Comparing the Microsoft® Kinect™ to a Traditional Mouse for Adjusting the Viewed Tissue Densities of Three-Dimensional Anatomical Structures

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ABSTRACT

Advancements in medical image visualization in recent years have enabled three-dimensional (3D) medical images to be volume-rendered from magnetic resonance imaging (MRI) and computed tomography (CT) scans. Medical data is crucial for patient diagnosis and medical education, and analyzing these three-dimensional models rather than two-dimensional (2D) slices would enable more efficient analysis by surgeons and physicians, especially non-radiologists. An interaction device that is intuitive, robust, and easily learned is necessary to integrate 3D modeling software into the medical community. The keyboard and mouse configuration does not readily manipulate 3D models because these traditional interface devices function within two degrees of freedom, not the six degrees of freedom presented in three dimensions. Using a familiar, commercial-off-the-shelf (COTS) device for interaction would minimize training time and enable maximum usability with 3D medical images. Multiple techniques are available to manipulate 3D medical images and provide doctors more innovative ways of visualizing patient data. One such example is windowing. Windowing is used to adjust the viewed tissue density of digital medical data. A software platform available at the Virtual Reality Applications Center (VRAC), named Isis, was used to visualize and interact with the 3D representations of medical data. In this paper, we present the methodology and results of a user study that examined the usability of windowing 3D medical imaging using a Kinect™ device compared to a traditional mouse.

1. INTRODUCTION

Usability is an important factor for integrating three-dimensional (3D) imaging into medical environments. A major barrier for implementing 3D medical imaging into clinical practice is time-consuming training required to learn how to interact with the software [1]. COTS hardware such as the Nintendo® Wii Remote™, Microsoft® Kinect™, and Xbox 360 gamepad are interaction devices with which many individuals have some familiarity as they are available in the public market. If these could be used for medical training, diagnosis, and treatment tasks, it is theorized that accuracy could increase in les time for less cost. These devices have the possibility to enable 3D spatial interaction more efficiently than the traditional mouse because they manipulate position and orientation with six degrees of freedom (DOF) [2]. These devices are designed for a fast learning and ease of use for a broad range of users. Harnessing this for medical tasks, involving digital medical data, offers tremendous potential.

2. BACKGROUND

2.1 Commercial-off-the-shelf devices

The gamepad is a controller that uses the fingers and thumbs to provide user input, and it has been used as a COTS device for interacting with 3D virtual environments because it is ergonometric and low cost (Figure 1c). It has been found that the gamepad enables easy learning as an interaction device, and its various buttons provide numerous possibilities for manipulation input. The gamepad also offers a high degree of precision and control because of the inclusion of dual analog joysticks [3].

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After the release of the Nintendo® Wii™, developers discovered the potential of the Wii Remote™ as a COTS device for interaction with a 3D virtual environment (Figure 1a). In 2007, a system for head tracking using head-mounted infrared lights was developed which gave positional data to track the user's head when detected by the Wii Remote™ cameras [4]. Research groups began to look at the Wii Remote's™ capabilities for pointing and aiming in a head-mounted virtual reality space. One study analyzed two Wii Remote™ based tracking methods specifically for human computer interaction research because the Wii Remote offered previously unheard of tracking capabilities for a device that was so inexpensive in comparison to older devices [5]. However, the study concluded that the Wii Remote™ was imprecise, relying on nothing but two infrared points for location and an accelerometer for each axis of rotation [6].

The Kinect™ uses two cameras and an array of infrared points projected onto a user. The Kinect™ takes point locations from both cameras and uses the disparities to triangulate each point's position in 3D space. There is another RGB camera for overlaying an actual image onto the 3D mesh to create a lifelike partial 3D model of the subject. In order to sense human movement and hand gestures, the Kinect™ has built-in skeletal tracking, which approximates the position of the user's limbs [7]. The Microsoft® Kinect™ is regarded as an effective COTS solution for hands-free manipulation of 3D visual representations such as volume renderings of medical data (Figure 1b) [8].

(a)

(b)

(c)

Figure 1. (a)The Nintendo® Wii Remote™ is a COTS device that operates via one-handed navigation. (www.ic4uae.com/Product.aspx?productid=63005) (b)The Microsoft® Kinect™ is a COTS device that operates via touch-free navigation. (annporter.wordpress.com/2012/04/10/interior-design-via-kinect/) (c)The gamepad is a COTS device that operates via two-handed navigation. (compactiongames.about.com/od/hardware/tp/gamepads.htm)

Research to understand user's personal preference for interaction devices with respect to 3D medical imaging has been limited. However, studies addressing other 3D environments have evaluated user preference of COTS interaction devices. One study compared the Wii Remote™ and Kinect™ as interaction devices for 3D geographical mapping and used yaw, pitch, and roll gestures to navigate. In the study, the Computer System Usability Questionnaire provided results on a scale of 1 (strongly disagree) to 7 (strongly agree). The Kinect™ performed tasks easier and with less variability (μ=5.4, σ=0.82) than the Wii Remote™ (μ=5.17, σ=0.94). The study also found that the Kinect™ was observed to be more efficient (μ=5.39) than the Wii Remote™ (μ=4.41) because users found the Kinect™ less distracting. The study's findings conclude "the more the interface is natural (in the sense that it disappears behind the gesture) the more the users are involved in the virtual environment and hosted activities" [9]. Another study compared the Wii Remote™, gamepad, and mouse and keyboard as interaction devices for rotating a virtual object in one task and changing the object's path in a second task. Findings of the study concluded that the average time to perform both tasks was slowest for the Wii Remote™ (29.09 s), second slowest for the gamepad (21.55 s), and fastest for the mouse and keyboard (20.40 s). Participants were unable to complete the rotation task using the Wii Remote™ in 80% of total attempts, and the Wii Remote™ was selected as the least favorite interface by 90% of the participants [3].

Maintaining a sterile environment, in addition to usability, is an important consideration for integrating 3D imaging into medical environments. Sterility is extremely critical in medical settings, especially operating rooms, intensive care units, and autopsy suites. While the gamepad and Wii Remote™ provide the 3D motion mapping that the traditional mouse does not, such interaction devices require physical contact with the medical user and could increase contamination by transferring pathogens [10]. The Microsoft® Kinect™ provides touch-free navigation, allowing remote manipulation of 3D medical images through hand gestures [9].

2.2 Windowing

The method of changing the tissue densities displayed in 3D medical images (Figure 2) is called windowing. Through windowing one can isolate tissue density ranges for investigation of a specific anatomical feature. For example, orthopedic specialists could track changes in bone density by adjusting the windowed values to view a patients bone structure [11]. Most 3D medical imaging studies focus on rotation, clipping, zooming and translation, with only limited research focused on the usability of COTS devices with respect to windowing [12, 13].

Figure 2. The windowing technique enables medical professionals to adjust the viewed tissue density of 3D medical images. In this figure, the same 3D cardiac image is displayed in four different viewed tissue density ranges.

In one study ten medical professionals tested a Kinect™ and a voice recognition software configuration compared to a traditional mouse and keyboard configuration. Participants recreated medical image screenshots using windowing, rotation, and zooming techniques. The Kinect™ and a voice recognition software configuration took 75.1 seconds on average, while a traditional mouse and keyboard configuration took 52.1 seconds on average to complete the task. Preferred interactions with windowing techniques for medical professionals were not discussed [13]. Although this study was valuable: 1) recreating medical viewpoints is not a typical task performed by medical professionals and 2) performing tasks to find and identify anatomical features requires specific anatomical knowledge.

Implementation of COTS interaction devices for manipulation of 3D medical images in medical facilities is the wave of the future as these devices offer extended capabilities beyond tradition mouse and keyboard configurations. However, medical environments create unique challenges that need to be addressed before the appropriate COTS devices can be selected and used effectively. Medical professionals need tools that are efficient and easy to learn and use. From our observation, technicians operate computers with patient data to maintain a sterile working environment for doctors. This situation is not ideal, natural communication barriers between the doctor and technician increases operating time and chances for mistakes. This research explores options of returning computer control to the doctor through touch-less navigation of 3D medical images through the use of a Microsoft® Kinect™.

3. METHODOLOGY

This study compared user performance for a windowing task when using both the Kinect™ and a traditional mouse. A software platform, Isis, was developed at the VRAC for the express purpose of studying various technologies for use in visualizing and manipulating digital medical data. Isis includes zooming, rotating, coloring, clipping and windowing functionality; however, all features except windowing were disabled for the experiment. The study consisted of three sections: pre-evaluation, task performance and post-evaluation.

3.1 Pre-evaluation

This section began with a pre-survey. Participants were asked to complete basic background questions about themselves, education, experience with medical imaging and commercially available virtual realty technology (e.g., Kinect, and 3D movies). The pre-evaluation wrapped up with the completion of the Mental Rotation Test [14]. These evaluations served to identify a participant's ability, which could impact the study.

3.2 Task performance

Participants performed the same eight tasks with both the Kinect™ and the mouse. The task order was alternated to reduce a learning curve associated with repetition and the order of interaction devices was randomized between participants. Before each interaction device, participants familiarized themselves with the interaction device and its corresponding response with the software. Participants were given two minutes to complete each task.

For each task a different orientation of an anatomical region was shown on a computer screen (Figure 3a). Based on a verbal command, participants adjusted the double handled slider bar to reveal the appropriate anatomy. Once a participant indicated they adjusted the position of the tissue density range such that the targeted anatomical structure was displayed most clearly (Figure 3b) the study moderator captured the location of both slider bars and task completion time. If the participant was unable to successfully locate the anatomical structure within a two-minute time frame, the

(a) (b)

Figure 3. (a) An anatomical region is shown, and the participant will be instructed that he/she has two minutes to locate a specific structure by only windowing. For this specific anatomical region, the participant will be instructed to locate the teeth. (b) When the participant indicates that he/she has windowed to display the target anatomical structure displayed most clearly, the moderator captured the slider bar values and task completion time.

next anatomical region was displayed and the previous task was counted as incorrect. The procedure was repeated for eight anatomical structures.

Once the tasks were complete using the first interaction device, participants would be trained with the interaction device not previously used. The participant will be asked to identify the same eight anatomical structures in a different order, using the same methodology used for the first interaction device. Slider bar values and task completion time were again captured if the participant indicates that the target anatomical structures was clearly displayed within the two-minute time period. The captured data will be evaluated to determine if the selected region corresponds with calibrated values for CT Hounsfield units of specific tissue types [15].

3.3 Post-evaluation

Participants were asked to complete two final evaluations based on their experience with the Kinect™ and mouse. The first was a comparison survey with a 10-point scale between the mouse and Kinect™. They were given six statements and asked to mark their preference between the two devices (Figure 4). Participants marks were numerically converted for analysis purposes. The mouse was assigned the rating zero and the Kinect™ was assigned a rating of 10. Finally, participants answered five questions to provide qualitative feedback about their experience with the interaction device. Their statements were included in appropriate sections of the results section.

Mouse |-----|-----|-----|-----|-----|-----|-----|-----|-----|-----| Kinect™

Figure 4. Scale used to preference between the mouse or Kinect™ during comparison evaluation.

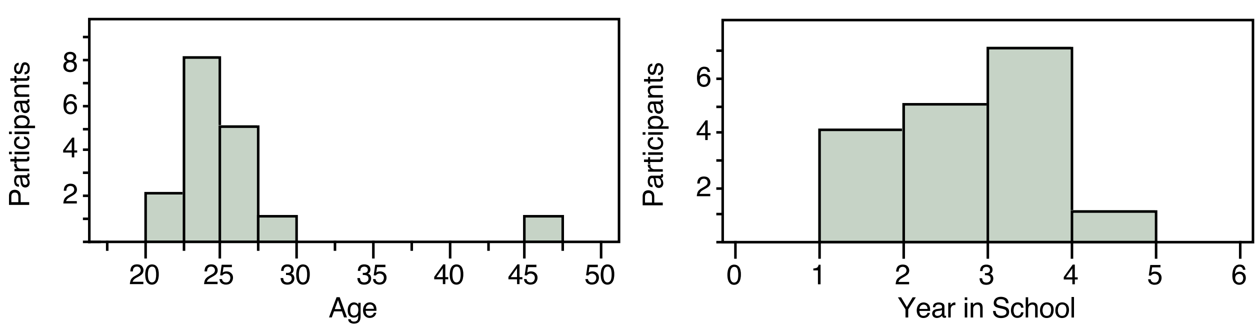
3.4 Equipment

The computer was a Dell Precision T5500 with a Xeon W5580 at 3.20GHz CPU, 4 GB of RAM, and nVidia Quadro FX 5800 graphics card. The monitor was a 24in Dell 2408WFPb, running at a resolution of 1920x1200. The Kinect™ was the Xbox 360 version.

4. RESULTS

4.1 Demographics

Participants included first through fourth year veterinary medical students who had taken a gross anatomy course. A total of 17 participants were part of the study; 4-first year students, 5-second year students, 7-third year students and 1-fourth year student. Participants range in age from 22 to 45 with a median age of 24. Two participants were male, while the rest were females. All participants reported minimal experience with 2D medical images with these being in an observation setting (classroom and clinical observation) or a radiology course offered at the University. Three students had prior experience with 3D medical imaging and all cases were mono-vision.



(a) (b)

Figure 5. (a) Distribution of participants by age. (b) Distribution of participants by year in school.

4.2 Procedure

Each participant was presented an informed consent document to begin the study. They were familiarized with the study, including information about the tasks they would be asked to complete, pre- and post-evaluation surveys. Participants were also made aware that the study was completely voluntary and they had the right end the study at any time. Participants were compensation for their time. This procedure is in accordance with Institutional Review Board (IRB) policy.

Each participant was given eight tasks with both the Kinect™ and mouse, equaling 16 tasks per participants. One participant's results were removed from the study due to an error in the timing function, thus data from 256 tasks was available to evaluate. The first metric analyzed was task completion. Participants had two minutes to adjust the anatomy via windowing based on the task command. 22 (nine for Kinect™ and 13 for mouse) tasks were not completed within the allotted time period. The next metric examined was accuracy. Specific Hounsfield units were assigned to the various anatomical structures in the participant tasks [15] as shown in Table 1. However, determining if a response was "correct" was not as simple as seeing if the range determined by the participant included either the single value or range predetermined in Table 1. For example, when two ranges were being compared they might overlap. It was difficult to determine what percentage of overlap constituted an answer as correct. It was decided to simply extend the range the participant determined. It was tested using percentages (5%, 20%) as well as adding 500 to each side of the range. The only thing affected was the number of tasks considered correct. With only a 5% range increase over 100 tasks would be deemed incorrect. With a 20% range increase, approximately 30 cases would be incorrect. This is truly a judgment as participants are deciding based solely on visual feedback. A representation could visually be close, but mathematically be incorrect. After having performed this study, it is recommended that an expert determine if final values are correct or not. For the remainder of this paper, the ±500 is used. Using this, 12 cases (nine for Kinect™ and three for mouse) were deemed incorrect. Overall, 18 tasks were removed from the Kinect™ and 16 tasks from the mouse for reasons of exceeding the time limit or incorrectly identifying the anatomical feature.

Table 1. Selected calibrated Hounsfield Units specific to tasks [15].

Tissue Type	Hounsfield Units		Tissue Type	Hounsfield Units
Muscle	1027		Ribcage	1575
Blood	1055		Hard Bone	1783
Skin	1075		Cranium	1903

4.3 Task Analysis

The remaining 222 completed and correct tasks were further analyzed between use of a mouse or the Kinect™ device. The completion time, window width lower bound and window width upper bound were captured for each task. The data presented below shows 80% confidence and higher, including associated median values for the Kinect™ and Mouse. Tasks are not presented in the order of participant completion.

Task One (Table 1 - Blood): Window so the blood vessels from the chin to eye sockets are clearly displayed. Participants took less time to complete this task when using the Kinect™ compared to the mouse. Time was statistically significant at a confidence level of 85% and p=0.15 with a one-sided t-test. The median time to complete this task for the Kinect™ was 25.02 seconds, while the mouse took 38.96 seconds. Window center and window width were not statistically significant above an 80% confidence level with p=0.2.

Task Two (Table 1 - Blood): Window so the blood vessels and skin are visible.
Differences were not of statistical significance above an 80% confidence level with p=0.2.

Task Three (Table 1 - Cranium): Window so the skull is clearly displayed with no muscle visible.
For this task, participants choose a more centralized window center when using the Kinect™ compared to using the mouse. Window center was statistically significant at a confidence level of 80% and p=0.2 with a one-sided

t-test. The median window centers for this task were 1612 for the Kinect™ and 1754.5 for the mouse. Time and window width were not statistically significant about an 80% confidence level of p=0.2.

Task Four (Table 1 – Ribcage to Cranium): Window so the skull and ribcage are isolated.
Differences were not of statistical significance above an 80% confidence level with p=0.2.

Task Five (Table 1 - Skin): Window do the skin is visible and opaque.
Differences were not of statistical significance above an 80% confidence level with p=0.2.

Task Six (Table 1 - Skin): Window so only the skin is showing with no internal anatomies visible.
Differences were not of statistical significance above an 80% confidence level with p=0.2.

Task Seven (Table 1 – Skin to Muscle): Window so the skin and soft tissue begin to disappear.
Participants took less time to complete this task when using the Kinect™ compared to the mouse. Time was statistically significant at a confidence level of 85% and p=0.15 with a one-sided t-test. The median time to complete this task for the Kinect™ was 17.76 seconds, while the mouse took 22.70 seconds. Window center and window width were not statistically significant above an 80% confidence level with p=0.2.

Task Eight (Table 1 – Hard Bone): Window to make the teeth as visible as possible.
For this task, participants choose a more centralized window center when using the Kinect™ compared to using the mouse. Window center was statistically significant at a confidence level of 90% and p=0.1 with a one-sided t-test. The median window centers for this task were 1903.5 for the Kinect™ and 2220 for the mouse. Time and window width were not statistically significant about an 80% confidence level of p=0.2.

As seen, four of the 24 task measures were statistically significant for the eight tasks. However, this is due to the relatively small number (> 16) of data points compared for each task and interaction device. Analysis of all task data was also complete.

Time: Overall, the time for participants to complete tasks took longer on the median with the Kinect™ compared to the mouse. Time was statistically significant at a confidence level of 85% at p=0.15. However, the median values for the Kinect™ were not vastly different, the median time for all tasks were 23.82 seconds for the Kinect™ and 23.2 seconds for the mouse. Times for the Kinect™ ranged from 6.1 seconds to 81.32 seconds, while the time ranges for the mouse were 7.02 seconds to 80.09 seconds.

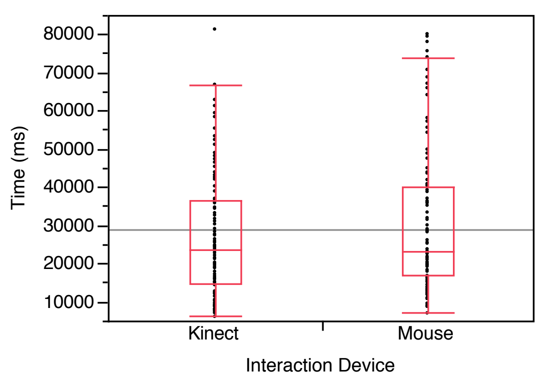


Figure 6. Distribution of participant times for complete all tasks. Participants spent more time completing tasks with the than with the mouse.

Center: Differences were not of statistical significance above an 80% confidence level with p=0.2.

Width: Differences were not of statistical significance above an 80% confidence level with p=0.2.

4.4 Survey Analysis

After completion of the tasks, participants were asked a series of questions. The first set was a comparison survey to evaluate the participant's preference between the two interaction devices. The first two statements asked about shifting the tissue density range from higher tissue densities to lower tissue densities and the reverse of shifting from lower tissue densities to higher tissue densities. There was no statistically significant difference present above an 80% confidence level with p=0.2.

The second set of statements in the comparison survey evaluated participants preference for making large adjustments compared to small adjustments with the interaction devices. Participants preferred making large adjustments with the Kinect™ and small adjustments with the mouse. Adjusting the tissue densities by larger or small margins was statistically significant at a 99% confidence level of p=0.01.

The final statement was independently evaluated. Participants preferred to use the mouse to obtain their desired range of tissue densities. A score closer to zero indicates a preference for the mouse, while a score closer to ten indicates a preference for the Kinect™. The median score for obtaining their desired range of tissue densities was 2, with a maximum score of 8 and a minimum score of 0.

Participant scores on the MRT were analyzed along side the preference scale completed after using both interaction devices to determine if there was a correlation between high-visual-spatial skills and participants preference toward one device or the other. Individuals who scored higher on the MRT preferred using the Kinect™ to shift from higher to lower tissue density ranges. This correlation was statistically significant at a 90% confidence level of p=0.1. The five remaining preference ratings did not show statistical significance above an 80% confidence level and p=0.2.

5. DISCUSSION

The results of this study suggest improvements to Kinect's™ interaction design need to address before the device can effectively be implemented as a primary interaction device for 3D medical imaging. Most participants choose the mouse as their preferred device for reasons of precision. Participants were able to accurately choose the desired location for the slider bars, which allowed for smaller window widths. The Kinect™ struggled to identify participant hands when moved close enough together to achieve smaller window widths. It would no longer recognize two objects, but only one and would seek to find the "missing" hand.

A trend in the data also showed that participants using the Kinect™ very rarely moved both slider bars to one extreme end or the other on the Hounsfield units range when select the appropriate view of an anatomical feature. The median values for both devices were within a few units, the range window centers for the Kinect™ was from 598.5 to 2256.5 compared to the mouse with a range of 206 to 2508. The extreme ranges of data were much more accessible with the mouse compared to the Kinect™.

For this study we used direct mapping for interaction, where the number of pixels across the screen directly mapped to the viewable width available with the Kinect™. Research needs to be conducted to improve the mapping between the participant hand locations and the interaction with the software, specifically in the extreme regions of the lower and upper ranges of Hounsfield Units and when a user's hands get close enough to achieve small window widths.

A novelty factor was also present during participant use with the Kinect™, participants were unfamiliar with how to effectively correct when an undesired response occurred. It appeared that many of the participants used a trial and error approach when operating the Kinect™ compared to known method of operating the mouse for many years. These two approaches showed a learning curve that must be identified and overcome before the Kinect™ can be an effective device to replace the mouse in 3D medical imaging environments. Understanding how professionals intend to use an interaction device will improve the overall design and functionality.

The effect of the Kinect™ being a novelty to the participants also affected the amount of time each participant took for each task. The Kinect™ appeared to have more fumbling that resulted in increased time per task. Evaluating quartile time data, showed consistently lower time to complete tasks for the Kinect™ compared to the mouse, except at the median. Individuals using the mouse spent their extra time contemplating the correctness of their answer, since readjusting a hand position did not result the slider bars shifting location. For example one participant exceeded the time limit for all of the tasks involving the mouse and only two out of eight upon switching to the Kinect™.

Overall, the preferred interaction device to complete a window task was the mouse. Students were familiar with the device and how it would interact with the software. Additional research must be conducted to identify standards for effective implementation of the Kinect™ into 3D medical imaging environments.

6. CONCLUSION

Using the Kinect™ as an interaction device to perform 3D medical imaging windowing tasks shows opportunity. With the appropriate design that improves the Kinect™ interaction in the extreme regions of Hounsfield units and when a participants hands are close enough for small window widths. Kinect™ does have the opportunity to offer a sterile working environment for medical professionals, if the precisions is improved, the interaction device will be a plausible option for operating rooms and other sterile environments. The Kinect™ has the potential to reduce the time on task for participants; however there would be a reduction in the time professionals would spend analyzing an anatomical region

7. FUTURE WORK

Additional work needs to be completed to reevaluate this work and also identify improved methods of mapping participant's hand movements to the windowing functionality. There is opportunity for the Kinect™ to be an effective interaction design, but not until an appropriate design is developed to improve the efficiency of the work, instead of decrease the efficiency of the work

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