Segmentation of the prostate surface. (a) User draws contours using Livewire, contours are interpolated (b) and the result is visualized as a 3D surface model (c).

Segmentation Framework To obtain patient-specific 3D models, we developed a framework which allows physicians to segment the important structures in MRI data and then export the models. For the extraction of the prostate surface we use a semi-interactive segmentation. Initialization contours have to be drawn in several image slices. Using Livewire, the urologist can set the initialization contours close to the the actual image edges (see Fig. 1(a)). The drawn contours are then interpolated by computing a 3D implicit function as presented in [8], resulting in a three-dimensional organ model (see Fig. 1(c)). If the process does not yield a sufficient segmentation, additional contours can be added to enhance the result. The same approach is used for the extraction of the tumor surface.

Because the urethra is close to the resolution limit and in most cases just visible in a single slide, we decided to use manual segmentation for the urethra. The urologist can draw the segmentation directly on the image data. Afterwards a smoothed 3D model is generated from the marked voxels. After the segmentation the models can be exported. Due to the high amount of user interaction we adjusted the framework to work with a graphics tablet, thus enabling a more accurate and comfortable user input. To allow for later correction in case of errors the user input by means of the initial contours and the hand drawn segmentation is saved as well and can be reloaded into the framework if desired.

3D Printing We parameterized the generated surface models to prepare them for production. For the production process we chose Stereolithography, a technique in which a computer-controlled moving laser beam is used to build up the required structure, layer by layer, from a liquid polymer that hardens on contact with light. Our approach uses photopolymers which solidify when exposed to ultraviolet light and allows for a layered construction of the organ from transparent material. Optionally, the tumor and urethra cavities can be filled with colored silicone to make them more pronounced, as these are structures of high interest during a consultation. For the application, the model was propped up on a pillar and base plate. Tumor and urethra have been removed from the model, for they will be augmented with the application. The resulting print is shown in Fig. 2.

Application Development We built a prototypical system to support the conversation between patient and physician by combining the 3D printed prostate model with the digital content from the documented segmentation algorithm. In doing so, we provide the possibility for a graphical and tangible representation of the current state of the pathology and/or possible treatments. Dubbed UroMagicLens, the application employs the video see-through effect often found in mobile applications and head mounted displays (HMDs) that offer AR. In accordance with the user centered design principles, a user interview was conducted to figure out the requirements (hard- and software).

- The system was required to include touch screen and camera

- It must be mobile without compromising too much on screen real estate.

- The software required highlighting capabilities for the augmentations it has to calculate in the scene.

- The operating system of the device must be capable of installing 3rd party applications, so the app can be installed on the device.
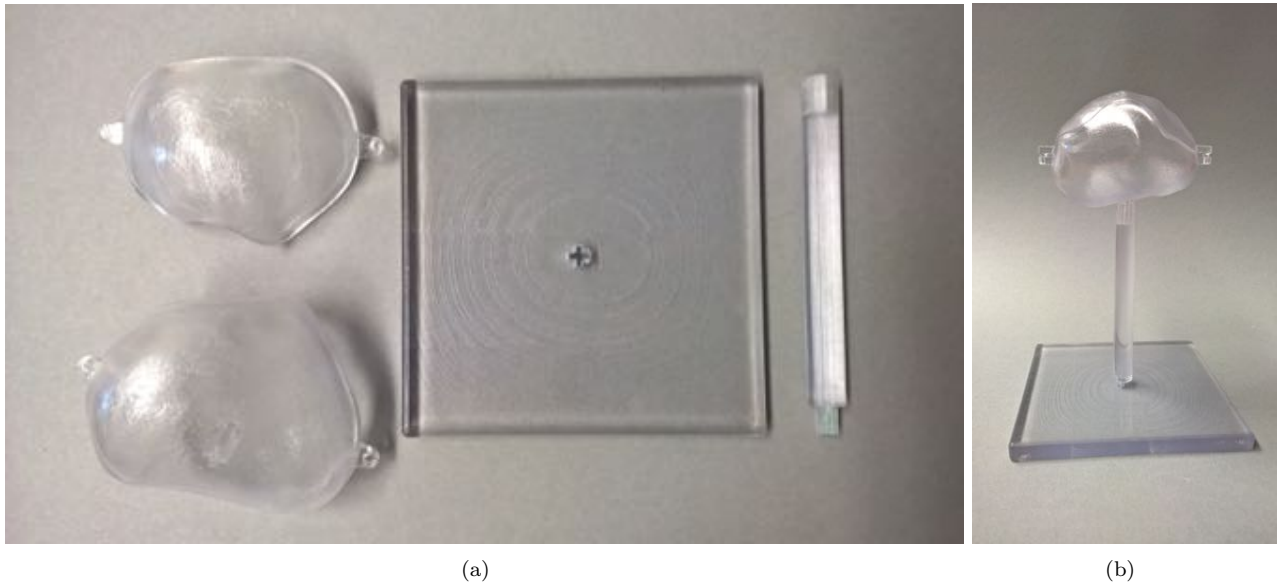
(a)   (b)

Figure 2: (a) Separate parts of the 3D printed prostate model from the printer, and (b) assembled model as it may be used in doctor-patient interview.

The application employs computer vision algorithms on printed images, so called image targets. Once those targets have been recognized, digital content can be aligned and fitted into the scene. Two different targets are used, each with their own purpose: one target is used to simulate buttons, the other one augments the 3D prostate model. The application was written in C#, using Unity3D, a game development software, in combination with the Vuforia Augmented Reality Plugin.

User Interaction We offer two different interaction paradigms, one based on standard touch input on the iPad, the other based on a technique called virtual buttons (VB). VB are image targets that may be occluded by the user, i.e. hovering the hand over it whilst in the field of view (FoV) of the tablets camera. This fires a subsequent action, similar to a button press. Printed on a piece of paper, see Fig. 4, the virtual buttons offer the same functionality as the user interface (UI) of the application.

Evaluation A user study (n = 11, 11 male, age: 31.2 ± 5.6 years) was conducted to check our usability hypothesis. The evaluation was done twofold: first, the results of the questionnaires were simply compared to each other, and secondly the summed scores of each participant per questionnaire were statistically evaluated.

Both paradigms in the systems were tested for usability with two different questionnaires, ISONORM – based on ISO 9241-110 [9] – and QUESI [10]. It was hypothesized, that the display based paradigm would score considerably better in both questionnaires, based on the following assumptions: touch displays are already a ubiquitous way of interaction with mobile devices, thus users are already accustomed to using them and, furthermore, the video see-through paradigm is altered in the VB based paradigm is altered by the distortion between the fields of view in both the devices camera and the user.

Depending on a randomly assigned number (1 or 2), participants were asked to work through a block of four tasks, once with the display based paradigm and once with the virtual buttons. The tasks included typical use cases of the application, such as displaying and hiding of specific structures and changing their opacity. The assigned number determined, which paradigm should be used first. The order of tasks was shuffled, so to minimize simple repetition. A pilot test confirmed feasibility and functionality of the study.

3   Results

From the ISONORM questionnaire, some questions have been excluded from evaluation due to inapplicability to our project. Those questions dealt with menus and masks, error tolerance and individualization. Results are shown in Fig. 5a. These results show that participants evaluated the usability of the display based paradigm better than that of the VB paradigm. The one tailed, paired t-test we employed for significance testing confirms

(a)
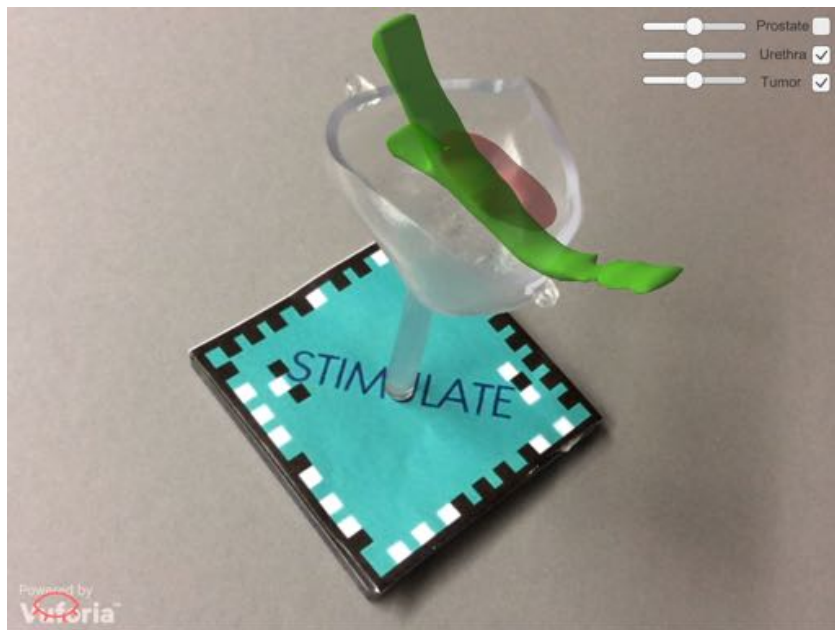
(b)

Figure 3: (a) Combining a 3D print of the prostate with an AR application. (b) shows a screenshot of the tablet application.

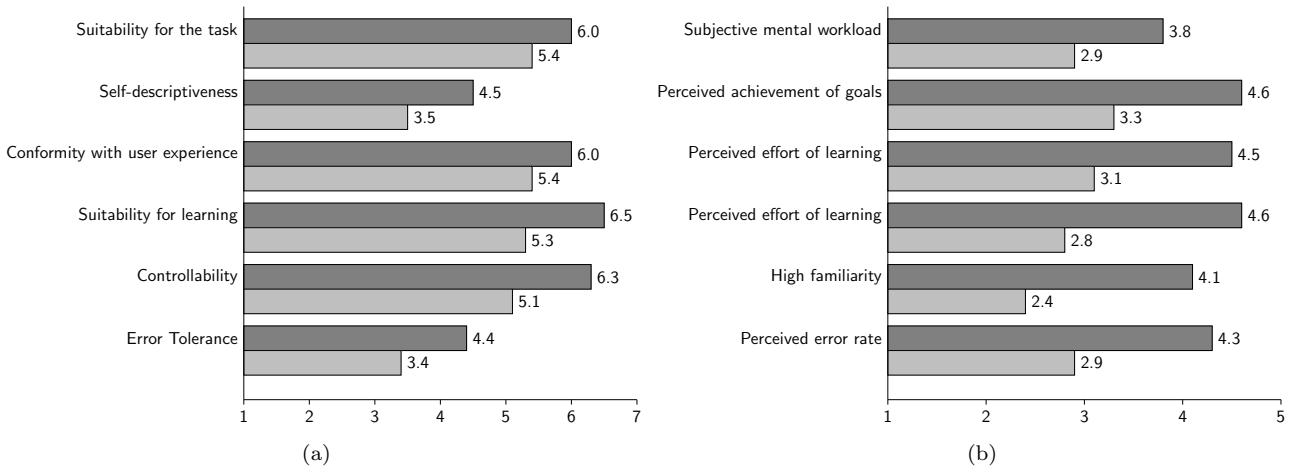Figure 4: The image target for the virtual buttons.
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Figure 5: (a) Mean values from the ISONORM questionnaires comparing the intuitive use of touch display interaction (dark gray) and virtual button interaction (light gray). ISONORM is based on a 7-point-Likert scale with 7 being the best, and (b) mean values from the QUESI questionnaires comparing the intuitive use of touch display interaction (dark gray) and virtual button interaction (light gray). QUESI is based on a 5-point-Likert scale with 5 being the best.

the findings. At a significance level of $\alpha = 0.05$, the resulting p-value 0.0045 (t=3.25) shows a superiority of the display based paradigm, proving our hypothesis with ISONORM.

For the second questionnaire, the same tasks were given to the participants. Before they started, they had to fill out both questionnaires for the first paradigm. The application was brought into its original state and the experiment was resumed with the other paradigm. The QUESI results lead to the same conclusion: the display paradigm outperforms virtual buttons in every metric, see Fig. 5b. The t-test on the summed scores per user shows similar results (p=0.003, t=3.503).

In order to measure the time required for the four different tasks, participants were filmed. Participants required between 76 and 143 seconds (mean = 120 s, SD = 33 s) 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 s, maximum 387 s (m = 253 s, SD = 82 s).

4 Discussion and Future Work

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. This was due to the small time frame in which the experiment had to be finished. Thus, using virtual buttons, 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, effects of the interaction are shown on the display. Whilst 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 cameras FoV and the users point of view (PoV) differ in their perspective, users would have a misaligned view, forcing them to switch focus. The prototyping phase proved that the tool chain we used allows for quick reiterations with fast and simple changes. It was stated by the participating urologists that the prototype of UroMagicLens, 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 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 relatives. 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.

The application was developed as a tool to help medical specialists convey information to patients, mostly laymen. Furthermore, a segmentation framework for use in urology and a process for 3D printing model of a prostate have been presented. It provides a basis for future applications, e.g. 3D treatment planning or risk analysis software for prostate therapy, such as available for abdominal surgery [11]. For such 3D applications, the user should be trained in using a medical training software as proposed by Mönch et al. [12]. In the future the

AR visualization could be improved by using advanced anatomical labels [13] and by using illustrative rendering techniques similar to those proposed in Lawonn et al. [14]. The application can be improved regarding spatial perception of the different structures and it should further be evaluated with respect to the improved knowledge transfer to the patient.

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