Mobile Interactive Displays for Medical Visualization

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ABSTRACT
Medical visualization proves to be essential in modern health care systems. Collaborative diagnosis and treatment decisions as well as medical education and training can be enhanced using interactive 2D and 3D graphics. However, besides developing effective visualizations, the challenge remains on how to support optimal interaction especially on mobile devices. This paper presents possible future scenarios of using mobile displays by different medical experts in collaborative environments. Typical tasks, technical requirements, open research issues and challenges on interacting with mobile medical visualization are discussed.

General terms: Design, Human Factors

Keywords: Medical visualization, mobile displays, multiple displays, interaction techniques, multitouch, collaboration

MOTIVATION

Medical visualization techniques play an essential role in current and future health care systems. Main application areas are diagnosis, treatment planning, intraoperative support and education [1]. Amongst others, interactive 2D and 3D visualizations are used for the diagnosis of diseases. Such visualizations might include measurements (extend of pathologic structures) and annotations like encircled regions or arrows to enhance their interpretation. Visualizations are generated to be discussed among colleagues and to enhance the planning of surgical interventions. Therefore virtual 3D models are very useful since they provide an overview of the morphology. Spatial relations between pathologic lesions and structures at risk may be evaluated better with 3D visualizations (Figure 1). For example, Krüger et al. presented a medical visualization method for neck dissection planning [2]. Training systems like the *LiverSurgeryTrainer* [3] (Figure 2) were developed for computer-assisted, preoperative planning of liver tumor resections based on individual patient anatomy and pathology.

VISION

A challenging task, not only for medical visualization, is to provide efficient input devices and easy-to–learn, yet effective interaction techniques for exploring and editing medical visualizations. Nowadays, a multitude of heterogeneous information is being generated from several medical doctors in different situations and usage contexts.

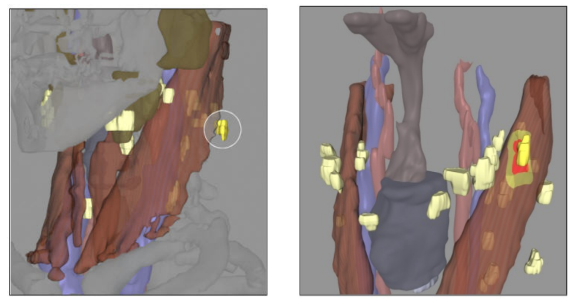

Figure 1: 3D surface visualization of relevant anatomical structures for neck surgery planning. Left: The desired object, an enlarged lymph node, is highlighted. Right: The distance between an enlarged and potentially malignant lymph node to a muscle is color-coded to support the decision whether the muscle should be removed or not [2].

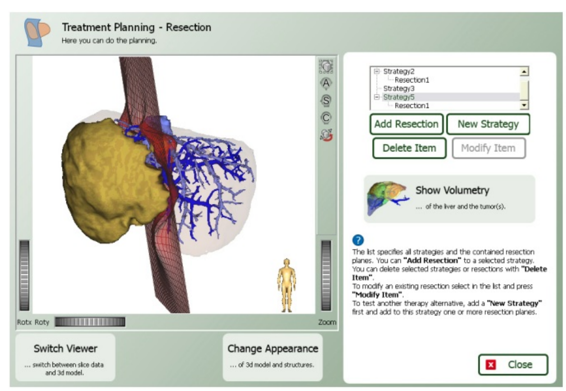

Figure 2: Liver surgery treatment planning with the training software *LiverSurgeryTrainer* [3]. A deformable resection plane can be controlled and modified interactively by the user. The challenging goal is the exact resection of the tumor and saving the functionality of the remnant liver parenchyma.

Radiologists generate digital reports during their diagnosis; surgeons use these reports and additional image data to prepare surgical interventions. Moreover, surgeons generate new information, such as intraoperative findings, that need to be documented as fast and as comfortable as possible. Nevertheless, personal conversations between medical experts are very essential in order to clarify ambiguous medical reports or image details. Current multi-touch smartphones and tablets are very promising for these cooperative clinical workflows. Together with wireless connectivity they enable access to relevant patient information at different places, e.g. at the bedside of the patient. Portable medical systems enable the location-independent selection of laboratory data and radiological images, zooming in selected data, specifying measurements or entering digital notes into a hospital information system. Often, information is conveyed from doctor to patient in a verbal manner which is sometimes misunderstood because of the jargons and medical terms used. Hence, portable devices are highly welcome by medical doctors since they enable explaining surgical strategies using movies, animations or 3D renderings. Moreover, gesture- and touch-based interfaces are considered very attractive by a large majority of medical experts. The problem however remains on how to design effective and intuitive interaction techniques for daily use.

Modern smartphones and tablets are fast enough to visualize large medical datasets and interactive 3D elements directly on the device. Single and multitouch gestures are the typical mode of interaction for these devices. Several gestures already exist for the exploration of data. For example, pinch gestures are already established for zooming images. Nevertheless, the design of appropriate gestures for interacting with more complex visualizations is a challenging task. A gesture set should be carefully limited and the gestures should be unique enough to avoid misinterpretation with similar gestures (cf. [4]).

In this article, several future scenarios and research topics concerning medical visualization on mobile displays are sketched and discussed. Typical tasks and requirements as well as possible solutions for exploring medical data on mobile devices are presented in the following section. Furthermore, we want to raise open research topics in this special and important application domain. In our research agenda we want to reach three main goals:

- The enhancement of patient interviews with mobile multimedia material as a visual support on mobile devices.
- The support of medical education and training with interactive 3D visualizations on mobile devices.
- The support of collaborative workflows using multiple mobile and large displays.

EXAMPLE SCENARIOS

Scenario 1: Patient Interview

A typical task in clinical routine is the doctor-patient-conversation. During that ward round, clinical values (e.g. blood pressure, pulse, temperature etc.) are monitored and documented, often by handwritten notes, in paper-based medical records. Furthermore, the patient has the chance to ask questions, e.g. concerning surgical procedure and possible complications. These tasks can be enhanced by using mobile devices. Additional information could be entered in a digital patient record on a smartphone or tablet. Thus, misunderstandings due to unreadable handwritten notes are avoided.

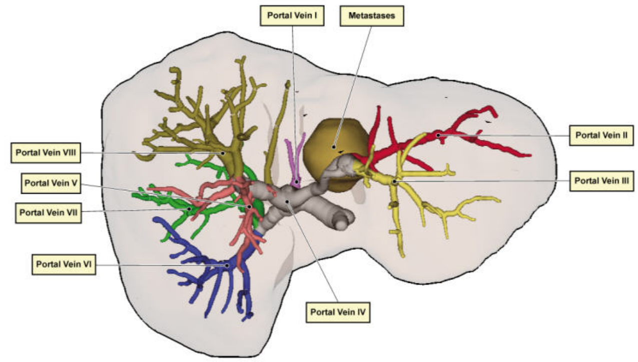

Figure 3: Virtual 3D model of a liver surface with annotation labels for medical education purpose. Labels indicate anatomical elements of the liver, like metastasis and the parts of the liver portal vein.

Further, the digital input enables automatically generated diagrams based on the stored values. These diagrams are useful to visually gain insight into the abstract data and to recognize vital trends. Moreover, multimedia elements and animations can be used to explain certain activities planned for the surgery, e.g. resecting a tumor or stitching vessels. Furthermore, the talk can be enhanced by using links to websites providing additional textual information, high-quality movies and animated 3D content.

An appropriately designed multimedia presentation can be very useful for visually explaining the steps during surgery and for improving the patient's trust. An important requirement for that scenario is a lightweight mobile device and simple interaction techniques supporting a clear and comprehensible patient interview using imagery and schematic graphics without too much or realistic detail.

Scenario 2: Medical Education and Training

Nowadays, human anatomy teaching is often based on static schoolbooks or on lectures where anatomical facts and concepts are transferred from one teacher to many students. But lectures and books poorly convey the three-dimensional nature of anatomical structures [5]. New e-learning portals are trying to fill the gap by providing Web-based 3D multimedia contents combined with social Web 2.0 techniques.

We are trying to envision the following scenario: A medical student wants to test his/her knowledge about human anatomy and different pathologies. The student opens a website, which allows access to a case-based medical education system. It provides different patient-individual datasets with various kinds of vessel anomalies and tumors/metastasis. The Web application can be used to get and train knowledge about vessel systems and territories, different diseases and their effects as well as various resection methods.

The mobile application enables exploring medical 2D and 3D data by using single- and multi-touch gestures. For example, a single-touch gesture could be used for scrolling up/down in the image stack. Multi-touch input can be used to interactively zoom and pan the imagery. Pan is controlled by dragging two fingers in the multi-touch interface, and the zoom level is adjusted with two-finger pinching. Furthermore, medical 3D models can be rotated, translated and zoomed freely by the user, which allows for more realistic and detailed representation of anatomical and pathological structures. However, free exploration of 3D scenes like rotating the scene, zooming in/out and enabling/disabling different structures can be a complex and tedious task for unfamiliar users. Therefore, easy-to-learn interaction modes have to be considered to ease the exploration of the 3D models and to reduce the learning effort.

We suggest deploying certain widgets, like sliders or thumbwheels, to enable the user to rotate and zoom the 3D objects around fixed axes. Thus, unwanted viewpoints might be avoided. A simple drag touch input on a thumbwheel widget meets the requirements to interactively explore the 3D scene. We also suggest using the mobile device *itself* for direct interaction with virtual 3D visualizations. For example, tilting the device to a certain orientation might rotate or zoom the 3D model around fixed axes in that direction.

The educational application is enhanced by an anatomical quiz where multiple choice questions can be answered by touch input. After finishing the task, the user gets a visual feedback on his/her answer. If needed, anatomical labels can be activated in order to help answering the questions (Figure 3). Additionally, Web 2.0 elements, like forums, blogs and chats are desirable in order to ask questions to the tutor or for communication with fellow students.

This mobile scenario has several advantages: It allows medical e-learning everywhere *just in time* and multi-touch input for interactive selection and manipulation of virtual anatomical structures. Compared to the first scenario, the interaction with medical 2D images and 3D structures has to be focused and designed carefully. Among the requirements for that scenario are suitable constraints for rotating, zooming, translating and editing 3D objects. Furthermore, appropriate visualization and animation techniques are important to highlight certain anatomical elements and thereby supporting the learning process of the user.

Scenario 3: Multi-Disciplinary Collaboration

Multi-disciplinary team meetings are very essential in healthcare. Based on their domain-specific expertise, medical specialists (e.g. radiologists, surgeons and internists) present and discuss relevant information about patient cases. The overall goal is to deliberate on a careful therapy concept. Now, imagine an enhanced cooperative future scenario using tablets.

Instead of bringing a bulk of paper reports into the discussion, every doctor has his/her own mobile device equipped with wireless connection and multi-touch input. The person's own "private view" on his/her data is displayed on the tablet. For example, a *radiologist* can access and explore 2D medical image data as well as segmented structures and manual annotations. A *surgeon* benefits from prepared and interactive 3D models of anatomical and pathological structures. The overall goal is a computer-supported and efficient communication between all experts. The individual view of every person should be synchronized in a collaborative way to gain insight into the specific patient data.

The *radiologist* might send medical examinations (X-Ray images or volume data from computed tomography) to an interactive whiteboard turning his/her private view into a public one. Using e.g. a flick gesture on the device causes sliding through the 2D image stack. Since whiteboard and tablets are synchronized, the displays are updated continuously. One of the primary motivations is to enable the participants to point on certain medical structures from any location in the room. This could be achieved by touching and dragging with a single finger on the touch-screen device. Different users are distinguished by colored cursors.

Another desirable feature would be to highlight important findings, e.g. tumors, to discuss treatment options with colleagues and to review these annotated areas in future meetings. To fulfill these needs, several easy-to-use controls have to be considered. For example, a toolbar with large buttons could be deployed to enable different annotation modes like pointing, freehand sketching and placing arrows or text labels on the imagery. These annotations should of course be linked to the medical record after the meeting and physicians should at any time be able to access them. The annotated areas might be collected in a "clip gallery" that enables users to directly navigate to important areas of interest, e.g. to review proposed surgical structures. It is also conceivable to match annotated lesions over several imagery examinations to identify progress trends of tumors.

The *surgeon*'s aim is to present interactive medical 3D renderings to the colleagues and to discuss an optimal access path during surgery. In order to let all people have a look on the 3D model, the surgeon might shake the mobile device. Thus, the private view is sent to all connected tablets and can be explored by every person individually. The surgeon could tilt the device itself to rotate the virtual 3D model around the fixed rotation axis or to zoom in. Every person can follow the demonstration since the view is displayed on each device simultaneously. If one wants to get a detailed view on the data, it is possible to interact with it on the personal tablet for making measurements or leaving annotations.

One could raise concerns about the issue of multiple users trying to interact simultaneously with the radiology images. In order to avoid chaos during the meeting, technical policies should be implemented: Each physician is able to interact with the imagery one after another, but every person should be able to adapt annotations of his/her colleagues.

Compared to both scenarios described before, supporting collaborative processes is the most important issue here. Images, movies, annotations or 3D objects can be shared easily by synchronizing the interactive devices. This multimedia-based procedure yields a better understanding of medical reports instead of just "talking about" the findings.

ISSUES & CHALLENGES

Scalability and Platform Independence. Several devices with different hardware and platform systems as well as different display sizes and interaction capabilities have to be considered. The visualization should be scalable, which enables the rendering on small and large screens. A platform-independent visualization on smartphones, tablets as well as on interactive tabletop surfaces is desirable to address a variety of users. Ideally, visualizations are accessible in real-time and sharable between different devices and operating systems. Special care has to be taken for scaling interaction techniques. For example, while measurement tools by touch can be easily performed on a tabletop, a smartphone's size prohibits fine adjustments.

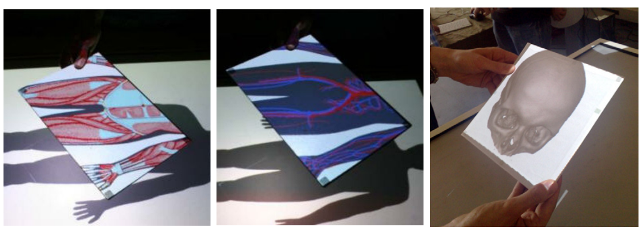

Figure 4: Various layers of a 3D information space can be revealed by lifting and lowering a *tangible magic lens* [6] on top of a projected human body. Right: Directly interacting with volumetric data of a human head by tilting a lens in 3D space.

Interaction and Communication. Demanding issues are appropriate methods for interacting and communicating with and between mobile devices. Intuitive gesture sets have to be implemented to allow smooth exploration of 3D visualizations and effective collaboration on heterogeneous data. User interface elements should be scalable, customizable and easily operated by the user to reach a high user experience. Single-touch and multi-touch interfaces have to be carefully tested and evaluated with end users in order to verify if users understand certain gestures and can use them for their daily workflow. In particular, in medical systems exact input is desirable, e.g. when making measurements. It is a challenging task to find out if touch input is accurate enough, compared to mouse input, and provides a sufficient level of trust during diagnosis. In contrast, during multi-disciplinary team meetings it is not important to exactly outline a lesion but it is sufficient to sketch important areas quickly. Therefore, well-arranged user interfaces and intuitive widgets, e.g. large sized touch buttons, should be deployed. Furthermore, besides interacting *on* portable devices via touch or pen, novel interaction techniques such as tangible magic lenses proposed by Spindler et al. [6] can be used as natural metaphors to explore large information spaces *with* the spatially-aware device (Figure 4). A conceivable idea would be to adapt this metaphor to off-the-shelf mobile devices. A future use case could be to use a tracked, lightweight mobile display to explore large medical volumetric data, thus serving as a window into virtuality (c.f. Figure 4, right).

CONCLUSION

We have discussed several possible scenarios on using mobile devices in collaborative medical environments. The presented scenarios demonstrate the advantages of using interactive devices in patient consultations, medical education and multi-disciplinary team meetings. The most important benefits are portability, social collaboration and context awareness. Appropriate technologies have to be implemented to support the communication between devices and users. We have envisioned several single- and multi-touch interaction techniques for mobile 2D and 3D visualizations, which take well-suited constraints (e.g. fixed rotation axes) and widgets (e.g. interactive thumbwheels) into considerations. An ongoing question is, how already approved high-level visualization techniques can be ported to smartphones or tablets. Thereby, several technical restrictions like smaller displays, limited size of memory, rendering speed and bandwidth have to be considered.

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