Improving User Interfaces for Physicians through New Materials, Tangible Interaction, and Tactile Feedback

Anke V. Reinschluessel[a], Tanja Döring[a] and Rainer Malaka[a]

[a] *University of Bremen, Digital Media Lab, Bremen, Germany*

Abstract

In the field of medicine, the standard human-computer interaction is still widely based on classical WIMP interfaces with 2D screens. Due to the ever increasing number of computational systems in medical care this leads to a situation, in which these systems are hard to handle, especially as often a number of different activities need to be executed in parallel. Furthermore, physicians have little time to familiarize themselves with software and hardware. Due to these reasons multimodal interaction approaches with devices that offer clear affordances and that are directly integrated into existing medical activities – instead of introducing additional computer-based tasks – have the potential to significantly improve the physicians' work. Especially as medical treatments often are manual tasks, enhancing existing medical tools or using new materials and tangibles for interaction fits the target group of medical professionals well. This ongoing research explores this design space. In this paper, we present three different user interfaces incorporating electroluminescence displays, tactile feedback and 3D-printed tangibles in combination with virtual reality to support physicians.

Keywords

health, medical imaging, tangible user interface, TUI, vibrotactile feedback, electroluminescence, VR, user study

1. Introduction

In the fields of medicine and health, advancements in technology can have an enormous impact on the well-being of individuals. When talking about serious diseases like cancer, new methods might even help the decision between life and death, especially as cancer is among the world's leading causes for morbidity and mortality [1]. Among various other tests, one diagnostic tool is imaging of the patient's body. Using the means of computed tomography scans (CT scans) or magnetic resonance imaging (MRI/MR) physicians create a vast amount of image data to locate possible malicious areas. To verify whether it is really cancerous tissue, the physicians take tissue samples, i.e. make a biopsy, if possible. Modern digital tools, such as visualization software, can be powerful instruments assisting the surgeon [2, 3]. Nevertheless, to the best of our knowledge, all commercial tools are still using a 2D display and some form of WIMP (windows, icons, menus, pointer) interface. The task itself on the other hand is a 3D task, as

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EMAIL: areinsch@uni-bremen.de (A. V. Reinschluessel); tanja.doering@uni-bremen.de (T. Döring); malaka@uni-bremen.de (R. Malaka)
URL: https://www.uni-bremen.de/dmlab-1/team/anke-reinschluessel (A. V. Reinschluessel)

the human body expands in all dimensions. Therefore, this viewing and interaction concept is maybe not the most suitable one and there are various opportunities to design better interfaces using for example new materials or tangibles. These approaches fit medical professionals especially well, as medicine (1) relies on manual senses, e.g. during surgery or feeling the patient's physical condition, and therefore tangible devices fit their line of work, (2) physicians generally do not accept technology even if they perceive it as useful [4] and (3) physicians are always short on time and therefore the devices they use need clear affordances and are best designed in a way, that they are familiar to them. A good design in this field makes use of a physician's everyday objects and skills.

In the following sections, we will describe three works: two will focus on how to improve or change the workflow of biopsy taking and one will discuss another way of viewing medical data generated by CT or MR scans. In each section, we will briefly discuss relevant related work. These works will use new materials like electroluminescence displays and make use of tactile feedback to present information to physicians. The last work about viewing medical data will use the benefits of tangible interaction in combination with virtual reality (VR) systems.

2. Needle Guidance

After suspecting certain regions of tissue to be malicious, a biopsy is performed. To verify the certain kind of cancer, various tissue samples from the respective organ, e.g. prostate or liver, have to be taken. In the following, we will present two ways to support the biopsy workflow: on the one hand with an illuminated needle guidance template using electroluminescence and on the other hand with vibration guidance.

2.1. Related Work

Various approaches have been developed to support surgical navigation. Different devices have been evaluated to realize overlaying the navigational information onto the view of the operator by using augmented (AR) or mixed reality (MR), e.g., head-mounted displays (HMDs), tablet computers [5, 6, 7] or projection [8]. Additional approaches incorporate instrument-mounted displays [9] or audio, i.e. sonification of navigational information [10]. As some biopsies and treatments take place within the MRI, MRI-safe technologies are of interest. The aforementioned technologies are not MRI-safe, i.e., they are not allowed in the strong magnetic field of an MRI scanner and thus are not feasible options for MRI-guided interventions.

Besides manual placement, robotic placement is also an area of research. There are moveable templates, which can be manipulated by two rotary guides [11, 12] with the help of a robot. Zangos et al. [13] tested a commercially-available MRI-compatible manipulator (Innomotion) for prostate biopsy.

2.2. Needle Guidance in MRIs

One very common cancer among males is prostate cancer [1, 14]. To obtain prostate tissue samples and also to perform therapy like radiation therapy [15], cryoablation or thermal ablation [16], a needle-shaped tool is inserted into the prostate through either the perineum

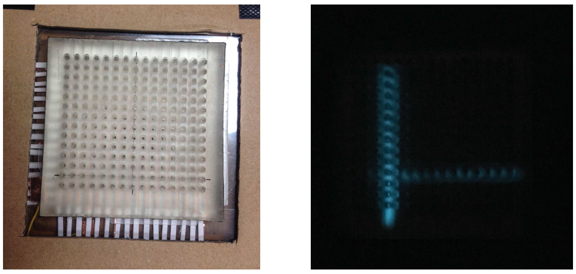

Figure 1: The illuminated template prototype (left) & the visual feedback of the illuminated (right).

(the area between the anus and the outer sexual organs) or the rectum. Besides having a skilled physician to place the needle correctly, a needle guidance template can support the physician during this task [17]. This template works best in combination with the software 3D Slicer[1] and an MRI scanner for needle and template tracking.

The template consists of 210 holes (see Figure 1 (left)), having a diameter of 1.3 mm, with a spacing of 5 mm. The template is placed at arm's length at the centre of an MRI scanner to achieve the best image quality. Even though the software 3D Slicer already calculates which holes to use, the operating physician still has to manually count the holes, which is prone to prolonged procedure time and human error. We added an EL (electroluminescent) display to the tangible needle guidance template, which points towards the insertion point using a cross-hair metaphor (see Figure 1 (right)). By adding this type of display, the task completion time of inserting the needle can be reduced by 51 % as well as the task load by 47 % [18]. Additionally, we increased the usability by 30 % compared to the regular manual counting. EL displays have the advantage that they can be used in the critical environment of MRI scanners, where other technologies are not allowed due to the strong magnetic field. This shows that "novel" materials, which have not been applied in this context, can overcome design problems and therefore support the physicians in their daily work.

Although viewing the insertion point is already of help, possible interesting future work would be to explore which other information would be helpful and how to visualise this in a useful manner. As for needle placement the depth of the needle is another crucial aspect, one could think about ways to visualise the insertion depth. Here questions about showing the insertion depth in a linear or non-linear fashion arise, as more precision is needed the closer the needle is to the target.

2.3. Needle Guidance using Vibrations

As already mentioned, the needles can be placed manually as well. There are also systems like the CAS-One optical surgical navigation system[2] that support this process by showing a 3D view with the needle, the target and the optimal trajectory to reach the target on a 2D monitor. In real settings, the placement of the monitor regarding ergonomic aspects is not

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[1] https://www.slicer.org/

[2] http://cascination.com/

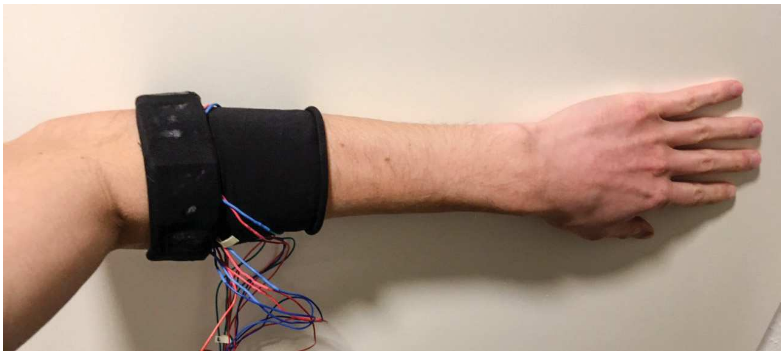

Figure 2: The vibro-band.

always great, e.g., far left or right of the users and the users have to split their attention between the screen, the needle and the patient. Therefore, we investigated with a vibration wristband ("virbo-band") (see Figure 2) (1) whether users can integrate tactile navigational cues with the visual navigation, (2) if they can correctly identify the vibration and (3) if the vibrations disrupt their performance of fine motor skills [19]. The results are promising, as all participants performed the fine motor skill task without interferences and the identification of the vibration direction was good. Similar results in the aspects time, accuracy, task load and usability were achieved. The video analysis showed that also some participants focused more on the "patient" with the vibration condition compared to the visual only condition. This nicely shows how a multimodal approach could shift the focus towards the patient. One interesting question to answer in future work would be, if the users focus their attention even more on the patient with more training with the system as the identification of the directions already worked well with a minimal training period.

3. Tangibles and Medical 3D Data

While the two previous approaches are about either verifying a diagnose or treating the disease with radiotherapy or ablations, physicians view the medical data and discuss possible diagnoses beforehand. Currently, it is still state of the art to view the 2D images as created by CT and MRI scanners as they are. The physicians have to make the effort to create their own mental 3D model based on the images and their prior anatomy knowledge. This is challenging and as a cooperating head surgeon stated once "The ability to imagine the 3D situation can decide between a palliative or a curative approach for the patient.". One support for this challenge could be 3D models and VR. The 3D models could be either viewed in VR to achieve a better understanding of the spatial features or be 3D printed to add a haptic component as well.

3.1. Related Work

Researchers investigated the use of virtual environments to show medical image data. One example is the VR by Reinschluessel et al. [20], who evaluated different gestures to interact with 2D images shown on a screen in a virtual setting. King et al. [21] explored showing 2D images

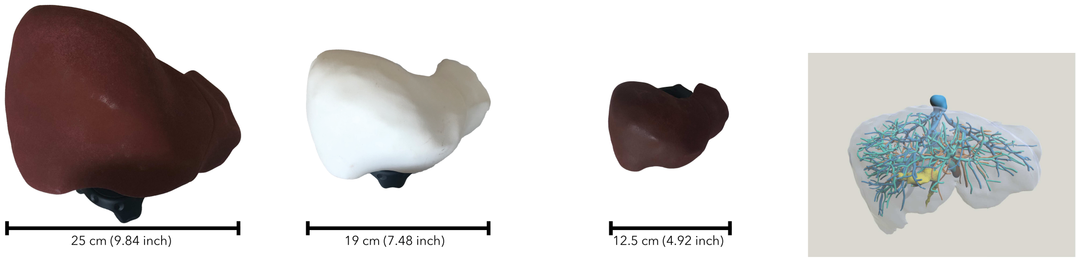

Figure 3: The tangible organ models and the virtual 3D model (bottom right). Top: 100 %, middle: 75 %, bottom: 50 %. Scales are relative to a real patients' organ size.

of MRI and CT scans in the complete field of view in the virtual space and thereby allowing for more images to compare at once.

Also the use of 3D printing in medicine has been increasing since 2000 [22]. A literature review by Martelli et al. [23] for the period of time between 2005 and 2015 showed that 71.5 % used it to produce anatomical models. The main advantage reported was better preoperative planning (48.7 %) and that it saved time in the operating room (32.9 %). As 3D printing is an expensive endeavor, there are efforts to make it more cost effective and affordable as published by Witowski et al. [24]. One example for using 3D printed organ models has been conducted by Zein et al. [25]. In this work, the authors used 3D printed livers or parts of the liver to discover potential anomalies in the anatomical structure before transplantations.

3.2. 3D-Printed Organ Models with VR

All VR solutions so far either use gestures or a device to explore the images or model. 3D-prints on the other hand as used by Zein et al. [25] for example have the benefit that the haptics match the view, but the view is fixed. Therefore, we aim at combining both modalities into one system. This should lower the cognitive load, as the viewing interaction can be as natural as with the "real" organ or a real object. Our first approach already showed that surgeons are very fond of the idea and rate our approach as useful [26]. We showed them an early prototype of a 3D model of a liver in VR (see Figure 3 (bottom right)), which was yet to be controlled with standard HTC VIVE[3] controllers and a transparent 3D print of the same liver (in the size 50 % of the real size). The participants of the workshop highlighted the advantage of easier grasping the spatial relations. Furthermore, we observed that a physical same-shaped object naturally sparked discussions.

The next question to answer is about the size of the liver controller, i.e. the liver-shaped object used to control the view of the 3D model in VR. The liver print used in the workshop had 50 % of the original size and therefore had a "convenient" size. Previous research suggests that the real shape results in higher satisfaction [27, 28, 29] and that tangible interaction is faster and more intuitive [30] because it benefits from the natural spatial memory of humans [31]. Yet, existing research barely addresses the size of the tangible objects. E.g., when building tangible devices in game research, like guns for shooters, researchers tried to map the size [28].

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[3] https://www.htcvive.com/

Tinguy et al. [32] explored the just-noticeable difference regarding width, local orientation and curvature when grasping an object, which indicates that tangible and virtual objects do not need to be an exact match.

Still, there are no results about the size differences. This is especially important for large objects like the liver. A real liver weights about 1400-1800 gram (49.4-63.5 oz), has a transversal size of 20-23 cm (7.87-9.05 inch), and a lateral size of 15-18 cm (5.90-7.08 inch)[4], depending on gender, age, body size, weight and health. Adding the shape of the liver, this results in a quite unhandy object, when thinking of an interaction device. In VR though, we still need the real size to be able to make decisions about cutting planes and infiltrations. Therefore, we evaluated three different sizes (50 %, 75 % and 100 %) of the liver controller to investigate whether we needed a 100 % sized object as used in related work (see Figure 3). Further interesting research questions could explore what haptic properties of the liver controller increase immersion and create a more convincing experience for medical professionals. Therefore, we aim at experimenting with 3D printing materials varying in softness and texture. As medical professionals judge the usefulness also on the ease of use [4], the integration of features like zooming, marking and changing views as well as patient data are design challenges in terms of intuitive use.

4. Conclusion

This work showed an overview of different approaches how new (tangible) technologies can support surgeons. By using materials like electroluminescence displays, we were able to design for a very specific design space - the MRI scanner - and improve an existing tangible user interface. The results of 51 % faster task completion time in combination with significantly reduced task load and improved usability clearly show the benefit of our solution. Yet, we only improved one aspect of this process. Working on a similar problem, needle placement, we showed that tactile feedback can be an option to present information in a medical context without disrupting the process. Its whole impact yet has to be investigated, but we can carefully interpret the results in a way that it can help to focus the attention of the user more on the task instead of a computer screen, which might even be placed in a non-ergonomic way. Last, we discussed how tangibles in the shape of the visually presented 3D models can improve the viewing process of medical data. Although 3D-prints are already used in medicine and other fields, the question about the appropriate size of an interaction device in relation to its visual representation in VR remains. All three projects have in common that they aim at better representations of spatial information, which is among the most important aspects for the medical professionals. This was highlighted in the various interviews during the design processes. Therefore using the means of new materials to overcome design space restrictions, exploring new ways of feedback and especially using tangibles are promising approaches for this application domain.

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[4] https://radiopaedia.org/articles/hepatomegaly

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