VRRRRoom: Virtual Reality for Radiologists in the Reading Room

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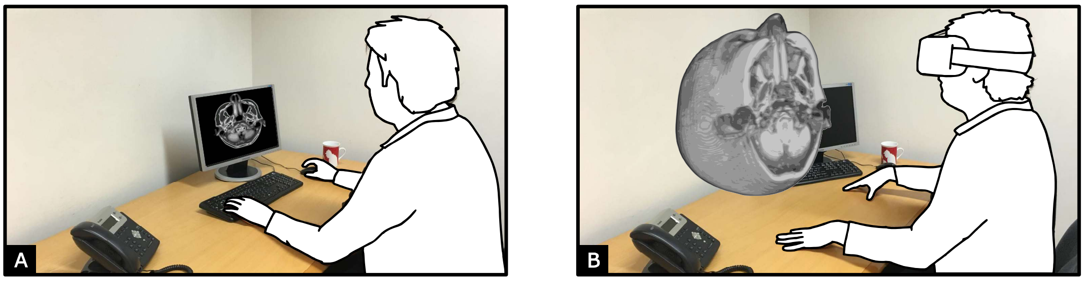

Figure 1. A) A typical radiology reading room; B) Our approach combining virtual reality and desktop touch interactions.

ABSTRACT
Reading room conditions such as illumination, ambient light, human factors and display luminance, play an important role on how radiologists analyze and interpret images. Indeed, serious diagnostic errors can appear when observing images through everyday monitors. Typically, these occur whenever professionals are ill-positioned with respect to the display or visualize images under improper light and luminance conditions. In this work, we show that virtual reality can assist radiodiagnostics by considerably diminishing or cancel out the effects of unsuitable ambient conditions. Our approach combines immersive head-mounted displays with interactive surfaces to support professional radiologists in analyzing medical images and formulating diagnostics. We evaluated our prototype with two senior medical doctors and four seasoned radiology fellows. Results indicate that our approach constitutes a viable, flexible, portable and cost-efficient option to traditional radiology reading rooms.

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H.5.2 Information Interfaces and Presentation (e.g. HCI): Interaction styles, Graphical User Interfaces

Author Keywords
Virtual Reality; Multitouch Surfaces; Medical Visualization; Interaction Design

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INTRODUCTION
Digital imaging is commonly used by the medical community. The reason is related to the ease of storage, retrieval and distribution of content. As a result, digital imaging has a profoundly positive impact on medical diagnosis and even surgical planning. Radiologists often analyze tomographic imagery while seated in front of a desktop display. Figure 1A illustrates a typical radiology reading room. However, inadequate ergonomic postures and, more importantly, improper room conditions can cause erroneous diagnostics when professionals examine such digital images using common displays [20]. Varying illumination, ambient light and display luminance are known to distort the images, which are characteristically laden with complex and hard-to-read fine details.

Although some institutions are aware of the optimal requirements and have the resources to implement them, many public hospitals and clinics are often unable to afford such environments. Typically, the equipment found in a reading room, e.g. grayscale displays, specialized equipment and fixed ambient light lamps, is priced in the tens of thousands of dollars [8]. For these reasons, we believe that Virtual Reality (VR) can offer a substantial contribution. Indeed, head-mounted displays (HMDs) are increasingly popular and technological improvements to portable display technology are helping to reduce their cost, while improving image quality. Moreover, immersive displays can improve the visualization conditions for radiodiagnostic.

We present VRRRRoom, a VR radiology reading room that allows imagiologists to focus on the medical image data, while avoiding the conditions that can interfere with radiodiagnostic. Physician resistance to novel systems and technologies is a well-known issue [2, 17, 18]. Therefore, our approach adopts a natural user interface using simple hand touches on a typical desktop surface to interact with medical images, as depicted in Figure 1B. We contribute a novel, cost-effective (below $2000) and portable method to study 3D medical images. Our evaluation with experts suggests that VR is a viable approach to overcome existing ergonomic, ambient and illumination conditions. Additionally, interacting with the desk surface helps promoting its adoption by medical professionals.

RELATED WORK

HMDs and CAVE-like systems have proven to be suitable devices for analyzing volume data sets, and also have been reported to improve the effectiveness of several interactive volume visualization applications [5, 16]. In particular, these VR devices have been adopted for rendering medical images to aid surgery [19, 23], virtual endoscopy [13], medical education [4, 15], and interventional radiology [7]. More recently, VR started its incursion into the diagnostic radiology domain. Most noticeably, King et al. [14] proposed a portable and low-cost VR application for viewing multiple 2D image slices. It uses eye gaze for selection, a gamepad to control visualization attributes and hand recognition for image repositioning. However, this work does not consider 3D imagery (i.e., volume renderings) nor ergonomic factors as images may be tilted in space, causing undesirable perspective distortions. In addition, the gamepad is hard to use for inexperienced users [3].

Seminal work by Hinckley et al. [12] adopted two-handed interactions on a tangible object to define cutting planes on a volumetric medical data set. Newer studies point out tabletop technology as a means to support volume data exploration and analysis with 2D touch gestures. In particular, and although not specifically designed as a low-cost portable VR system tailored for radiodiagnostic applications, Coffey et al. [6] proposed a comprehensive VR system to navigate volumetric medical data sets using an interactive multitouch table and a large stereoscopic display wall. This allows 3D imagery to appear on a volumetric space above the touch surface, similar to semi-immersive stereoscopic tabletops. There is considerable research that supports 3D volume manipulations with several degrees of freedom (DOF) using 2D interactions on tabletops. Exploring the surface beneath the digital content, Benko and Feiner [1] decomposed 3DOF selection tasks using a balloon metaphor. Triangle Cursor [22] follows a similar approach to manipulate virtual objects but uses two touches to define an equilateral triangle, with a cursor on the top vertex. However, it has been shown that indirect touch manipulation might be better, as it provides less discomfort, not occluding imagery [21]. To manipulate objects in full 9DOF, Toucheo [10] proposed a setup with co-located 3D stereoscopic visualization, combining 2D TRS interactions on the surface [11] with the balloon metaphor and additional widgets.

Succinctly, while using HMDs or tabletops to interact with 3D data is not new, combining them for medical diagnosis has not been studied. Much research focuses on VR-based surgical planning and navigation. However, our approach addresses diagnosis. Moreover, we specifically worked with health professionals and our tabletop interaction was purposely designed to combine novel, yet familiar, touch gestures with immersive visualization.

INTERACTION DESIGN

In order to mitigate or even cancel out the external conditions and to deal with resistance to non-typical medical practices and procedures, our approach relies on rendering 3D medical data which is placed to float above a virtual desk in VR. By definition, a VR head mounted display restricts the user's vision to the virtual environment for better immersion, which is the optimal approach to deal with interferences from the real world, such as varying illumination and reflections. On the other hand, to appropriate the physical desk surface for touch input serves to cut back the resistance to novelty through the introduction of familiar touch-based input interaction. Also, our approach leverages the fact that desk surfaces provide sufficient area for touch based interaction without the need for positional awareness of the hands. Therefore, our approach relies on the indirect manipulation of 3D medical images through touches on top of a common desk. In fact, previous research has shown that indirect touch manipulation is well suited for 3D manipulation tasks with stereoscopic imagery [21].

Instead of menus, our approach relies on bimanual interactions [9] where each hand can simultaneously perform separate and independent actions (Figure 2). The left hand can manage render properties, while the right hand can execute volume manipulations. Also, resting hands on the desk surface should not provoke an undesired action. Which means that radiologists can comfortably support their hands on the surface until the need to perform an action arises. Subsequently, we introduce a series of interactions to manipulate the displayed content.

Changing Properties

With the left hand, medical professionals can either adjust the image brightness or navigate through the available slices, as depicted in Figure 2 on the left. Moving the hand forwards and backwards causes the slices' cutting plane to move accordingly to reveal each slice of the rendered volume. Likewise, adjusting brightness is achieved by moving the hand to the right or left directions, where shifting to the right matches an increase of the brightness levels.

Volume Manipulation

The current anatomical plane in focus is the one facing the user. Right hand gestures are then reserved for transformations of scale and rotation (Figure 2 on the right). Changing the volume's scale can be achieved using a pinch gesture. Scale

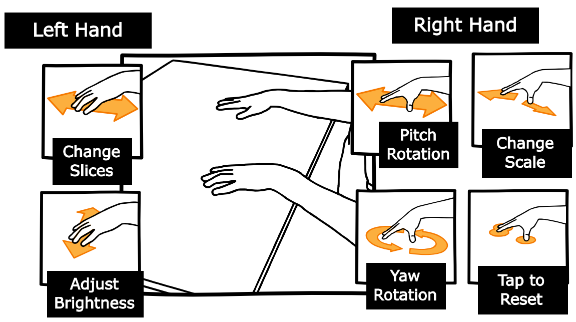

Figure 2. Desk surface gestures for left and right hands.

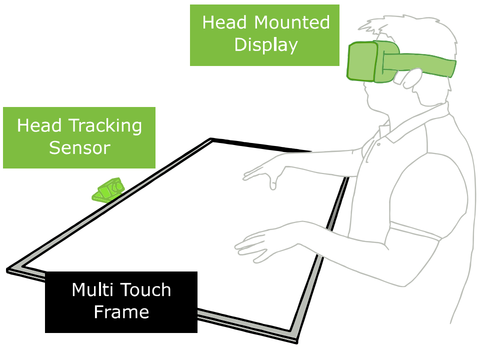

Figure 3. The setup consists of an Oculus Rift HMD with a head tracking sensor and a multitouch frame to detect touches on the desk surface.

transformations are limited between 50 centimeters to 5 meters wide. A hand rotation is required to transform the volume's yaw rotation. When the necessary rotation angle is achieved to reveal the next anatomical plane, focus changes to this next one. Pitch rotation may also be needed to slightly customize the viewing angle for better readability and comfort. This transformation can be achieved by moving the hand through the forward-backward axis. By tapping with five fingers, the 3D model is set to its initial state in regard to scale and rotation, while all clipping planes are placed at their initial position.

IMPLEMENTATION

Our approach adopts a tabletop metaphor to construct the environment to visualize and manipulate 3D medical data in VR. In VRRRRoom, the physical desk has a virtual proxy representation enhanced with realtime active feedback, to provide a familiar setting for imagiologists. Furthermore, in order to avoid occlusion, the volume rendering is displayed above and behind the virtual desk. The major benefit of our approach is the interaction technique that allows for touch-based input while seated. It is our belief that in the future all surfaces and objects can be outfitted with the ability to detect touches via non-intrusive hardware. Indeed, sensing touch on desk surfaces is the focal point of related current research [24], but for the purpose of our work, we physically attached an off-the-shelf multitouch frame to a typical office desk. Therefore, the setup consists of a desktop computer to drive the experiment, an Oculus Rift DK2 head-mounted display with an external head tracking sensor and a multitouch frame repurpose on top of the working desk, as depicted in Figure 3. We used Unity cross-platform game engine to develop all components of the prototype. In a nutshell, the developed environment adopts an input device to detect hand gestures on a desk surface and a head mounted display for visualization.

Processing Desk Touches

The multitouch frame we employed can detect up to 16 individual touch points. In order not to force an unnatural interaction style on physicians we allow people to touch the desk the way they feel more comfortable with (using from one up to five simultaneous touches per hand), by treating all fingers of the same hand as a single contact point. Touches on the left half of the desk are associated with the left hand. Similarly, right half touches are ascribed to the right hand. Each hand position is given by the centroid of the corresponding touches, calculated as the average of touches' minimum and maximum x and y values. When two or more touches are detected we also calculate the hands' delta yaw according to its initial orientation, averaging touches' rotation around the centroid. Similarly, we derive changes in scale for each hand by averaging each contact point distance to the centroid.

Visualization

The visualization component refers to the rendering of a reconstructed 3D model from individual slices and the interactive graphical elements that make up the virtual desk. Figure 4 displays the graphical elements of our prototype that the user can interact with. Tomographic data comes from cross-sectional images of a scanned patient. These cross-sectional images are commonly handled by the medical community using ISO standard format DICOM (Digital Imaging and Communications in Medicine) files. Our prototype gathers all images in the correct order, removes the undesirable black background, and then renders in 3D all the image pixels within each slice, which are mapped to a 3D Texture processed by conventional texture-based volume rendering algorithms.

The virtual desk component serves as a proxy to the real physical desk while providing the situation awareness needed to start the medical image analysis. Additionally, the virtual desk provides realtime visual feedback for each action, as shown in Figure 4. Touches on the desk surface are indicated by a knob for each hand. These knobs also show the gesture being executed by changing size when scaling the volume and changing rotation accordingly to the user's hand. The brightness percentage and the slices clipping plane progression are shown by two progress status bars, each parallel to the direction of the associated hand gesture: transverse direction for the brightness bar and longitudinal for the slice progress status bar. In addition, the virtual desk contains indicators for the anatomical plane orientation in focus and the number of the current slice. These graphical elements serve mostly to familiarize imagiologists with the interface. Indeed, we observed that after an initial adaptation period, users are able to operate the interface without looking down, making the interaction more fluid.

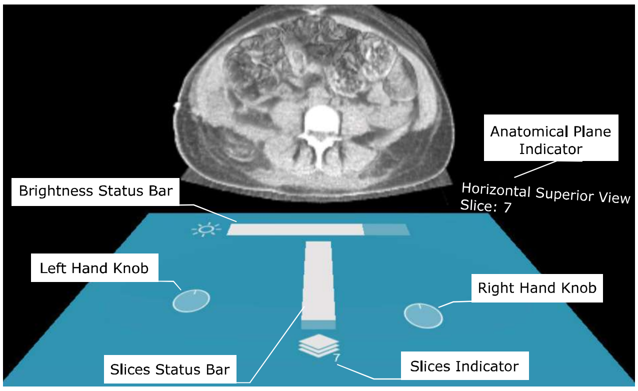

Figure 4. Virtual desk and volume rendered from medical images.

EVALUATION

We wanted to assess whether VR can be used in professional settings to overcome external factors that are known to affect diagnosis. To this end we employed medical images retrieved from a CT scan of a middle aged female pelvis containing a small fracture and a metal hip prosthesis. Evaluation sessions comprised four stages: 1) *Introduction*, 2) *Free Experimentation*, 3) *Questionnaire* and 4) a *Guided Interview*. We asked participants to sit through the test during approximately 40 minutes, with 15 to freely observe the volume data.

Participants We evaluated the system with six medical professionals, two of which were female. Four were medical doctors: one radiology senior resident with 6 years of experience, one neuroradiology intern, one gynecologist and obstetrician with 35 years of experience, and one general surgeon with 26 years of experience. The remaining two participants were dental implantologist interns. Five participants reported no previous experience with virtual reality, but all were highly familiarized with multitouch devices. All reported that they analyze medical images for diagnostic purposes on a daily basis.

Results and Discussion

We assessed user preferences with a list of statements scored on a 6-point Likert Scale (6 indicate full agreement). Data gathered also included observational notes taken during evaluation sessions and transcripts of the interviews.

User Experience Responses to the questionnaire suggest that the interaction design is adequate for analysing medical images. Indeed, when asked whether the prototype was in general easy to use, participants classified it with a median of 5 (IQR = 2). Moreover, no participant reported discomfort, dizziness or fatigue. Regarding the interaction techniques employed, participants reported that all were both highly useful and very easy to perform, with adequate gestures and feedback, except for pitch rotation (Table 1). Although data sets are volumetric, medical professionals reported being accustomed to interact with them as planar images. As such, tilting the volume does not fit their mental model. In addition, dental implantologists pointed that senior practitioners are commonly afflicted by *Carpal Tunnel Syndrome* due to long exposure to vibrations from high-speed mechanical instruments. Therefore, 1:1 hand rotation gestures to change anatomical plane (>45°) may cause discomfort.

Data Visualization The participants were able to identify organs and all medical doctors correctly identified the fracture and the prosthesis, even though none were prompted to do so. During the interview, all medical doctors reported that the quality of the rendering was insufficient for everyday diagnosis (median = 3, IQR = 3). Notwithstanding, dental implantologists classified the image renderings slightly higher than medical doctors. Low resolution was the major complaint. Radiodiagnosis requires visualizing subtle details that sometimes only become visible after performing many brightness and contrast adjustments to the image.

Viability Medical professionals are famously known to be resistant to changes in their workflow. Yet, all participants were enthusiastic and anxious to have our prototype as a work tool, as stated by a senior surgeon: *"I want to use this tomorrow for surgery planning"*. Another physician expressed his belief that *"With a sharper image, this will render endoscopies obsolete"*. *"This is the future of diagnostic tools"*, one senior surgeon said. Even when discounting for novelty (although one of the senior practitioners reported having bought a GearVR equipment and uses it regularly) these statements are encouraging and bring about the possibility of adopting novel VR-based diagnostic and surgical planning tools in everyday practice. Most physicians suggested that the setup could become very suitable for surgical planning and training. As a diagnosis tool, they highlighted that the minimalistic immersive display effectively cancels out external factors such as varying display quality, ambient light, glare and point-of-view variations, rendering diagnostics both more reliable and reproducible. All participants reported a longer attention span as a major benefit of the system, as it reduces the usual distracting surrounding conditions. Furthermore, our setup's low cost and portability were referred to as major advantages over current settings.

	Brightness	Slice	Scale	Pitch	Yaw
Usefulness	5 (2)	5.5 (1)	5 (3)	4.5 (4)	6 (1)
Easiness	5 (2)	5 (2)	5.5 (1)	3 (4)	5 (2)
Gesture	5.5 (2)	5.5 (1)	5.5 (1)	3 (4)	5 (2)
Feedback	5.5 (1)	5.5 (1)	5.5 (1)	3 (4)	6 (1)

Table 1. Questionnaire results regarding user experience and preferences: median and inter-quartile range (IQR).

CONCLUSIONS

In this work, we proposed and evaluated a VR system designed to aid radiologists in reading rooms. Our approach tackles the critical issues related to room conditions that are known to cause medical professionals to misinterpret images and ultimately to produce incorrect diagnosis. We fully describe our proposed interaction design techniques and detail the aspects of our prototype. We conducted an ecologically sound evaluation with both radiologists and medical professionals from different specialities who routinely analyze medical images. Our results strongly suggest that VR is a feasible way to overcome improper room conditions. Furthermore, physicians were positively impressed and highlighted many promising facets in the approach. Moreover, participants in our evaluation suggested that the user experience and interaction methods were adequate. Medical doctors also reported a need for higher resolution displays, which should be available in a couple of years. In the next iteration of our research, we intend to conduct a thorough quantitative evaluation against a baseline condition. Nevertheless, results are highly encouraging. We look forward to improving the visualization quality both by increasing resolution as well as adding semi-automatic image enhancement tools. This will help physicians produce higher-quality diagnostics in real, affordable and flexible settings.

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