Novel Spatial Interaction Techniques for Exploring 3D Medical Images

Pedro Duarte de Figueiredo Parreira

Thesis to obtain the Master of Science Degree in

Biomedical Engineering

Supervisors: Prof. Dr. Joaquim Armando Pires Jorge
Dr. Daniel Simões Lopes

Abstract
Analyzing 3D medical images and the anatomical structures they contain, demands visualization from any desired perspective. Although conventional methods use mouse and keyboard based controls, it can still be a difficult task, mainly because a 2D interface is used to interact with a 3D object. Often users struggle to obtain the right orientation of a 3D image, only achieving the desired view after several attempts. When it comes to surgical scenarios, as procedures have become increasingly reliant on digital imaging systems for navigation, reference, diagnosis and documentation, there is a demand for improved interaction design. The surgical environment is demanding as several user experience limitations appear, mainly due to boundaries between sterile and non-sterile aspects that typically characterize such environments, forcing physicians to interact with the software in an indirect manner, which can result in miscommunications and delays, leading to potential medical complications. We propose a spatial interface based on touchless hand gestures to control the position and orientation of a 3D image. Hand gestures and body postures are directly mapped to 3D movements of the volume, discarding the need for a physical interface and require only a minimalistic graphics user interface. Our goal is to allow for an easy and rapid manipulation of 3D images, giving the user control of the volume as if they were interacting with a real physical object. Results have indicated that with a good spatial awareness and familiarity with motion controls, this approach can yield better result then what is possible with a mouse.

Keywords
3D images, Kinect, Surgery, Touchless Interaction, Spatial Interface, Anatomical Education.

1. INTRODUCTION

Despite being able to move in three dimensions, volume manipulation is often difficult since most visualization systems use the traditional mouse and keyboard controls, which are limited to two dimensional movements. This lack of freedom in control often makes it difficult to obtain specific orientations of the volume, requiring more time to obtain the desired result or using more complex user interfaces and controls.

When physicians analyze medical images, any relevant information or any conclusions made by them are then used as a basis for planning treatment and surgery by other doctors and are of the upmost importance for patient care, so a thorough and comprehensive interpretation of the data is essential.

Several methods and equipment have been developed to take advantage of three dimensional motion and gestures for interacting with volumes but they require either complex or cumbersome controls. Interaction becomes even more complicated when the interface is heavily dependent on the window-icon-menu-pointer (WIMP) approach or requires a long sequence of actions to obtain a desired result.

The surgeons, who need to maintain sterility in the surgical block during a procedure, are then forced to often rely on other personnel to explore and manipulate images in their stead, which comes with several drawbacks and potential complications (O'Hara et al., 2014).

The main question raised by this thesis in then: Can Spatial User Interfaces (SUI) improve a users' ability to manipulate and explored medical volumes, when compared to the traditional WIMP approach?

The goal is to achieve touchless three dimensional interactions while maintaining asepsis during surgery and not limiting the surgeons' ability to perform is functions by becoming too cumbersome or requiring complex movements. Furthermore, through the development of the application MirrorMe, we aim to explore the educational potential of these techniques, in order to provide users with no anatomical background an interactive tool for anatomical awareness and exploration, providing a better understanding of human anatomy.

2. BACKGROUND

2.1 State of the Art

Visualization of medical images is a daily necessity in a clinical context, as it serves an essential role in several medical procedures, from diagnostics to surgery, even in education as tool for students. Thus, a versatile and capable system for storing and viewing medical data is needed.

The devices used to access these images are generally computer terminals, equipped with high resolution screens, a mouse and keyboard, which the physicians use on a regular basis.

While scientific visualization typically deals with datasets that define structures in 3D space, image acquisition is done primarily in slices. In most techniques, an image is captured as a slice along the body of the subject, human or otherwise, and subsequent images are acquired along the length of the region of interest.

While the primary focus of most imaging software is the visualization of these slices as 2D images, reconstruction of a 3D model is often useful, but limited to the same set of controls, most commonly the mouse and keyboard. This means that the user is forced to manipulate volumes, a three dimensional object, while mouse input is only two-dimensional, forcing one to map 2D inputs as 3D manipulations for several data-types and exploration techniques.

2.2 Problem Statement

With the increase in the number of functions available, and the complexity of these functions, user interfaces have become increasingly cluttered and difficult to navigate. The WIMP layout usually employed in traditional interfaces has served mouse inputs for a long time, but this approach has become less desirable as it can compromise user experience and performance (Teather, 2008).

2.2.1 Surgical Environment

Surgical procedures have become increasingly reliant on a range of digital imaging systems, but the need to maintain boundaries between sterile and non-sterile aspects of the surgical environment gives rise to numerous new challenges when the surgeons need to interact with images.

These limitations are often the cause of difficulties for the surgical staff, as one of the main solutions used is the aid of a second member of the surgical team to manipulate images at the surgeons' request, even though this can interfere with the surgeons' ability to interpret and analyze medical images. This can result in errors and inefficiencies, which in turn can result in medical complications, leaving patients and the staff at risk.(O'Hara et al., 2014)

2.2.2 Information Asymmetry

In 1963, Stanford University professor Kenneth Arrow argued that the market for medical care is inherently flawed because of asymmetric information.(Matsushima et al., 1989) When confronted with a medical condition, the patients' ability to understand the severity and extent of the problem heavily depends on the doctors' ability to convey that information. The lack of formal or even informal education on the matter provides a great hindrance towards an effective communication, and since patients are often limited to the same medical images as their doctors, a visual interpretation of the problem is often difficult.

Whether the goal is to convey medical information to a patient during decision making or as an educational tool for students, research into new interaction technologies should take into account their potential application outside of the surgical scenario, such that less knowledgeable users may be able to use them as well.

2.3 Background Definitions

2.3.1 Bimanual Gestural Interface

When using motion controls for interaction purposes, one must take into account the nature of the interaction, and how to define how this interaction will be carried out. Specifically, when the user is required to use both hands has the source of interaction controls one must determine how each hand will interact with the interface.

In this regard, Yves Guiards' work with the Kinematic Chain theory (Guiard, 1987) serves as a powerful basis for designing a bimanual system. In his work, Guiard studied examples of real-world human bimanual interactions and observed a difference in the work performed by the two hands, but in a structured manner. From these observations, some principles were defined and a model known as the "kinematic chain model" was created. In this model, the right hand operates in a spatial reference frame that is dependent of the left hand, and thus the left hand usually precedes the actions of the right hand, with both of them operating in different spatial and temporal scales of motion.

2.3.2 Symmetric and Asymmetric Hand Gestures

Symmetric interactions are performed when the two hands contribute to a task in an equal manner, regardless of synchronicity. Alternatively, when each hand performs a different sub-task, the type of interaction is defined as asymmetric.

Guiards' work has laid the foundation for several research projects and studies regarding asymmetric interactions (Veit, Capobianco, & Bechmann, 2008), while research in symmetrical interfaces is more limited and requires further study (Latulipe, 2006).

2.3.3 SUI vs WIMP

With a greater number of functionalities and objects available to the user, researchers have looked for an alternative to the traditional window-icon-menu-pointer (WIMP) interfaces, since these can become easily cluttered and difficult to navigate, turning their attention towards Spatial User Interfaces (SUI).

A group of researchers at IBM Almaden Research Center have concluded that users would search for and acquire objects if they were displayed in 3D and in a realistic interface, rather than a regular 2D display (Dryer, Selker, Zhai, & Jose, 1998). The use of SUI has also shown to have a positive effect in enhancing user awareness and understanding (Lee, 2005) in a variety of environments in the real world.

2.3.4 Depth Sensor Camera

The Kinect One is an accessory for Microsoft's Xbox One game console which contains an array of microphones, a depth camera using structured light, and a color camera. The Kinect is intended to be used as a touch-free game controller, tracking the body or bodies of players inside its field of view.

Most cameras work by projecting 3D objects in real space onto a 2D image plane along straight lines going through the camera's optical plane of view, but the distance that a 3D point "travels" along its line of projection is lost in the 2D display. A 3D camera like the Kinect provides the missing bit of information by determining the 3D point's distance along its projection line

Dedicated software uses a series of machine learning algorithms to map a series of joints to the object, which are then saved as variables.

2.3.5 Exploring Volumes in an Educational context

Volumetric representation and exploration of volumes in not only a valuable subject in a medical context, it is also important as a tool for education, with some universities trying to implement biomedical imaging informatics curriculums to train interdisciplinary experts to better take advantage of the data currently available (Imielinska & Molholt, 1996) and smaller groups attempting to combine scientific storytelling and the latest in computer volume visualization to incorporate biomechanics and physiology in interactive models of the human anatomy (Thibeault, 2014)

2.4 Related Work

Several works have attempted to improve interactivity and visualization of medical volumes in a three dimensional environments, resulting in numerous new approaches to solving this problem.

Microsoft as attempted to use the HoloLens (Fingas, 2015) to visualize three dimensional medical data as a teaching tool for exploring anatomical structures. Some have taken the idea further, using head mounted displays such as the Oculus Rift and Samsung Gear VR so that surgeons can oversee the operating theater from the eyes of the consulting surgeon (MedicalRealities, 2015). This type of approach gives users a greater sense of immersion and awareness of anatomical structures but interaction is limited to non-existent and its use is similar to that of a video feed.

Other studies have focused more on manipulation of data, like Laha and Bowman (Laha & Bowman, 2013) who have attempted to segment a data volume without the loss of context or distortion of the volume, associated with focusing on a point of interest. They aimed to implement a bimanual interaction based on the metaphor of cracking open a volume, aptly named Volume Cracker. However, this type of interaction depends heavily on dedicated peripherals and hardware which complicates practical applications of this type of technology.

As a way of making equipment less cumbersome, companies such as Gestureplux have created relatively small wrist bands that take advantage of EMG and accelerometers to interpret users' movements and map them to commands

(Plux, 2015), but since the users are limited to simple hand gestures, each gesture may only be used for a simple command, meaning that complex commands required the user to resort to either long or complicated series of gestures.

Noticing these faults, some systems have taken steps to move away from wearable equipment, while still making interaction with volumes as natural and fluid as possible.

In his Masters' thesis, Brendan Polley (Polley, 2014) has attempted to use simple hand gestures to interact with volumes generated from medical images with is project, Form and Function 3D using a sensor placed underneath the hand. While simpler and less obstructive, this setup still requires a dedicated space near the screen, making it necessary for the surgeon to move next to it to operate the images.

Another way to track movement is by using depth cameras, such as the Kinect One (Kinect v2 or simply Kinect). This gives us a very versatile tool for tracking body movement, at a relatively reduced cost.

The company Gestsure (Gestsure, 2015) has taken advantage of the Kinect to create an easy to use system that allows surgeons to interact with their image viewing software using simple hand gestures to explore image slices during surgery.

Microsoft itself has taken steps into similar applications (O'Hara et al., 2014), taking into account not only the needs of the physicians during surgery, but also the socio-technical concerns at play when designing this type of technology, giving further insight into the trials and tribulations inside the surgical block.

Unfortunately, most of these projects focus on using the Kinects capabilities to simply emulate the standard mouse and keyboard controls, maintaining a WIMP framework and focusing on observing 2D slices.

3. METHODOLOGY

The focus of this thesis is to create a group of mechanics that reproduce the functions present in the traditional software, as these are essential for volume control and exploration, but implement these mechanics in a simple manner that takes advantage of the available technologies and resources of the Kinect.

3.1 Unity3D

Unity3D was chosen as the platform for developing the platform due to its low barrier to entry and extensive documentation. Due to the lack of an extensive background in object programming and dealing with geometry in a virtual environment, Unity's comprehensive environment and detailed tutorials were ideal for learning and developing the necessary skills needed for this thesis.

3.2 Volume Data

A stack of 2D medical images was used as the basis for the volume. Each image was converted from its original DICOM format to a bitmap format (.bmp), so that the data of the image may be read by Unity. The color of each pixel in each image was extracted and a three dimensional tensor was created to hold the color information, with the dimensions of the tensor being that of the intended resolution for the final rendered volume. The information in the tensor was applied to a 3D Texture and applied to a material of a cube object in the virtual environment, and scaled appropriately. The volume was rendered using a Raymarching algorithm, with shaders accounting for depth and opacity.

3.3 Kinect Implementation

Interaction with the application is done almost exclusively with the Kinect camera.

Information from the Kinect sensor was obtained using the Kinects SDK and a custom application which obtained and organized the relevant information. Position and orientation of the joints and the state of the hands was sent via a Local Wireless Network to the computer running the application

Aside from the position and orientation variables, two additional variables were also obtained: the left and right hand states. Hand states are variables that determine if each hand represents one of three predetermined positions: "lasso" (Figure 1, A)), "open" (Figure 1, B)) and "closed" (Figure 1, C)).

Lasso – The hand is closed except for a single finger which points outwards.

Closed – The hand is closed in a fist.

Open – The hand is open, with all fingers pointing outwards, making a palm

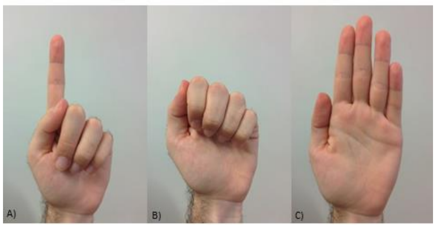

Figure 1 - Example of Hand Gestures: A) Lasso; B) Closed; C) Open

This gives greater versatility in terms of controls without the need for complex movements or voice controls to switch between the types of interaction.

3.4 Voxel Explorer

Voxel Explorer is a platform whose goal is to allow the users to manipulate and explore volumes based on medical data, using three dimensional controls without the need for physical contact or the use of cumbersome or expensive tracking hardware.

3.4.1 Display

The main display of Voxel Explorer consists of the main volume (Figure 2, A)), a white panel at the bottom of the screen (Figure 2, B)) and a cube with colored axis at the lower left (Figure 2, C)), with two vertical panels displaying several buttons at each side if these menus are selected. A small text, indicating whether dragging rotation controls are being used or not, can be seen at the top of the screen.

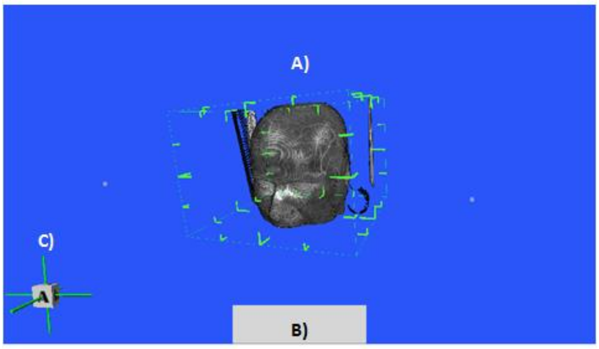

Figure 2 - Interface of Voxel Explorer with a volume displayed in the center. A) Volume; B) Display panel; C) Orientation Cube

Interaction is done in an asymmetrical bimanual manner, were the left hand is used primarily for movement based controls, such as translation and rotation, while the right hand is used mainly for selecting functions or commands. When the users' hands are positioned inside the bounds of the screen, two cursors appear on screen with positions relative to the positions of the corresponding hand; if the hands are outside the left or right bounds of the screen, but within the horizontal bounds, the side menus can be accessed and interacted with.

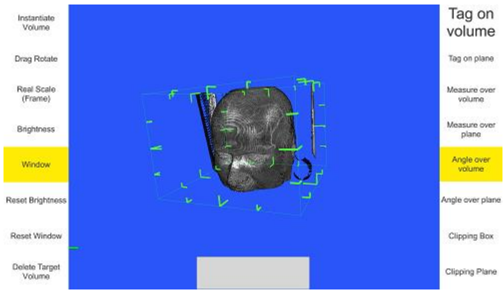

Figure 3 - Left and right menu of Voxel Explorer displayed, with the highlighted functions in Yellow

This was done as a way of displaying the least necessary amount of buttons on screen unless the users' intention is to interact with them. The button layout is maintained to retain a certain sense of familiarity with the users, who are most likely used to the traditional WIMP display instead of a more minimalistic approach.

Selecting a function is done by accessing the side menus and selecting the desired function button. The height of the hand determines the button selected, which is highlighted in yellow, and selecting that button is done making a fist ("closed") on the desired function for 2 continuous seconds (during which the button will appear red).

3.4.2 Volume Manipulation With Hand Gestures

Translation and rotation of the volume is possible when no function is selected to avoid conflict with other functionalities, and is done primarily with the left hand.

When the user closes his left fist, the position of the hand is marked as the offset point. At every frame, a vector is computed from the offset point to the current position of the hand. This vector is then added to the position of the volume, and its rotation is changed so that it faces the new point.

The user may also rotate the volume in a fashion similar to the traditional mouse controls. When the option is selected, the user may simply close their left fist and move it the x and y axis, the z axis being irrelevant, and the volume will rotate according to this movement.

The purpose of this option is to compare the reaction of users to both methods of rotation, one of them being more familiar, and the new, more novel approach with the Kinect.

In the lower left corner, a directional box is presented. This box serves a dual purpose, both as a source of information and an interaction tool. This box adapts the same rotation as the volume being manipulated, with each face of the cube indicating the face of the volume (A – anterior, R – right, L – Left, P – posterior, U – upper, L - Lower). The axis presented around the cube also allow the user to change the volumes rotation and position along each axis, since using each command over a certain axis limits movement to that axis, which allows for a more fine control of the volume (Decle, 2011)

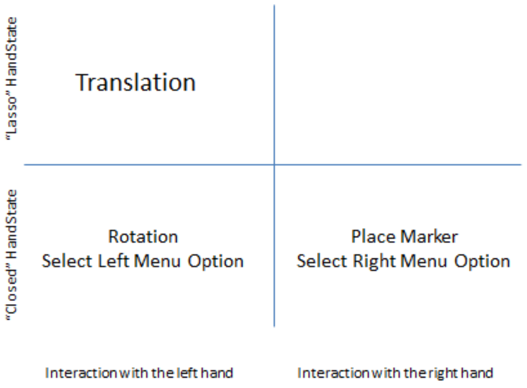

Figure 4 - General display of the interaction controls with Voxel Explorer

3.4.3 Measure Box

A wireframe box surrounding the volume is rendered "above" the volume in order to give the users a better perception of the volumes dimension. Each edge is divided into four segments, with the middle, longer line dividing the edge in half and two smaller lines dividing each half in quarters. This is done over each face of the box connected to the edge and the main goal is to give the user a better perception of the dimensions of the volume

3.4.4 Measure Lengths, Angles and Apply Tags

Users have the ability to make measurements over the faces of the volume or over any of the clipping planes, canonical or free.

After selecting the desired option a cursor appears, which can be moved in the x and y axis using the left hand "lasso" state. At each frame, a ray is casted forward and is checked for collision with either the plane or the box surrounding the limits of the volume. If there is no collision, the cross inside the cursor is displayed red, and you cannot make any measurements. If a collision is detected, the cross is moved to the point of collision and is displayed green. To set a marker, the user needs to close the right hand (indicating the "closed" state of the hand).

In order to measure lengths, two markers need to be set, and a line appears after the second marker is set, connecting the two, with the length of the measurement being displayed midway between both markers, in red letters.

Angles are determined in a similar fashion, utilizing three markers instead of two, with the measured angle appearing over the second marker.

Finally, the user may simply tag the volume, by placing a single marker.

All markers and lines are rendered "over" the volume, maintaining their relative position during translation and rotation, and are still visible independently of the clipping planes applied to the volume.

3.4.5 Clipping Box

The users have the ability to clip the volume along a plane perpendicular to each axis. When the option is selected, the user may choose which plane to move by using the regular translation methods when a plane is selected. When the cursor is over a plane, that plane is highlighted in green, indicating it has been selected, and then highlighted in red when moved. A plane may be dropped by using the "open" state of the left hand.

3.5 MirrorMe

MirrorMe is an application designed to display anatomical information over the human body, giving users more interaction and awareness when exploring volumes and structures.

3.5.1 Main Display

The main scene in the anatomical MirrorMe application consists of a skeletal dummy, representing the human body whose movements are the same as the user.

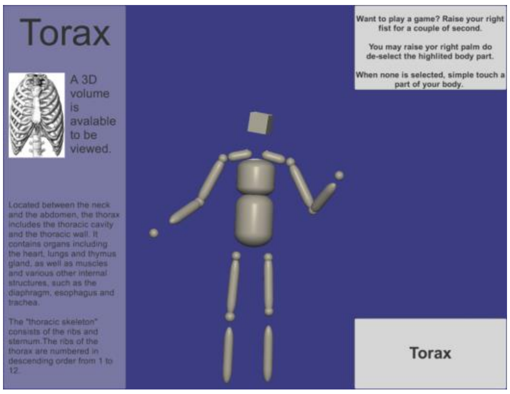

Figure 5 - General display of the MirrorMe user interface

There are three main panels being displayed:

- A panel in the lower right corner, displaying the name of the body part highlighted by the user

- A panel in the upper right corner, displaying instructions for the user

- A panel on the left side of the screen, displaying information about the highlighted body part. The highlight panel only displays the name of a body part if one is selected, if none is selected, the panel will appear blank, and the left panel will not appear at all.

While in the main scene, the user may select a certain part of the body in order to obtain information related to it. To do this, the user can simply touch that part of their body with their right hand, and deselect it by raising their right palm for 2 seconds. While a body part is selected, information about that body part is presented on the left side of the screen.

3.5.2 View Anatomical Volumes

When certain body parts are selected, the user may raise their left finger (left hand in the "lasso" state) to enter a new scene were a volume is displayed over the skeleton, following the movements of the user. The user may also move forward and backwards in order to change which transfer function to apply to the volume, with each transfer function revealing different features of the volume. Raising the left finger again returns the user to the main scene.

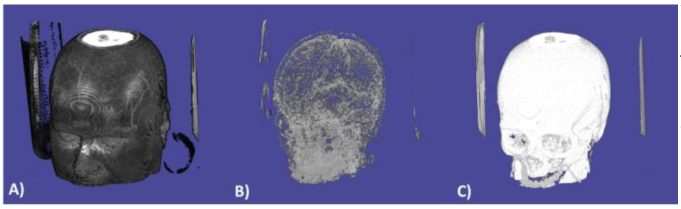

Figure 6 - Volume of a human head with three filters applied when the user is in near (A), mid (B) and far (C) range of the Kinect

The main purpose of this feature is to give users a better awareness of the anatomical structure being displayed, by giving them the larger context of the body, instead of just the isolated segment.

3.5.3 Quiz

The users can also participate in a quiz based on the information displayed in the main scene, to promote a greater involvement and enthusiasm from users from the fact that they are using their body to answer these questions, instead of the traditional test or quiz format.

4. RESULTS

4.1 User Performance Tests

To determine if Voxel Explorer can be a suitable alternative, or even improve upon traditional WIMP interfaces, three major aspects needed to be determined:

1) Is the application capable of accomplishing the same basic and essential tasks as the traditional manipulation software?
2) Can these tasks be accomplished in a similar or shorter time when compared to the traditional software?
3) Can this setup provide a substantial benefit over mouse controls?

To find the answer to these three major questions, user tests were designed to evaluate performance while executing several basic tasks, using both Voxel Explorer and traditional software. For the purpose of these tests, the volume rendering software VolView (Volview, 2015) was chosen because it possesses many of the functionalities commonly present in clinically used software.

To evaluate users' ability to translate and rotate volumes with each system, they were asked to manipulate volumes as to match the position and orientation of displayed images. A total of five images were presented per volume, with one volume serving as a training volume and two as task volumes, and the time necessary to complete each task was measured. The number of attempts a user needed to complete the task was determined for a subset of the user sample.

To determine the number of attempts needed to obtain the desired result, a single attempt was counted at the beginning of each task, an a new attempt was added when: 1) the user would reset the position of the volume (except if this was performed at the very beginning of the task); 2) the user would move the volume randomly (such as wildly rotating the mouse or hands); 3) the user would lose control of the volumes' rotation (either by accident or frustration) and would have to try again.

After the rotation and translation of the volume, users were asked to clip the volume as to reveal a specific structure within, over which they would be asked to measure a distance, an angle and tag a specific point. The highlighted structures and the measurements were pre-determined to be simple and easily recognizable, so that users would not be limited by their knowledge (or lack thereof) of anatomy and physiology.

Finally, users were asked to experiment with MirrorMe and fill out a survey with their information and opinions on their experience with both applications.

4.2 Participants

Fifteen unpaid participants (13 male and 2 female) were recruited for these tests, with ages ranging from 20 to 24 years old (M =22.60; SD =1.27). Eight of the 15 participants had a Masters degree in Biomedical Engineering, with the remaining participants having a background in Informatics engineering. One user reported being experienced with motion controls, while the remainder of participants reported only basic knowledge of this technology. As expected, users without a biomedical background reported having no experience with medical images, while those who had experience reported is as basic, although one reported to have used medical images at a professional level.

5. RESULTS

5.1 Voxel Explorer

After a superficial analysis of the results, the immediate conclusion is that the times obtained in Voxel Explorer are similar to the results obtained in Volview.

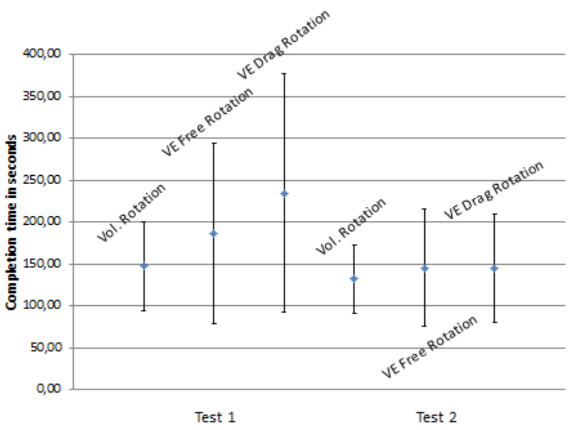

Figure 7 - Comparison between completion times using Volview (Vol) and Voxel Explorer (VE) using both drag and free rotation

While the slight difference between the first and second tasks may indicate an improvement in performance due to familiarity with the controls, there seems to be no significant improvement offered by the use of Voxel Explorer.

However, when we look into how many attempts it takes for each user to obtain the desired results, we can get a better understanding of how the Voxel explorer controls improve upon the traditional controls.

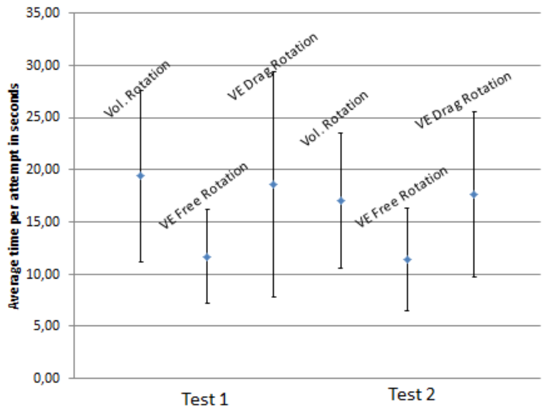

Figure 8 - Comparison between average times per attempt using Volview (Vol) and Voxel Explorer (VE) using both drag and free rotation

From the results obtained, we can determine that during the first test, when using the free rotation in the Voxel Explorer platform, the mean time used in each attempt (M=11.69; SD=4.54) is significantly smaller than the time used in both the Volview attempts (M=19.38; SD=8.20), paired t(7) = 5.52, two-tailed p=0.0006, with a CI of 99% of mean difference (3.35, 13.74). During the second test this trend is still visible, with attempts in Voxel Explorer (M=11.43; SD=4.89) being significantly faster than in Volview (M=17.08; SD=6.48), paired t(8) = 4.19, two-tailed p=0.004, with a C.I. of 99% of mean difference (1.93, 10.64), providing evidence that Voxel Explorer improves the time necessary for each attempt. Ideally, the desired rotation of a volume could be obtained with a single attempt in Voxel Explorer, provided the user is familiar with the volume at hand. By reducing the amount of, the user could obtain the desired orientation in a more efficient way than what is possible with mouse controls.

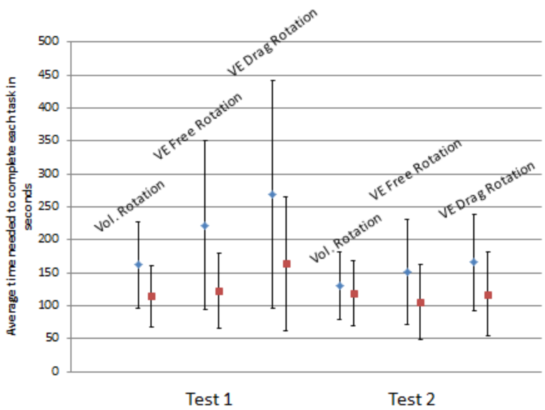

Figure 9 - Comparison between average completion times from users with a Biomedical background (Blue) and users with Informatics background (Red)

As we can observe from the results in Figure 9, users with a biomedical background performed worst in the first task, following the trend established by the general results presented previously, and obtained better and more consistent results during the second task. Users with no background in medical images however, but with a background in Informatics, obtained overall more consistent and slightly better results in both tasks. This may indicate that a visual culture of medical data may not be as influential as originally expected, and instead a spatial awareness is much more relevant to obtaining optimal results.

When applying measurements and clipping planes, using Voxel Explorer took considerably longer when compared with the traditional software. There was also no substantial improvement in performance between the first and second volume in any of the tasks using Voxel Explorer, which indicates that user experiences role in this case is either indifferent or insubstantial in the tests performed. While a slight improvement in user performance using Volview may be possible, the overall change was not significant enough to be statistically significant, which may indicate again an insubstantial effect of user experience.

One major hurdle noted during the execution of these tasks was the Kinects lack of precision. While users were relatively quick to identify the structures of interest, they had some trouble selecting the desired slice or placing the markers in the correct position, thus increasing the time necessary to complete the task.

As an overall opinion, users preferred the use of motion controls for both rotation (60%) and translation (100%) of the volume over the traditional mouse controls. However, when asked about their preference over which application to use for measurements and applying tags, results were more mixed, with Volview being preferred for both (60% preference for tags and 73.3 % preference for measurements). When asked about fatigue, users were mostly undisturbed by the physical strain of the tasks (M=2.87; SD=0.50; 1 – Very Tiring and 4 – Not Tiring) but did not regard it as unnoticeable. Each Voxel explorer task took around 30 minutes to complete (depending on user performance), which is substantially more than what surgeons or students would need. Despite the lack of empirical data on this matter, these results indicate that fatigue may not be a major concern when using these types of controls.

5.2 MirrorMe

Because of MirrorMe's early stage of development, the questions in the survey focused more on the users overall experience with the tool, rather than their performance using it.

Most users found that using their body as a canvas made it more compelling to explore information and interact with, but reported that the use of a more detailed volume would help to identify certain structures. Users also reported that they found it easier to learn many of the concepts presented thanks to the use of their body to locate the source of each piece of information.

6. DISCUSSION

The main question raised by this thesis was weather SUI could improve a users' ability to manipulate medical volumes when compared to the traditional approach.

The strength of Voxel Explorer is the ability to perform the trial and error procedure often associated with these tasks at a much faster rate. Ideally, obtaining the desired orientation in Voxel Explorer can be done using a single motion of the hand, and thus a single attempt, while traditional tools don't always allow for this type of efficiency, often requiring several movements because of the lack of degrees of freedom when using the mouse or touch controls. Thus, with enough practice, users may be able to obtain the desired orientation much faster than what is possible with the traditional software.

The biggest shortcomings of this approach were, as demonstrated by the results of the tests performed, the lack of familiarity with the controls and imprecise controls with the Kinect. Giving users the proper instructions or an explicit and compressive tutorial in volume manipulation may yield greater improvements rather than a proper interpretation of the medical data itself. If the correct way of using these controls is properly conveyed to, and learnt by, the users, then one of the main hurdles of this type of controls can be then overcome.

Users' initial response to the new type of interface was largely positive, mainly because of the novelty of the Kinect, since several users couldn´t resist gesticulating in front of the camera when first exposed to it.

While it may be met with some resistance due to unfamiliarity with the system, initial response from medical professionals has also been fairly positive which demonstrates a good level of acceptance from medical staff and their willingness to use this technology as an alternative to the standard, provided it can obtain the desired results.

To achieve this however, further steps into development need to have a greater involvement of the medical staff. Specifically, this interface needs to be tested in surgical environments to determine how functionalities perform, since user tests performed during this thesis took place in closed, controlled environments outside of the surgical context, which limits the quality of the feedback obtained.

7. CONCLUSIONS AND FUTURE WORK

With volume rendering being such a valuable and present aspect of clinical procedures, interfaces need to allow for an effective and interactive way of exploring medical data, not just in an educational context, but during surgical procedures as well. The use of a third dimension, while unfamiliar at first, can result in a much more direct manipulation of volume data and can produce better results that what traditional applications are capable of. Voxel Explorer has shown to introduce several aspects that improve upon WIMP interfaces and gives both those with and without a medical image background an easy to use tool for medical volume manipulation.

However, noisy measurements and incorrect gesture recognitions are still great limitations that need to be addressed before this tool can be used in a real-life surgical scenario. Finding new ways to explain and teach the rotation controls to users is perhaps the most obvious way of improving task performance, but better feedback and other ways of applying tools may be studied as well to improve interaction with the volume data. Before this can be done however, Voxel Explorer needs to be tested in a surgical environment so that the results in user performance can be properly evaluated, as well as highlight limitations that may be specific to that environment, such as improved tracking algorithms to avoid misinterpretation of the intended user when surgeons and nurses move in front of the Kinect.

8. REFERENCES

Decle, F. (2011). tBox: A 3D Transformation Widget designed for Touch-screens. Proceedings of the 2011 Annual Conference on Human Factors in Computing Systems, 3005–3008. http://doi.org/10.1145/1978942.1979387

Dryer, D. C., Selker, T., Zhai, S., & Jose, S. (1998). Representation Matters : The Effect of 3D Objects and a Spatial Metaphor in a Graphical User Interface. In People and Computers XIII, Proceedings of HCI'98, 209–219. http://doi.org/10.1.1.65.7848

Fingas, J. (2015, July 8). Here's how Microsoft HoloLens could teach the next wave of doctors. Retrieved October 27, 2015, from Endgadget: http://www.engadget.com/2015/07/08/microsoft-hololens-medical-student-demo/

Gestsure. (2015). Retrieved October 27, 2015, from http://www.gestsure.com/

Guiard, Y. (1987). Yves Guiard Centre National de la Recherche Scientifique & Université de la Méditerranée CP 910 , 163 avenue de Luminy 13288 Marseille cedex 09 - France. *Journal of Motor Behaviour*, (4), 1–23

Imielinska, C., & Molholt, P. (1996). 3D Virtual Anatomy Into. Communications of the ACM, 48(2), 49–54.

Laha, B., & Bowman, D. a. (2013). Poster: Volume Cracker: A bimanual 3D interaction technique for analysis of raw volumetric data. 3D User Interfaces (3DUI), 2013 IEEE Symposium on, C, 147–148. http://doi.org/10.1109/3DUI.2013.6550221

Latulipe, C. (2006). A symmetric interaction model for bimanual input. PhD Thesis. Retrieved from http://gradworks.umi.com/NR/23/NR23527.html

Lee, J. C.-H. (2005). Spatial User Interfaces : Augmenting Human Sensibilities in a Domestic Kitchen by Jackie Chia-Hsun Lee, (September).

Matsushima, Y., Okamoto, E., Toyosaka, a, Suzuki, E., Nose, K., & Nakamura, a. (1989). Diurnal changes in colonic motility in conscious dogs. Nihon Heikatsukin Gakkai Zasshi, 25(2), 47–54. http://doi.org/10.1126/science.151.3712.867-a

MedicalRealities. (2015). Retrieved October 27, 2015, from MedicalRealities: http://www.medicalrealities.com/

O'Hara, K., Dastur, N., Carrell, T., Gonzalez, G., Sellen, A., Penney, G., … Rouncefield, M. (2014). Touchless interaction in surgery. Communications of the ACM, 57(1), 70–77. http://doi.org/10.1145/2541883.2541899

Plux. (2015). Hands free control of mobile or PC devices. Retrieved October 27, 2015, from http://biosignalsplux.com/: http://biosignalsplux.com/index.php/en/gestureplux

Polley, B. (2014). Form and Function 3D: a Gesture-based User Interface by Brendan Polley. Retrieved October 27, 2015, from https://vimeo.com/108086973

Thibeault, M.-H. (2014, August 6). Student computer scientists bring Giant Walkthrough Brain to life. Retrieved October 27, 2015, from ucalgary: http://www.ucalgary.ca/utoday/issue/2014-08-06/student-computer-scientists-bring-giant-walkthrough-brain-life

Teather, R. . (2008). Comparing 2D and 3D Direct Manipulation Interfaces. Retrieved from http://www.cse.yorku.ca/~rteather/pdfs/thesis.pdf

Veit, M., Capobianco, A., & Bechmann, D. (2008). Consequence of Two-handed Manipulation on Speed, Precision and Perception on Spatial Input Task in 3D Modelling Applications. Journal of Universal Computer Science, 14(19), 3174–3187. Retrieved from http://jucs.org/jucs_14_19/consequence_of_two-handed/jucs_14_19_3174_3187_veit.pdf\nhttp://www.jucs.org/jucs_14_19/consequence_of_two-handed/jucs_14_19_3174_3187_veit.pdf

Volview. (2015). Retrieved October 28, 2015, from Volview: http://www.kitware.com/opensource/volview.htm