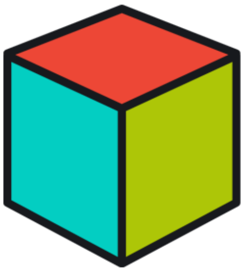

Interactive Tablets for Collaborative 3D Image Exploration

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Acabou? Não sei… Será apenas uma pausa? A verdade é que terminei o mestrado com o sentimento de dever cumprido e uma sensação de alívio e liberdade vazias… Estou livre !? Ponto final no meu percurso académico !? Desde que me conheço que não me vejo sem a escola e os estudos associados à minha vida… A caminhada até este objectivo foi longa e depois de terminada é tempo de traçar objectivos mais ambiciosos. Os próximos tempos vão certamente ser os melhores, sinto-me mais do que preparado para a nova vida, mas as saudades dos tempos académicos vão bater à porta… a sensação de vazio vai voltar, já não é a primeira vez…

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Abstract

In the last few decades, there has been a continuous integration between technology and healthcare, especially mobile healthcare. Everything is going mobile, this is a *motto* that also applies to medicine. Physicians already take advantage of currently available desktop and mobile software to perform their work, although current visualization systems still rely on interaction approaches that do not go beyond 2D interfaces. With the exponential growth in computational power, detailed 3D medical images visualization has become a reality and the current 2D interactions have become obsolete and inefficient in 3D spaces. The advent of portable devices, such as tablets, allied with the need to explore and enhance 3D manipulation techniques, build novel input interfaces and interaction mechanisms while providing at the same time a collaborative tool for volumetric image manipulation and visualization is what this document tries to address.

We propose a solution to integrate and combine mobile devices with powerful 3D rendering engines in a possible collaborative setup, offering novel 3D interactions with tangible and spatially aware mobile touch devices. Despite the difficulty to schedule a collaborative medical experience with physicians, which made it impossible to fully test the solution, we were able to conceptually validate the proposal with professional feedback and through a comprehensive set of interaction experiments with laypeople. The results obtained appear to be a promising improvement in medical visualization and interaction tools.

Keywords: Tablets, Tabletops, Sketch-Based Interfaces, Spatial Interfaces, Collaborative Scenarios, Volume Rendering.

Resumo

Nas últimas décadas tem existido uma contínua integração entre tecnologia e a área da saúde, sobretudo com cuidados de saúde móveis. Tudo se está a converter à tecnologia móvel, este é um *motto* que também se aplica à medicina. Actualmente os médicos já tiram proveito de software fixo e móvel para realizarem o seu trabalho, contudo os actuais sistemas de visualização ainda se baseiam em abordagens de interacção que não vão além de interfaces 2D. Com o crescimento exponencial do poder computacional, a visualização de imagens médicas detalhadas em 3D tornou-se uma realidade e as actuais interacções 2D tornaram-se obsoletas e ineficientes em espaços 3D. O advento dos dispositivos móveis, como o tablet, aliado com a necessidade de explorar e melhorar as técnicas de manipulação 3D, construir novas interfaces e mecanismos de interacção, oferecendo ao mesmo tempo uma ferramenta de trabalho colaborativo para visualização e edição de imagens volumétricas é o que este documento tenta visar.

Propomos uma solução para integrar e combinar dispositivos móveis com poderosos motores de renderização 3D num possível ambiente de colaboração médico, oferecendo nova interacções 3D com dispositivos de toque móveis e conscientes do espaço em seu redor. Apesar da dificuldade em calendarizar uma experiência colaborativa com médicos, o que tornou impossível de testar completamente a solução, foi possível validar conceptualmente a proposta com parecer profissional e através de um conjunto de experiências de interação exaustivas com leigos. Os resultados obtidos parecem ser um promissor avanço em ferramentas de visualização e interacção médicas.

Palavras-Chave: Tablets, Tabletops, Interfaces de Esboço, Interfaces Espaciais, Cenários Colaborativos, Renderização de Volumes.

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List of Acronyms

CT	Computed Tomography
DOF	Degrees Of Freedom
GUI	Graphical User Interface
HCI	Human-Computer Interface
HFF	Hospital Professor Doutor Ferreira Fonseca
MRI	Magnetic Resonance Imaging
RPC	Remote Procedure Call
TACS	Tablets for Collaborative Scenarios
TIPS	Transfer Function Design with Interactive Pointers
UDP	User Datagram Protocol
UI	User Interface
VIMMI	Visualization and Intelligent Multimodal Interfaces
VRS	Volume Rendering Systems
WIMP	Windows-Icons-Menus-Pointers

Chapter 1

1. Introduction

1.1. Motivation

Symbiotic relation between medicine and technology has become a research topic useful to obtain improved results in surgical scenarios and clinical procedures, as well as brand new interactive, excitant and engaging ways to lecture medical contents. Mobile technology has become a factor of such importance to healthcare, making it possible to reach new horizons and paradigms in computer science. Each passing day, mobile systems are giving physicians more opportunities to practice medicine, and not just doctors are demanding mobile healthcare, patients are as well. *Chris Wasden*[1], global healthcare innovation leader said: "Mobile apps will be core in the practice of medicine" due to their ability to change behaviours in both patients and physicians (Information & Society 2012). There is still a long path to cover until medicine and other several areas become one with technology, although mobile applications are already becoming an essential part of clinical practice, research, illustration and education (O'Neill et al. 2013).

Current physicians already take advantage of computational horsepower to explore and visualize 3D medical images, since nowadays volume rendering systems (VRS) support attractive functionalities. Despite the notorious advances in 3D medical visualization, there is still a deficit regarding the development of 3D interaction mechanisms and methodologies, leading to a direct mapping of 2D to 3D interaction techniques (zoom, navigate, rotate, etc.), which does not exploit the touch and spatial interface potential. The final piece in this puzzle is the way medical practitioners view and interact with images, since the search for practical input devices to manipulate 3D objects becomes of greater relevance to many disciplines (Subramanian & Ijsselsteijn 2000).

Medical imaging specialists have traditionally used keyboard and mouse based techniques and interfaces for examining both 2D and 3D volumetric medical images, such as MRIs (magnetic resonance imaging), based on familiar Windows, Icons, Menus & Point-and-click (WIMP) metaphors, these techniques have become increasingly cumbersome for imaging specialists (Seyed et al. 2014b). Such interface techniques do not accommodate well on how medical imaging specialist manipulate and reason about 3D medical images (Seyed et al. 2014a). Even worse, such interfaces are immensely based on indirect control (i.e., crowded with menus and buttons), which hamper the users' performance (Dam 1997). This lack of freedom in control often makes it difficult and time consuming to obtain specific orientations of medical volume.

[1] http://www.chriswasden.com/

Despite the growing popularity of interactive technologies, a huge gap remains between current VRS interfaces and advanced human-computer interaction (HCI). Novel interface design and interaction techniques are required so that healthcare practitioners can spend less time struggling with unfriendly user interfaces and more time dedicated to diagnosis or surgical navigation. This project addresses this problem by developing new interaction techniques based on interactive surfaces, namely tablets, in order to surpass the lack of naturalness and efficient exploration in conventional VRS. The technological improvement to medical image visualization is essentially touch and spatial, and mobile devices present an effective solution to replace 2D traditional techniques, offering means to explore and navigate complex 3D medical data sets, also providing increased fluidity and flexibility, leveraging users already existing skills with tangible objects (Seyed et al. 2014b). As the popularity and usage of touch devices is increasing, the need for a mobile collaborative medical application has also arisen. Collaborative radiology systems enable multiple medical experts to view, analyse and discuss regions of interest in medical images. Current medical applications do not provide the concept of collaboration during this medical task, not offering any specialized tool for medical doctors to perform collaborative diagnosis (Pasha et al. 2012).

In this project, tablets gain special notoriety providing user easy acceptance, as well as perceptive handling (Ponto et al. 2011), as they will be used as a multipurpose input device allied with a sketch-based interface. The deliberate choice was made to use tablets with their ever expanding feature list and new forms of user interactions, making them more readily accepted by users as majority of imaging specialists already use tablet devices comfortably, albeit not necessarily for medical imaging tasks (Souza et al. 2010) (Seyed et al. 2014a). Tablets will yield a favourable environment for a more natural interaction with 3D medical images, acting as a 3D cursor in space, allowing content to be clipped, anatomical parameters measured and transfer functions designed through a sketch-based interface. Spatially aware handheld displays are a promising approach to interact with complex information spaces in a more natural way by extending the interaction space from the 2D surface to the 3D physical space around them (Spindler et al. 2014). On the other hand, tabletops will serve to display multiple views of the content, although navigational interactions can be available for collaborative tasks. Interested users, namely, radiologists, surgeons, medical students, medical illustrators and even patients, will be around the tabletop or wall carrying tablets and interacting with the content while discussing at the same time. To this end, motion capture plays an important role to capture users' tablets position and orientation. Such interaction techniques that promote collaborative task completion, combined with a powerful volume rendering engine, can allow the direct manipulation of large 3D medical image datasets through a visually enriched feedback.

1.2. Scope and Objectives

The major aim of this research project is to augment or even replace desktop systems used in current healthcare VRS, as well as to evidence the interaction potential within a tablet to explore and discuss 3D medical image data. By using its interactive surface and converting it into a tangible device capable of directly interact with the data displayed on a wide screen (e.g., tabletop, TV, wall, etc.), we expect to convert a tablet into a portable multipurpose tool that empowers the user by enabling a more efficient exploration of large 3D data sets. Proposing viable solutions to these interaction challenges may lead to a more productive and less time consuming 3D medical image analysis, while allowing healthcare professionals to focus more on patient diagnosis and surgical aspects.

Based on the *Voxel TIPS* application developed by (Parreira, Mendes, et al. 2015) for the tabletop system (**Figure 1**), it is necessary to make it run on a set of tablets that can guarantee both singular and collaborative task completion. In addition, this proposal will present spatial interaction techniques to explore, visualize, and hereafter segment 3D medical image data.

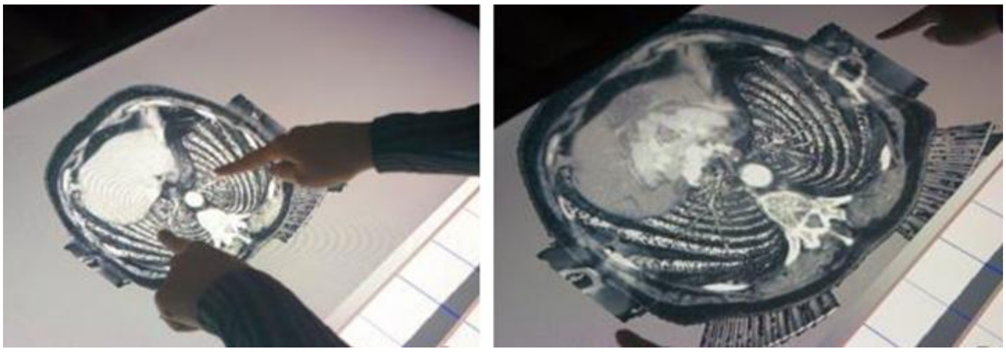


Figure 1 - Voxel TIPS tabletop interaction with volume render.

One of the core tasks is to convert a tablet into a tangible computing input device. This task is achieved using their spatial position and orientation for interaction purposes (Spindler et al. 2014), allowing users to take advantage of interacting directly with the 3D images as they were interacting with a physical object, which can be explored without any physical limitation, even though the content is displayed on a larger screen.

Another innovative feature of this project proposal consists of a novel collaborative exploration tool that allows healthcare practitioners to discuss and communicate, while interacting with a real-time rendered volume. Based on previous research results, the purpose of our work is: to develop a portable, interactive and efficient touch tool for data exploration, which in the past, has largely focused on mouse-based interactions, and understand how it can benefit from interactive surfaces (Isenberg et al. 2012). Following these assumptions, the objectives proposed to the project are:

- Recreate and adapt tools and techniques that are currently used in medical imaging software, through novel interfaces;
- Match previous software to run on a series of tablet devices, which will interact with the 3D image content and promote a collaborative environment;

- Define a multipurpose input device, as well as interface, to provide more powerful visualization and exploration tools than traditional WIMP approaches;
- Create a portable interaction tool that can easily connect to any machine, offering research opportunities on novel interaction paradigms;
- Convert tablet device into a tangible computing device. Therefore, its 6 degrees of freedom will act as a 3D cursor and plane in space;
- Understand and reasoning on how novel interface and input modalities (touch and spatial) change the ability of users to perceive and interact with 3D data.
- Obtain professional feedback on the software developed.

1.3. Contributions

This master thesis contributions are transversal to the multimedia community in human-computer interactions area and to the medical software field of study, and include:

- The development of novel interaction techniques in touch devices for medical purposes;
- The development of novel interaction techniques with spatial interfaces, using a physical 3D cursor in space to manipulate digital content;
- The development of a universal touch interaction tool, portable and easy to connect, that can be used not only to manipulate 3D medical volumes, but to perform every human-computer interaction task;
- The addition of a collaborative architecture in a medical software, where multiple devices can connect and interact at the same time.

Chapter 2

2. Related Work

In this section, we start by present important information about handheld touch devices state-of-the-art, as well as collaborative work involving multi-surface environments, ending with relevant content related to 3D navigation and spatial interaction, congregating the line of reasoning developed through the previous topics. *Appendix B* is available with a brief table analysis of the research projects discussed during this section.

2.1. Touch Medicine: Going Mobile

3D imaging techniques have revolutionized medicine. Almost all modern medicine surgery treatment relies on 3D imaging techniques, which transforms 2D slices in 3D images, such as MRI and CT scanners (Seyed et al. 2014a). The emerging problem relies on actual interfaces and controllers inability to explore and interact with 3D images, taking away the forthcoming potential and progress made in 3D rendering volume visualization. Current workstations for medical image reading support standard modalities, allowing basic navigation through images such as: annotation, marking and quantification of structures (**Figure 2**). Due to cost and space limitations, these workstations are usually constrained to a fixed location in the hospital and not available at every place (Ritter et al. 2015).

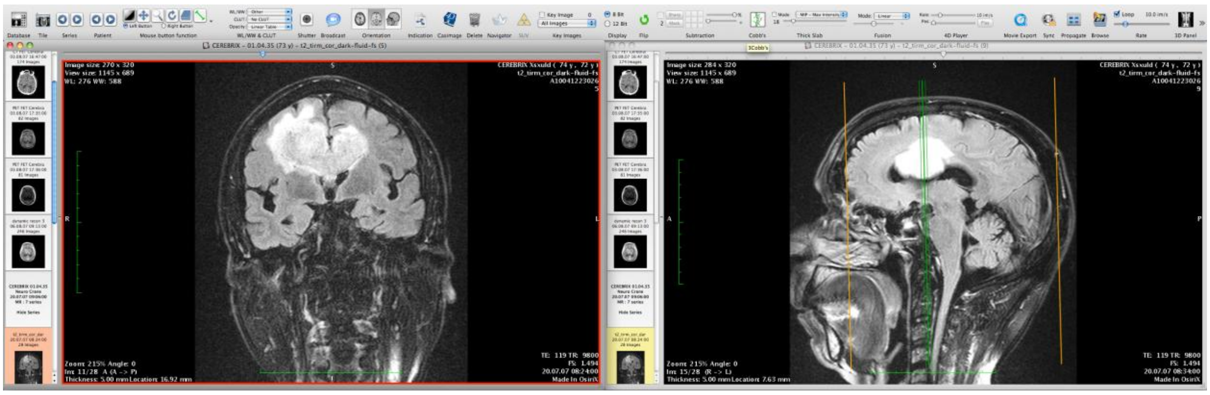


Figure 2 - Traditional workstation image viewer software using crowded WIMP interactions, from OsiriX MD[2]

In the last decade, technology has rapidly improved, not only in terms of computing power and mobility, but also on how we interact with it. Nowadays, mobile devices are not only capable to perform decent 3D renderings, but also to communicate with improved wireless communications, turning this

[2] http://www.osirix-viewer.com/

device into a centralized portal to view, share and interact with data on demand. Albeit the progress made, most of actual interactions are still reduced to exchange and download data (Alexander 2014) emerging as the most popular platform to assist our daily activities.

Tablet devices have reached the complexity needed to be an excellent portable digital tool, to access and communicate to every other machine. This concept is currently limited by the processing capability and the software design of these devices, which is undoubtedly going to change with the further advancement of tablet technology and software. These problems become more apparent when trying to run complex 3D virtual environments. It is impractical not only to copy 3D content from one device to another whenever a user decides, but also to render the complex 3D data locally on computational resource-limited devices such as smartphones and tablets (Alexander 2014).

It is easy to forget that the revolutionary tablet device only hit the shops in 2010, practically yesterday in the timeline of technologic advances, and yet it has already transformed the way many doctors access and interact with images. The field of medical applications is becoming one of the most dynamic and emerging tendencies in medicine due to the great potential it holds to improve clinical practice (Larrosa et al. 2013). Hospitals have already seen the advantage of 'filmless' radiology and gradually are adopting this concept. Even though, initially seen as an expensive tool, more and more clinicians have discovered ways for smartphone and tablet devices to be assimilated and useful to their practice (Edirisinghe & Crossette 2012).

Although portability and manageability are important aspects to retain from tablet devices, many research projects are developed based on other versatile components of these computational-rendering powered machines gifted with high-tech sensors, making them a unique tool capable to add a *wow* factor to any system. Next sub-topics contain shallow but relevant information to the upcoming detailed related work. This will be helpful to contextualize, understand and explore some of the capabilities that make these first-rate machines the future of interaction, design and research, granting answers to the questions: *Why choose a tablet device? What does it offer?*

2.1.1. Universal Controller

So far, the great majority of first generation mobile applications related to medical imaging inspection do not introduce interaction styles beyond basic gestures (e.g., pinch gesture to magnify). However, using fingers to grab, measure, fold, or annotate make certain tasks easier to achieve despite our long-term training towards mouse interaction. The aim to overcome the one-finger interaction, is to develop a set of gestures to easily access functionalities of high relevance (Ritter el al, 2015), these smartphone and tablet devices can be an optimal and cost-effective extension or even replacement to current medical workstations (Székely et al. 2013). The need for evidences in medical practice with mobile technology is starting to be recognized as a necessity. As a first step to determine whether a tablet device has an integral role to play in the digital medical field some small studies have been conducted to analyse and process 3D rendered data using a tablet device (Edirisinghe & Crossette

2012). If current trends continue, tablet devices can become a very strong platform to handle digital radiology and increase productivity itself.

Research projects exploring touch-sensitive properties of mobile devices are numerous, and the search for a universal controller that can interact with any display is giving its first steps. The touch screen can replace the need for mouse buttons and allow interaction with elements displayed on the device, such example was tested with a project for a touch-sensitive phone strapped to a computer mouse, *LensMouse* (Yang et al. 2010). Other commercial applications take advantage of the display and touch properties to transform a phone into a secondary display or enhanced input touchpad (Piazza et al. 2013), or people can simply interact with projected surfaces (not touch-interactive) by using their mobile devices as a proxy (Tang & Irani 2011).

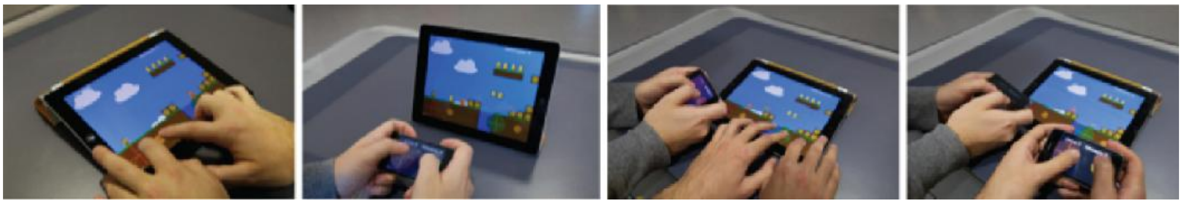


Figure 3 - Smartphone working as a game controller with interactive Tablet (Piazza et al. 2013).

2.1.2. Connectivity

Mobile interaction with clinical data is becoming increasingly popular as multi-touch mobile devices evolve into personal information hubs (Ritter et al. 2015). The appeal of tablet devices has emerged through their portability and versatility compared to laptop computers (Edirisinghe & Crossette 2012). It is occurring to the current generation of medical practitioners to own a tablet and/or smartphone device empowered with networking capabilities. Since the focus of this proposal is to interact with rich 3D medical content in a broad range of end-devices while working together in real-time collaboration, a connection mechanism is essential.

Figure 4 - Workstation and tablet connection symbiosis from (Ritter et al. 2015) research.

In the last decade, wireless networks have provided faster, more stable and reliable connections to mobile devices and considerable efforts have been made to access content with mobile computing. (Ritter et al. 2015) research project has a setup in which a mobile device acts as a hybrid image

display and interaction device, changing its role during the workflow, allowing physicians to connect and interact with more powerful stations. Given both their mobility and adequacy to support direct manipulation, tablets are attractive devices to ease imaging analysis tasks, which have been successfully combined with tabletops, allowing new ways to explore volumetric data (Rateau et al. 2014). It's also an example the research project developed by (Souza et al. 2010), in this scenario users visualize their results on a third party software (e.g., running on a PC), but data is inputted freely with a smartphone device. The connection is performed through wireless capabilities, so there is no problem related to the distance between the user and the machine that runs the application, something that can happen with a device that communicates via Bluetooth connection.

2.1.3. Display and rendering

Tablet computers which have a large format, improved graphic display resolution and touch screen interface, may have advantages compared to smartphones and laptops for radiological images visualization. However, for diagnosis and image data visualization, the available screen space of these devices can be very limited (Ritter et al. 2015).

The above mentioned devices cannot compete with the resolution and screen size of modern medical displays, therefore they still can play an important role in diagnostic imaging. Their main disadvantage is that it can be difficult to perform measurements on the small screen using fingers, and to display the image data. Viewing in such small screen can also be stressful for the eyes, therefore these applications cannot substitute dedicated workstations (Székely et al. 2013), also leaving out possible simulations that modify the 3D content, which require high computational power, and as for mobile devices it may drain their entire battery (Alexander 2014) (Lamberti & Sanna 2005).

Figure 5 - Streamed data to less powerful computational devices, still using some WIMP interaction (Lamberti & Sanna 2007).

Tablet computers, which incorporate technological improvements in display resolution and a touchscreen interface, with larger-screen yet lightweight portable may have potential to successfully fill the need for remote radiological image review. Existing DICOM-viewers come with a disclaimer of "not for primary diagnosis applications" (Székely et al. 2013), and there is almost none published literature documenting the accuracy of primary radiological diagnosis made on these newer tablet computers (John et al. 2012) (Edirisinghe & Crossette 2012). Since image data should not be lossy, visualization

of extremely complex 3D scenes on portable devices is still considered a challenging task, nevertheless remote visualization can be an alternative, if a dedicated central server performs the necessary calculations, then a portable and less powerful device can display these images through wireless (Ponto et al. 2011). Such results are explicit in a stream based application for mobile viewing with limited interactivity (Lamberti & Sanna 2005). Another test project relying on streaming architecture was developed by (Lamberti & Sanna 2007) and (Hachaj 2014), however this approaches raise a set of issues related to channel bandwidth fluctuation, manipulation latency, and resources necessary at the client side to decode compressed information, with limited resolution.

2.1.4. Accelerometer

Usage of data sensors are becoming extremely common in modern mobile devices to control applications. Despite the recent advances in input devices for three-dimensional scenarios, most users still rely on mouse and keyboard to interact with computers (Souza et al. 2010). Accelerometers integrated in modern smartphones pave the way to intuitively use gestures to control interactive applications. However, most scenarios are still limited to controlling applications on the device itself. And even if acceleration data is used to control remote applications, it is typically limited to just one user and one handheld device such as demonstrated in (Souza et al. 2010) research project. Also, the project conducted by (Meng & Heng 2011) demonstrates single user interaction using multi-touch and 3D-tilt sensing capabilities, where a slicing plane can be directly manipulated at any desired position within the displayed volume data using a commonly available mobile device such as the iPod touch. Another interesting medical research project capable to use gyroscopic and accelerometer data from a tablet device to navigate through a 3D volumetric medical in the dataset and provide the necessary information for non-orthogonal slicing of a 3D volume, was developed by (Seyed et al. 2014a).

The concept of remotely control applications with acceleration sensor data is well known and commercialized with the Nintendo Wiimote[3]. Although, using game controllers may demotivate potential users in a platform designed to serve health professionals, since many of the new platforms use input mechanisms that target audiences like videogame consumers (Souza et al. 2010).

Figure 6 - Device accelerometer usage, to control 3D volume position in space (Souza et al. 2010).

[3] http://www.nintendo.com/wiiu

2.2. Collaborative work

Following the presented concepts around mobile devices capabilities and applications in a wide variety of research fields, it is now possible to combine some of those properties and develop a sense of cooperation and collaborative work. The tablet connectivity possibilities allow us to build a scenario where users can interact, without worrying about a physical connection (Souza et al. 2010). Much of the work developed focus on pairing similar mobile devices (Piazza et al. 2013), or complementary multi-device systems that can combine mobile devices with static devices such as large displays or tabletops (Ponto et al. 2011).

Despite the remarkable growth in the medical image processing capabilities, little progress has been made in the mechanisms that enable real-time interactive collaboration among multiple users, such as some initial research projects for telemedicine (Aziz & Ziccardi 2009). In such systems, collaboration tools include the usual image navigation and editing, using a simple lock concurrency control mechanism. These mechanisms usually degrade real-time interactive performance since only a single user can interact, while others wait until the lock is released (Alexander 2014), although *token* protocol approach in some collaborative environments is a viable solution (Lamberti & Sanna 2007). Current multi-touch smartphones and tablets are very promising tools for cooperative clinical workflows (as will be shown). Together with wireless connectivity they can also extend their collaborative capabilities enabling access to relevant patient information at different places (Birr et al. 2011).

Figure 7 – Typical collaborative scenario around an interactive wall display (left) and tabletop (right).

2.2.1. Collaborative concepts

Collaborative work scenarios are characterized by multiple participants smoothly transitioning from working together (coupled) to working alone (decoupled) to solve the problem at hand, varying coupling states throughout the collaborative session. These coupling transitions happen constantly, concurrently and seamlessly in any collaboration. As stated in McGrath research work (McGrath et al. 2012) based on Tang work (Tang et al. 2006), numerous groupware systems have been developed over the years, and we can retrieve some relevant research concepts based on computer-supported cooperative work (CSCW), grouped in the following items:

- **Coupling:** Refers to the dependency of participants during collaborative tasks in each other's work. When participants cannot do much work before having to interact the work is tightly coupled, contrary, when participants can work independently, is loosely coupled.

- **Coordination:** These mechanisms are used to manage shared resources by the participants, and are critical for efficient collaboration in order to minimize interference impact.

- **Territoriality:** People collaborating in the same physical space tend to form territories (spatial partition) that are used for personal work, shared work, or for storage. Some study about this activity has been conducted by (Scott et al. 2004) where personal and group territories were often used by participants to monitor the activity of their collaborators.

Having these concepts in mind, it is possible to reason that we can use a set of devices and displays with the ability to combine and inflate the above-mentioned characteristics in collaborative tasks. Following that, McGrath (McGrath et al. 2012) also introduce some important conceptions (based on the available surfaces) to consider when developing a multi-surface collaborative environment:

- **Tabletops:** Tabletop displays are particularly well suited to collaborative visualization. However, most of the systems cannot distinguish public and private views.

- **Public and private views:** This is a common practice, however private and public views currently used are still virtual spaces that occupy tabletop surface space (Scott 2014).

- **Multi-device environments:** Combining several collocated devices facilitates both solitary and collaborative work. They all rely on social protocols to achieve coordination during work (Coughlan et al. 2012).

- **Personal and shared devices:** Most systems for collocated collaborative search provide participants with their own device, often supplemented with a shared display. This provides a natural physical partitioning for uncoupled and coupled work (Coughlan et al. 2012).

These guidelines suggest that technology for collaborative work must support some of these properties: natural interaction, smooth transitions between (personal or group) activities, transitions between tools, access shared physical or digital objects, flexible user arrangements, and simultaneous user interactions (Scott et al. 2003). Systems that are modelled on these practices will have the additional advantage of supporting interaction skills that people have developed over years collaborating at traditional tables. Such findings are particularly interesting for the field of visualization, where collaboration has been named a grand challenge for research. Studies have also shown that involving multiple viewers in the analysis process generally improves the results (in quality and/or in time), as Seyed and Sousa tasks claimed (Seyed & Sousa 2013). Also, research performed by (Tang et al. 2006) shows the automatic tendency for people to work together across all conditions.

2.2.2. Multi-surface collaborative environments

The search for alternatives to traditional desktop computers has begun in a try to explore the potential collaborative benefits of tabletop displays. Combining large interactive stationary displays (e.g., walls and/or tabletops) with smaller, multi-touch mobile surface devices (e.g., smartphones and/or tablets) provides groups of users with both private and shared workspaces during collaborative activities (Spindler et al. 2014).

The single, shared surface provided by a tabletop has shown to provide a number of advantages such as enhanced workspace awareness and task coordination, however, this shared surface introduces challenges for supporting information privacy. To support such situations, there is a growing desire to use individual private workspaces, such as laptops, tablets, or smartphones, combined with large shared displays. Providing collaborators with both private and shared devices, also creates a need for appropriate interaction methods that enable content to be moved between the digital tabletop and the private devices, as explored by (Scott 2014) research, which bring us the question: *What do tablets can offer to multi-surface environments?*

Combining multi-surface environments with these emerging input devices can provide natural ways to interact with virtual content, while also combining several sensors with non-intrusive tracking solutions based on depth cameras (Mendes, Sousa, et al. 2013). Review from enhanced interactions with traditional tabletops, providing tablet devices to each user were conducted by (Mendes, Ferreira, et al. 2013), the aim was to explore tabletop excellent features to support collaborative tasks while also presenting several challenges, such as showing additional information that may occlude relevant content, and accessing virtual objects that are far away. So to test and try to solve this problem a tablet device was added to the equation (**Figure 8**).

Figure 8 - Tabletop-tablet interaction environment (Mendes, Ferreira, et al. 2013).

Even though tablets can solve interaction problems, key challenges for multi-surface environments still remain, which include finding what tasks can be accomplished in these environments and how collaboration can be made naturally. Collaborative exploration and manipulation of large 3D data has been a particular field of application to these technologies in areas such as medicine, but also for geologists, oil/gas exploration companies and architects (Seyed & Sousa 2013).

2.2.3. Collaborative tablets

All this information as already shown the potential of a tablet device in a collaborative environment, but *how can tablets presence be effective? What role these devices take in collaborative context?*

There is no definitive answer yet, this research field is starting to show up and mobile touch devices start to play an important role in the development of interaction techniques. A key challenge, therefore, is still to determine how to exploit the characteristics of individual devices and how these can be combined to support collaborative activities. Collaborative interactions with many existing tabletop systems still lack the fluidity of collaborating around a table using traditional media (e.g. pen and paper). A central concern is in how users can switch their attention between devices without losing focus and taking the best benefit from it. As argued in (Coughlan et al. 2012): "*a good tool is an invisible tool. By invisible, I mean that the tool does not intrude on your consciousness; you focus on the task, not the tool"*.

Although, one approach that has already been taken into account when developing shared workspaces is to provide one device to control other displays (Marquardt et al. 2011). A universal input device for all tabletop activities would make transitioning between activities smoother. With the widespread use of mobile devices, part of this vision is now a reality, but it currently presents a disordered user experience. Most of current systems still associate different input devices with different activities and traditional computer technology does not support multi-user, concurrent interaction, instead, users are forced to share the available input device when working together at a single computer. Providing only one standard input mode and device, ensures that there is no overhead from changing physical devices during activities. Thus, the benefits of each approach should be considered carefully, especially with regard to how often transitions between activities that require specialized devices will be necessary during the collaborative tasks (Scott et al. 2003). *So can tablets provide a solution?* That is what (Ponto et al. 2011) also tries to investigate in his research with multiple-touch devices (**Figure 9**).

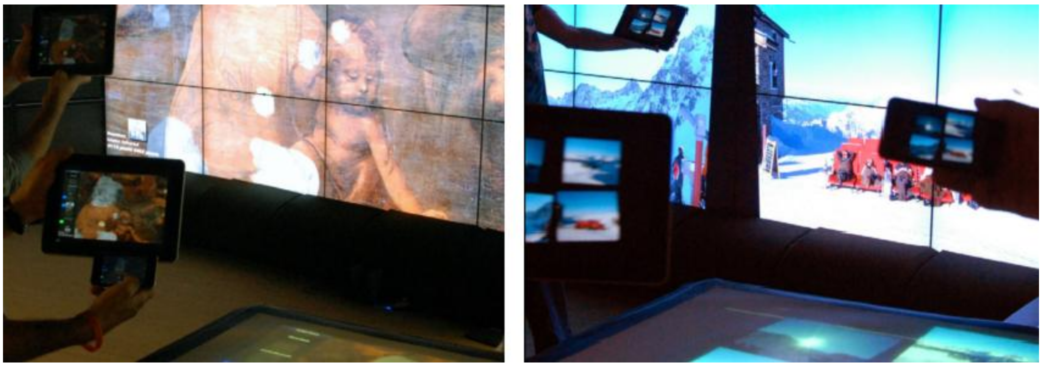


Figure 9 - Tablets and smartphones private view from a public Wall display (Ponto et al. 2011).

Nonetheless, interaction with these surfaces present yet several challenges and offer room for improvement. A system that can enhance tabletop interaction with 3D virtual content in a collaborative setting was also proposed by (Mendes, Ferreira, et al. 2013) supplying multi-touch tablets to each user for model editing and reviewing.

2.2.4. Surgical planning and diagnosis

The focus of this document is, in part, to apply some of these conceptualizations to medical tasks, so: *How do physicians* currently *stand relatively to mobile usage? How can this become useful to surgical practice?*

Surgeons are also starting to use tablet devices intra operatively for image viewing and operative assistance (O'Neill et al. 2013). Some mobile tools are already available in the market, even though their incapability to explore the interaction capabilities of touch devices is notorious, making some tasks less practical without the computational power of a desktop computer, such as explored by (Edirisinghe & Crossette 2012) and (John et al. 2012) in primary diagnosis. However studies conducted by (Ritter et al. 2015) revealed that 80 percent of doctors believe the iPad will have a promising future in healthcare. The system developed by Ritter's' where tablet devices are combined with conventional workstations had some positive radiologists feedback, in which they feel that this lets them focus more on the diagnostic images on the primary screen and does not hide additional information. This contrasts with other current mobile applications for the field (Edirisinghe & Crossette 2012)(John et al. 2012), since in Ritter's' project a highly increased display space coupled with processing power is paired with a device with more natural and direct image manipulation, as well as a higher mobility. Few medical applications have been approved for diagnostic reading, since all those applications use the screen of the mobile device to display the image data directly, but none of them integrates the mobile device with the existing workstations, such as in Ritter's' project. Another similar project was explored by (Székely et al. 2013) where the diagnostic screen is freed from menus, buttons, and bars as the radiologist interacts only on the less powerful mobile device.

Multi-disciplinary team meetings are essential in healthcare. Based on their domain-specific expertise, medical specialists (e.g. radiologists, surgeons and internists) present, discuss and deliberate relevant content about patient cases. Now, we can imagine an enhanced cooperative future scenario using tablets. Instead of bringing a heap of paper reports into the discussion, every doctor has his/her own mobile device equipped, sharing a discussion display view (Birr et al. 2011). An interesting case study was developed by (Larrosa et al. 2013) in rhinoplasty preoperative consultation and planning, with successful outcome. Current data from this study suggest that a tactile app could provide enhanced physician–patient communication and improve preoperative planning with positive impact in surgery.

2.2.5. Medical Education

Combinations of personal and multi-user devices also offer a lot of potential to education, where individual and collaborative learning can be structured through personal and shared devices (Coughlan et al. 2012). Nowadays, human anatomy teaching is based on schoolbooks and lectures where anatomical theory is transferred from one teacher to many students. But lectures and books poorly explore the three-dimensional nature of anatomical structures, so multifunctional and compact

devices may become an important tool in education (Székely et al. 2013). Multi-touch input can be used to freely interact with 3D medical models, which allows more realistic interaction and detailed representations of anatomical and pathological structures (Birr et al. 2011). Such advances also bring new opportunities and challenges to the teaching curriculum of medical education, although the clinical interaction itself is increasingly becoming more and more instrumented (Ward et al. 2001).

As presented by (Birr et al. 2011) or (Katzakis et al. 2015) we can envision the following scenarios: A medical student that wants to test his/her knowledge about human anatomy while interacting with 3D anatomical structures; or a professor demonstrating human anatomy with 3D graphics on a large projector screen, using his device to manipulate the model and answering questions from students.

2.3. 2D to 3D Interaction

In the traditional 2D graphical user interface (GUI), the combination mouse-keyboard established itself as the standard, yet there is no definite winner for 3D interfaces, and probably there may never be. Difficulties in establishing a standard 3D input device include: engineering challenges related to sensor technologies, limited knowledge about effective ways for humans to interact with virtual 3D environments, and also task-specific demands and constraints (Subramanian & Ijsselsteijn 2000). However, one thing is clear, free exploration of 3D scenes like rotating and zooming and enabling/disabling different structures can be a complex and tedious task for unaccustomed users. Therefore, easy-to-learn interaction techniques need to be considered in order to simplify the exploration of the 3D models and reduce the learning effort (Birr et al. 2011).

Traditionally, imaging specialists have preferred 2D visualization approach with keyboard-mouse based interfaces over 3D visualizations because are still less practical to interact than 2D ones. The difficulty with many of these techniques is that in the context of medical imaging, some of the input mechanisms may be obtrusive or require additional training to be properly utilized (Seyed et al. 2014b). Bowman (Bowman et al. 2011) experiments with radiologists suggest that although some 2D interaction techniques can be extended to 3D, to them, most of the time 2D is just fine. Furthermore, pointing, selecting, and typing are relatively fast and relatively error-free. These questions all relate to the interface design and interaction techniques for 3D applications, an area that is only extensively approached in futuristic films and books.

2.3.1. 3D Manipulation

Human interaction with the surrounding environment is naturally multimodal: we speak, point, and look at objects all at the same time. When it comes to HCI the limitations become noticeable, since we usually use only one interface device at a time, which is far from satisfactory. This becomes evident in a situation where we press the wrong key or when we need to navigate through a series of menus just

to change an object colour. These techniques developed for stone age devices like the mouse or keyboard, limit the pace with which a user can interact in today's computational panorama (Sharma et al. 1998). In this document specific case, exploration of volume data often requires the user to manipulate the orientation and position of a slicing plane in order to inspect, annotate or measure its internal structures. Such operations in 3D space are poorly mapped into interactions based on mouse-keyboard interfaces or even flat multi-touch displays alone (Meng & Heng 2011).

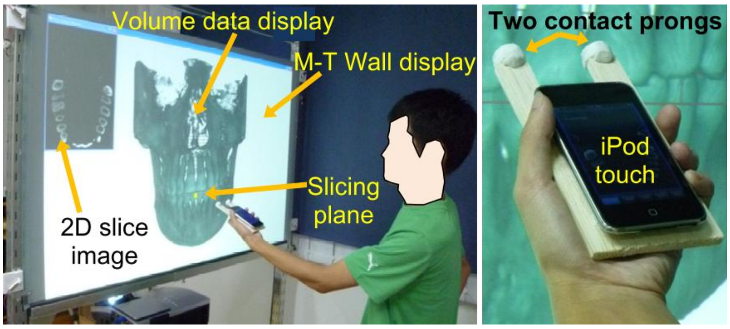


Figure 10 - Meng and Heng approach for more natural control of a slicing plane within a 3D volume.

Users typically find that interacting with mobile devices is much more enjoyable and efficient than using a mouse and keyboard, largely due to the device manageability as well as the comfort and input naturalness. Additionally, the user interfaces for such devices typically allow a user to focus more on the task at hand, rather than splitting attention between different input devices and visual elements. However, a major drawback with such touch input devices is the frequent occlusion of the display (Malik & Laszlo 2004).

To be able to manipulate 3D objects the user generally needs 6 degrees of freedom (6 DOF) to simulate motion throw three perpendicular axes. Generally, the degrees of freedom of the task should match the degrees of freedom of the interaction device, to avoid a complex composition of interactions. Taking the research work developed by (Subramanian & Ijsselsteijn 2000) related to spatial manipulation techniques, interaction devices can be classified based on the number of DOF, since for 3D interaction more than 2 DOF is required, we will just take into account what tablet integrated touch cannot offer:

- 6 DOF: these input devices can easily provide the basic 3D motions like translation and rotation.
- More than 6 DOF: Require two-handed interaction devices. These devices can provide up to 12 DOF. Motion tracking devices for animation purposes (e.g. body suits) can have an even larger number of DOFs.

2.3.2. Sketch-based interfaces

In the first few decades of computing, systems functionality and performance were the top main subjects, but when desktop productivity tools began to be used by millions of people, the concept of a

system success changed to its usability (user-friendly), which means that the user wants to focus on the task, not on the technology for a specific task. So post-WIMP GUIs are a step towards a much more compelling and natural interface that will ultimately take decades do develop. With current WIMP GUIs, the more complex the application is the harder is the learnability and complexity of the interface due to the abundance of features. The WIMP interface for 3D applications typically consists of control panels with 2D buttons and sliders that surround the 3D world creating greater visual complexity (Dam 1997). To solve this problem we need to understand the natural interaction practices that people use during individual or collaborative work with traditional media (e.g., canvas and pencil) (Scott 2014).

The project developed by (Piazza et al. 2013) is an important role model of interaction to this document, based on a painter interaction analogy. In Piazzas' project, making use of distributed information through displays, the painter analogy is introduced to a drawing application (**Figure 11**). This setup is suggested to facilitate sketching and drawing. The tablet is considered the primary input and output device for the majority of actions, and the phone can be used to extended input and output spaces. The main input activity, drawing, is performed on the tablet while drawing settings are adjusted on the phone.

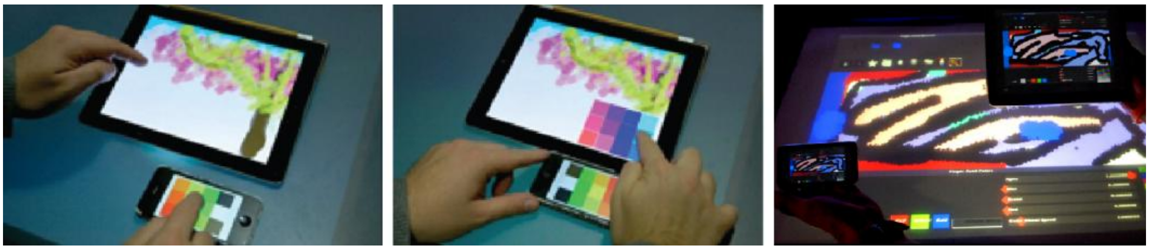


Figure 11 - Sketch-based interface, tablet acting as canvas to draw and smartphone as a color picker tool.

Another approach to split tasks is done by (Ritter et al. 2015) while working with radiologists, Ritters' noticed that only very few tools are used in visualization software, despite having more powerful analysis methods at their disposal in the screen. The solution was to offload secondary information to an interaction device with a display (tablet), but relevant information is still visible on the workstations display screens.

2.3.3. Scientific Illustration

In science, medicine and engineering, hand-drawn illustrations often include manipulating objects to interpret structures, uncover hidden features or reveal spatial relationships between different components. Hence, for illustrative manipulation, one must give priority to the interactivity and operability in the process of achieving illustrative visualization. Illustrative visualization is often associated with cutaway visual effects and non-photorealistic rendering, which is out of the scope of this project. Although (Correa et al. 2006) paper is concerned with the aspect of illustrative visualization, in particular, the creation of cutaway visual effects through interactive manipulation of volume datasets, in which a useful sketch-based interface could be applied to interact.

Figure 12 - Illustration example from Correa work.

2.4. Spatial Interaction

Limitations while interacting with mobile devices, as already mentioned, are associated with users' fingers, hands, or arms blocking part of the screen, which in medical context means blocking part of diagnostically relevant information. This is particularly impractical when doctors discuss images with either their patients or colleagues (Ritter et al. 2015). While touch allows for a more direct manipulation, it suffers from the well-known *'fat finger'* problem, which can interfere with the displayed data. *So, what can we add to tangible touch devices repertory to transform them in the universal multipurpose input interaction device?*

To overcome this problem, (Rateau et al. 2014) proposed to explore the space around tablet. This way, users do not block their view on relevant images details with their fingers, hands, or arms, although manipulating input devices in free space can easily fatigue the user. A poor interface design of spatial input devices risks to deteriorate user performance, dissatisfaction, or even injury the user. As suggested by (Hinckley & Goblel 1994) some human factor requirements must be taken in consideration when choosing the technology to use:

- Users should be able to move around and shift their body posture.
- The interface should not require the spatial input devices to be held within a fixed volume that cannot easily be adjusted by the user.
- Fatigue should only be associated with prolonged, uninterrupted use, it may be useful to build time-outs into the system which remind the user to take an occasional break.

Tablets and smartphones can offer these properties and more (which makes it a viable spatial input device) if the interface interaction is well design, also the device itself it's designed to comfortably be manipulated by the user without great effort and fatigue.

In general, to perform a task, the user's perceptual system needs something to refer to, something to experience. Using a spatial reference (tablet) is one way to provide this perceptual experience. Users may have difficulty controlling an interface, which requires simultaneous, precise control of an object's position and orientation. Even in the real world, we typically break down 6 DOF tasks into sub-tasks, such as translating to the location and then match orientation. A touchscreen could also be used for command/action selection, and might furthermore allow the user to perform 2D

direct manipulation tasks at the same time. Note the facility with which a touchscreen can be used: users can touch the screen directly with their spatial input devices while performing 3D tasks, instead of putting them down to use a mouse. Having this in mind: *Can the tablet devices be the spatial reference that everyone is looking for?*

2.4.1. Spatially aware tangible displays

Emerging game technologies such as NintendoWii[4], Sony Move[5] and Microsoft Kinect[6] are destined not just to change the way we play, they are also going to change the way we make and view art, design new products, analyse datasets, and more. Haptics might be combined with low-cost depth cameras, tangible props might be combined with multi-touch input and scientific applications might be combined with art and games. Emerging optical devices enable a variety of 3D interactions, although freehand unconstrained interaction can often be very difficult to control, a current critical challenge is to determine how to leverage the capabilities for 3D input with the advent of commercially available devices, such as the Kinect, while combining these capabilities with the advantages of tangible spatial input (LaViola & Keefe, 2011). Although as explored by (Spindler et al. 2014) due to the limited depth resolution of the Kinect, we currently cannot rely to detect displays in a constricted area, which is a frequent use case, other problems include occlusion and unfavourable viewing angles.

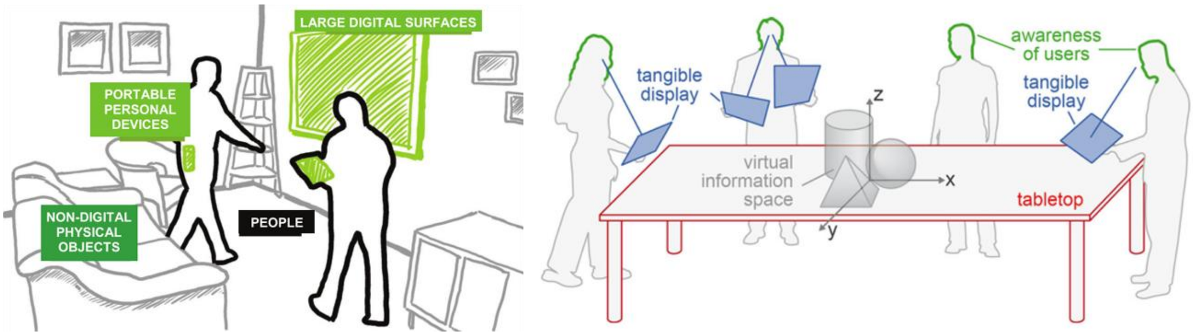


Figure 13 - Right figure represents the (Spindler, Büschel, Winkler, & Dachselt, 2014) setup schematics, and left figure the *SmartBoard* project schematics.

Identifying and tracking people and mobile devices indoors has many applications, but is still a challenging problem. The approach presented in this paper (Spindler, Büschel, Winkler, & Dachselt, 2014) proposes spatially aware tangible displays used in tabletop environments, where interaction with digital information is provided through physical manipulation of real-world objects, these objects can also be spatially aware handheld displays (e.g., tablets) that acts as a tangible reference into the virtual world (**Figure 13**). Spatial input relies on the system's knowledge about spatial positions of handheld displays that are being tracked in physical space with 6 DOF. This allows users to directly interact with a handheld display by moving or rotating it through the physical space. (Ballendat, Marquardt, & Greenberg, 2010) setup is also an example of position capture with passive infrared

4 http://www.nintendo.com/wiiu/
5 https://www.playstation.com/en-us/explore/accessories/playstation-move/
6 https://dev.windows.com/en-us/kinect/

reflective markers. Markers are detected using six cameras emitting infrared light placed around the *SmartBoard*. These markers are attached to tracked objects, allowing interaction with the *SmartBoard* throw spatial recognition.

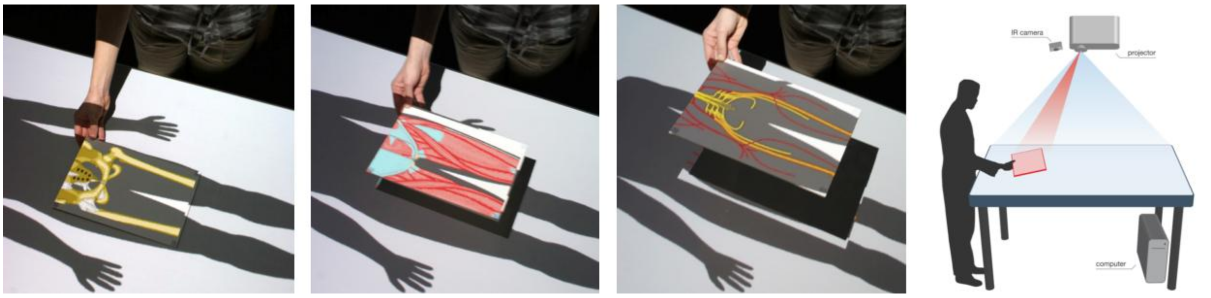


Figure 14 - *PaperLens* project using one infra red camera and a projector to detect the device (paper) where to project the content.

Spatially aware handheld displays are a promising approach to interact with complex information spaces in a more natural way by extending the interaction space from the 2D surface to the 3D physical space around them. This is achieved by utilizing their spatial position and orientation for interaction purposes. Along with a large stationary screen, such multi-display systems provide a rich space with a variety of benefits to users, such as the *PaperLens* system developed by (Spindler et al. 2009) in **Figure 14**. In terms of interaction, *PaperLens* uses the concept of spatially aware tangible displays that users can interact with by grabbing and moving the device around in 3D space (spatial input) which are tracked in three-dimensional space with 6 DOF.

The 3D cursor concept is also explored and presented in (Dorta et al. 2015) project, Hyve-3D, via tablet movements and multi-touch gestures. These tablet 3D cursors are naturally manipulated and tracked in 6 DOF making it possible for users to navigate inside a 3D virtual space using the tablets as tangible props.

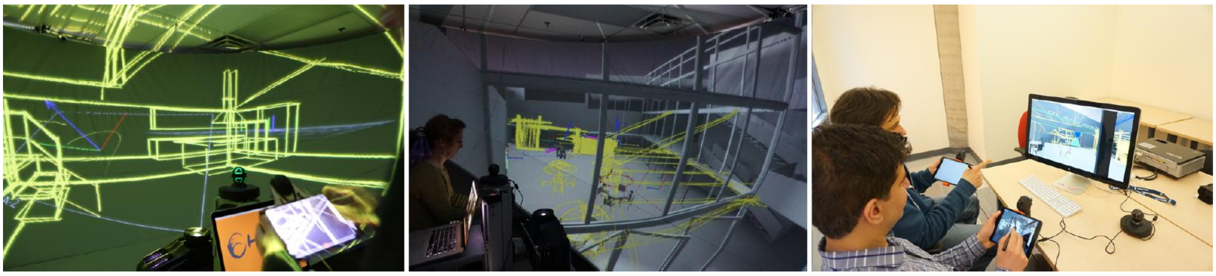


Figure 15 - The Hyve-3D cursor in immersive and non-immersive configurations

Chapter 3

3. Requirements Analysis

The software architecture and development of this project approached in the next chapter is based on: the previously discussed related work and *in person* requirement analysis made with medical specialists. The inexistence of specific related work that can combine novel interaction techniques and collaborative work in medical scenarios is a bottleneck to create a concrete architecture organization, features and interaction tools, so there was the need to retrieve information with professionals in the medical field that could have a real impact in our system.

3.1. Medical Requirements

Working side-by-side with Hospital Professor Doutor Fernando Fonseca (**HFF**) and Egas Moniz Dental Clinic was of extreme importance to develop specific use case scenarios tools for this project. During our visits to HFF and Egas Moniz to experience and talk about medical software and practices, it was possible to collect important requisites that this project could support (within the theme) in order to improve the standard tasks available in current software and surpass important gaps in those systems. Important to notice that we are solving a real problem with real application.

3.1.1. Hospital Professor Dr. Fernando Fonseca

Dr. Vitor Nunes[7] (General Surgery Director of HFF) was responsible for all interactions during requirements analyses making it possible for us to use, test and understand current medical practices, conducting to a better involvement with the tasks and limitations that physicians face with software. The main requirements collected from medical practitioners interactions during surgical planning and operation are:

- System with 3D visualization capabilities;
- Interactions that go beyond mouse and keyboard (sterilization purposes);
- Collaborative tool for physicians to interact with content during discussion in surgical planning;
- 3D volume 'live' free manipulation;
- Tool for sketch and coloring medical volumes;
- Clip 3D medical images;
- Explore 2D images as in current medicine (navigate, annotate and measure).

[7] https://www.researchgate.net/profile/Vitor_Nunes

3.1.2. Egas Moniz Dental Clinic

Prof. Dr. Alves de Matos and Dr. conducted an important tour through all the dental clinic processes and practices pointing out the importance of the modern hardware used in current dental medicine, as well as the current limitations of the software approaches used by this field. The main requirements collected from the field trip to the dental clinic are:

- 3D visualization mechanisms for doctor-patient interactions;
- Measure and tag medical images;
- Navigate through images in endodontics scenarios;
- Multi-interactions over medical images;
- 3D models for educational purposes.

Chapter 4

4. Voxel TACS

As evidenced and discussed in the previous chapters, current medical software is still one-step behind the recent available technologies, such as touch and spatial interfaces. The focus of the system developed is to create a novel interaction tool that can improve or even replace the obsolete interactions and functionalities existing in the traditional medical imaging visualization software. Based on the related work, and the limitations presented in previous works, we are trying to reach and obtain a sharpened and easy to use medical tool.

The result of all the work developed is: Voxel TACS (Tablets for Collaborative Scenarios), a tool that unites and upgrades the novel interactions and functionalities developed in the projects: Voxel TIPS (Mendes et al. 2015) and Voxel Explorer (Parreira et al. 2015), also capable of perform those same tasks in a collaborative scenario. As in the previous investigation works, Unity3D[8] was the platform chosen to develop the new system, due to its extensive list of open-source code, tutorials and projects, network capabilities and project export simplicity to different platforms. All the displayed applications were developed using Unity 5.0.2f1 version. A detailed explanation of the system architecture, organization and interactions developed to solve this thesis' problem is provided in the following chapters.

4.1. Architecture Overview

The software system is composed by two main applications: Voxel TIPS and Voxel TACS (which will be detailed in further chapters). The main purpose of this project was to develop a tool for visualization and another one for interaction, in order to achieve it as a smooth coordinated system, it was our main goal to make the system as modular, scalable and multi-purpose as possible. This means, splitting the project into an application that is responsible for the visualization mechanisms and another one for interaction and communication purposes. This way, we could create a system in which we can add or replace singular modules without compromising the entire structure, since the technology used in every component has a fast-pace evolution.

TIPS is an already working project that was reformulated and reorganized in order to connect and communicate with other software platforms, i.e., not only to work as a visualization and interaction tool but also as a central device to receive and share data (server). In TIPS original project, the system was responsible for the 3D image rendering, display and interaction in a tabletop, which was a limitation. To work as a collaborative tool, it is now provided with mechanisms for other devices to

[8] https://unity3d.com/

connect and communicate with, as well as the possibility for TIPS to work as a tool for visualization or interaction only, or both at the same time. Voxel TIPS is a multi-platform application that can run in any device capable of high graphic processing with *DirectX*, so it can be shown in any display equipment (e.g. TV, Wall, Tablet, etc.) that is equipped or can connect with a rendering machine.

TACS application was developed from scratch with the intent to replicate in mobile devices the sketch functionalities developed for TIPS tabletop version, this way everyone interacting can have access to its own interaction and sketch tool. In addition, novel interaction techniques could be obtained with this segregation, since there is now no limits to interact with the 3D volume. Mainly created to run on touch devices (tablets, smartphones, etc.), this application not only allows modern touch interactions as it is possible to equip the handheld touch devices with reflective markers in order to spatially interact and perform manipulation tasks.

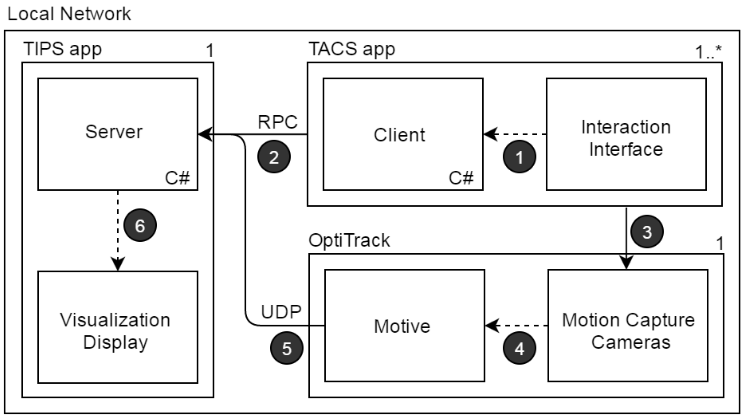


Figure 16 - Simplified system architecture scheme.

To create the necessary setup for machine communication and consequent collaboration it is necessary to create a local network (LAN) which guarantees that all devices belong to the same network and know each other. To connect the tablet devices to the primary display server (TIPS), different mechanisms are conceivable, to simplify it, the server machine IP address is manually inserted in the devices that want to connect (chapter **4.1.3**). To support communication activities between the two system applications, it must be possible for data to be transmitted from each handheld device or stationary device to the shared view in the tabletop surface, TV or Wall. For this purpose and as illustrated in **Figure 16** abstraction, the system follows a client-server architecture (explained in further topics), with several clients (TACS app) connected to a central server (TIPS app). The TIPS application acts as the server, receiving any changes made to the virtual model from the TACS users (**2** and **5**). RPC protocol (**2**) was the mechanism chosen for the client application to communicate with the server, due to Unity3D network settings already include this type of protocol. In addition, the system has to know the real-time position and orientation of the touch devices, for this, we use motion capture cameras and reflective markers (**3**), which requires an expensive but effective setup. The motion camera system is responsible to inform the server about each tablet device position and orientation in space (**5**), which is achieved through Motive broadcast software (**4**).

Spatial capabilities are provided to the TACS devices through the usage of 20 sensor depth cameras installed in the test laboratory environment, which allows millimetric precision and 6 DOF to the users movements. Communication with the reflective marked tablets is established with *OptiTrack*[9] software, *Motive*[10], based on UDP (**5**) communication that sends information updates directly to the server, to be applied to the rendered 3D volume.

To sum up, every modification made with touch interaction is received by the client module through direct function call (**1**) and sent to the server via RPC protocol (**2**). If the spatial recognition system is on, the motion capture cameras can detect the reflective markers on TACS devices to obtain its position and orientation (**3**). These camera sensors represent the collected data on Motive software (**4**) that broadcasts its content using UDP. The server contains an UDP listener that receives the correspondent TACS data with a specific ID (**5**). Every update from touch and spatial interaction it is sent to server through RCP (**2**) and UDP (**5**). For further understanding of the system flow, a real setup environment is covered in the chapter **4.1.3**.

4.1.1. Visualization

One of the most important features in a imaging visualization system is, without a doubt, the rendering engine, for that it was used the free open-source Ray Marching[11] algorithm project developed by Brain Su in order to render volumetric textures. Taking advantage of this project for 3D image rendering, some adjustments were made and some of them already discussed in (Mendes et al. 2015) and (Parreira et al. 2015) master thesis.

The main idea relies in a stack of 2D medical images to generate the 3D volume, using the predefined Texture3D[12] class from Unity to create the volume. Each 2D DICOM image is converted into one of the readable Unity formats, such as *.bmp*, *.jpeg* or *.png*, using *RadiAnt*[13], a free DICOM viewer. To provide depth and shadowing to the volume some Brian Su shaders were also used, making it possible to create a more realistic notion of the volume.

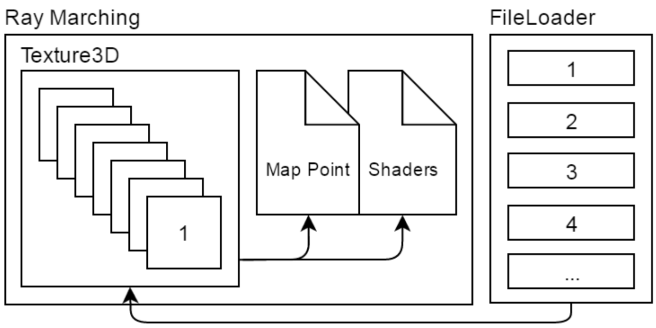


Figure 17 - Volume renderer simplified structure.

[9] http://optitrack.com/
[10] http://optitrack.com/products/motive/
[11] https://github.com/brianasu/unity-ray-marching/tree/volumetric-textures
[12] https://docs.unity3d.com/ScriptReference/Texture3D.html
[13] http://www.radiantviewer.com/

The representation of the volume is based on a 3DTexture composed by a group of 2D images that forms a set of voxels, which is an image pixel represented in space (pixel with volume). A File Loader was built to read medical images into the system, every single image is converted and made available to the ray marching algorithm. For each 2D image slice that composes the 3D texture, it is stored its map point (set of voxels) to be manipulated by the user through a simplified sketch based interface, as explained in chapter **4.3.3**.

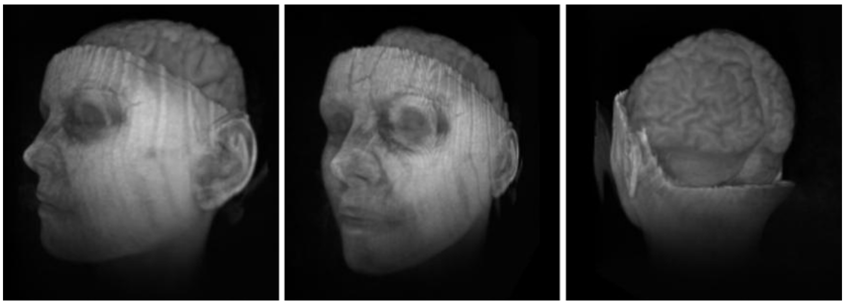


Figure 18 - Brian Su texture rendered example in multiple views.

4.1.2. Client-Server

To support multi device communication it was necessary to adopt an architecture that could connect multiple devices to a single processing machine. Client-server model was chosen to support this distributed application, since its characteristic can achieve the relationship of cooperating programs. This way the server component (TIPS) can provide a function or service to one or many clients (TACS), which initiate network requests for such services.

Using Unity3D game networking system, composed by a binding *NetworkView*[14], makes it possible to create and connect a server with multiple clients. The communication is done over a regular network connection. After the project has been configured and organized to work as a distributed application and added the indispensable Unity3D *NetworkView*, there was still the need to attach to the server and the client an object containing scripts shared and used by both parties to execute remote function calls. The network object attached to both applications, being the same in both parties, is shared through the network and not only contains server and client execution functions, but also functions used for data transmission. When the server is initiated, the port to listen is defined as well as the number of clients that can connect. On the client side, it has to know the server address as well as the port to communicate with. Chapter **4.3.1** contains more detailed information about RPC communication and message exchange mechanisms.

[14] https://docs.unity3d.com/ScriptReference/NetworkView.html

4.1.3. System Setup

The system setup has numerous variants for connecting devices, but every possible solution has one thing in common: a central server to connect that must be able to render a complex set of image, such as in (Ponto et al. 2011) and (Souza et al. 2010) projects.

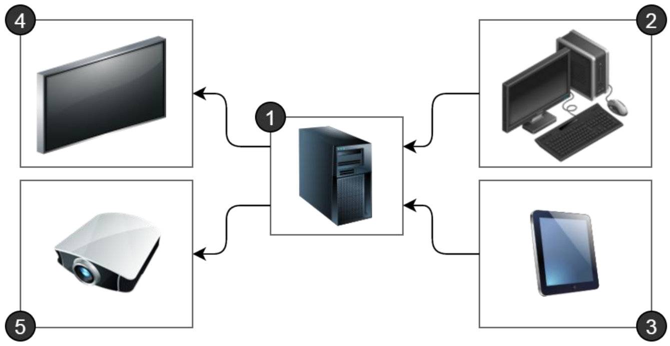


Figure 19 - System setup possibilities.

Figure 19 makes it explicit for the various connection possibilities to setup the system. The server running Voxel TIPS (**1**) can provide its content to display hardware, such as projectors (**5**) or TVs and tabletops (**4**). Every machine with a display and capable to register in the network, running the Voxel TACS application, is able to connect to the main server (**1**). Those devices can be portable devices, such as tablets and smartphones (**3**) or even other static computational machines (**2**).

4.1.4. Functionalities

Voxel TACS developed functionalities are synthetized in the following table. *Appendix F* contains visual insight of Voxel TIPS application in terms of user interface and possible interactions.

Functionality	Description
Sketching	2D sketch interface to apply the resulting sketch to the 3D content.
Image Download	Download from the server the 2D slices that compose the 3D volume.
Measuring	Takes length and angle measures over 2D medical images.
Touch Manipulation	Allows the user to manipulate 3D data with multi-touch interaction.
Touch Slicing	Allows the user to slice 3D data with multi-touch interaction.
Spatial Manipulation	Allows the user to manipulate 3D data through the usage of a 3D cursor in space.
Spatial Slicing	Allows the user to slice 3D data through the usage of a 3D cursor in space.

Table 1 - Voxel TACS functionalities summary.

4.2. Voxel TIPS

Voxel TIPS is designed to work as a display server where all information converges. Every update and state modification made by the connected systems is immediately communicated to the server and the changes applied. Since this architecture is a one-way information flow, only the devices connected to the server can change its state and only the server is responsible to contain system state information, the clients do not need to have access to any content information. A detailed organization of this project is described in the subsequent topics.

4.2.1. Architecture

The original TIPS project suffered a sizable revolution on its structure and organization, since we intended to achieve better interaction mechanisms and processing responses. TIPS initial project had every functionality encapsulated in a single processing machine, which created a bottleneck between interaction and visualization. These also unleashed problems in terms of portability and resources needed, since visualization and touch interactions were congregated in the same tabletop. All the system interactions not only were confined to the tabletop area (which made it obligatory to have a touch TV, for the effect), as the interaction was done in the same space of the volume display, which triggered image visualization obstruction problems.

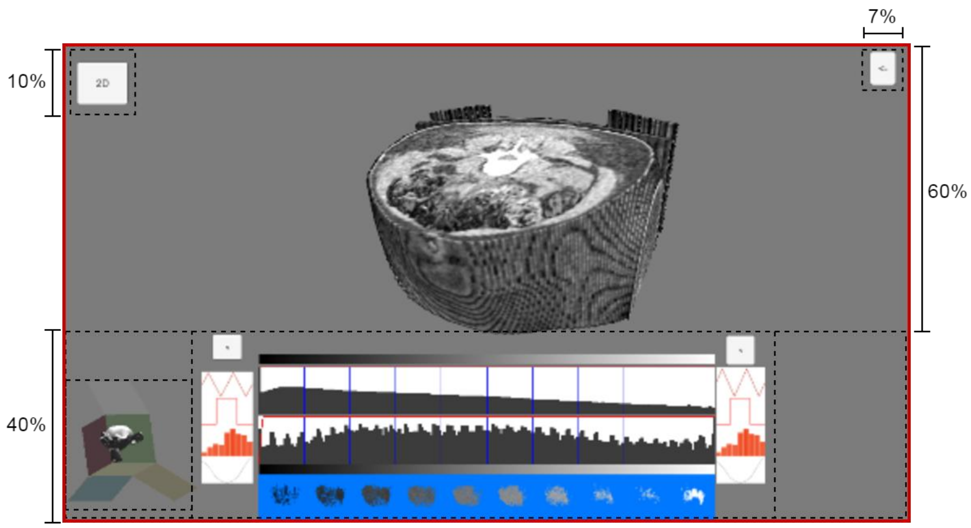


Figure 20 - Screen display area in the TIPS original project.

Figure 20 illustrates some of the above-referred problems. As shown by the black doted lines that split the figure, more than 40% of the screen display is occupied by poorly distributed buttons and interaction objects, which clearly shows mismanagement of space. The remaining available area for touch interaction makes it difficult, not only, for users to work collaboratively but to perform geometric transformations upon the displayed volume, since their hands and fingers obstruct and cover great part of the rendered 3D image.

To develop a new approach in terms of visualization and interaction, all main sketch based mechanisms were removed from the main application (TIPS), to be executed in a dedicated application (TACS). This allowed to release the TIPS application from all the processing and sketch interaction, but also created the need to make it connectable to other devices, converging to (Ritter et al. 2015) research. The intent of this project was to create novel interactions and open new possibilities for collaborative work, so transforming TIPS software into a display server was an architectural decision already taken from the beginning.

One of the major problems that TIPS was facing until this intervention was the lack of an architecture, and slow responsive interaction times (i.e. high latency). The single machine centralization of all the system functionalities, which had to deal with rendering and complex interactions at the same time, leaded to lag between rendering and real-time interaction responses. This metrics will not be measured in this document, since were processing times that exceeded the minimum time limit for having the user feel that the system is reacting instantaneously (Nielsen 1994).

There was a need to create, organize and simplify the inexistent system architecture, for that, it was built an API object that contains all the definitions, parameters and remote functions that could make this system segregation into multiple clients a reality. This way, all interaction mechanisms could reside on the client side, making the server (TIPS) only responsible to apply the received data to the rendered volume.

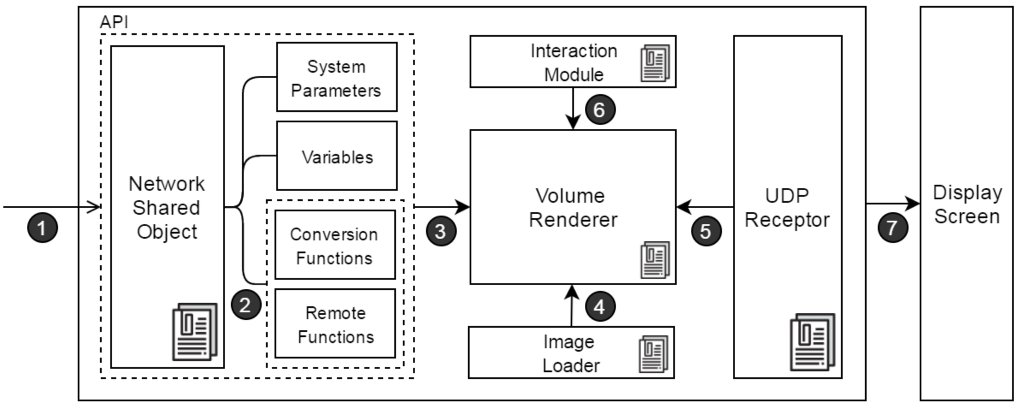


Figure 21 - Schematics of Voxel TIPS architecture and interactions.

In the schematics shown in **Figure 21**, it is illustrated an abstraction of TIPS application that is centered in the *Volume Renderer* engine. One of the most important advances was the incorporation of an *Image Loader* (**4**) that could read, on the fly, medical images into the system, which was a terrible existing limitation. The *Interaction Module* (**6**) stays intact and can be activated if the *Display Screen* (**7**) supports touch interaction. One of the main additions to TIPS system was the API module, that contains an already mentioned *Network Shared Object* (**2**) that is responsible to receive data from connected clients in the network (**1**) through the available and shared remote functions. This data is locally sent to the *Volume Renderer* (**3**). To support spatial interaction through motion capture, it was created an *UDP Receptor* (**5**) that listens in a specific *port* and applies the received broadcasted data directly to the *Volume Renderer*. The volume itself and all the received content that modifies it, is

visualized in the *Display Screen* (**7**) - which can be a: TV, PC, Wall or a Tabletop. The interface was also simplified with the partitioning of functionalities between two applications, as it is shown in the figure below.

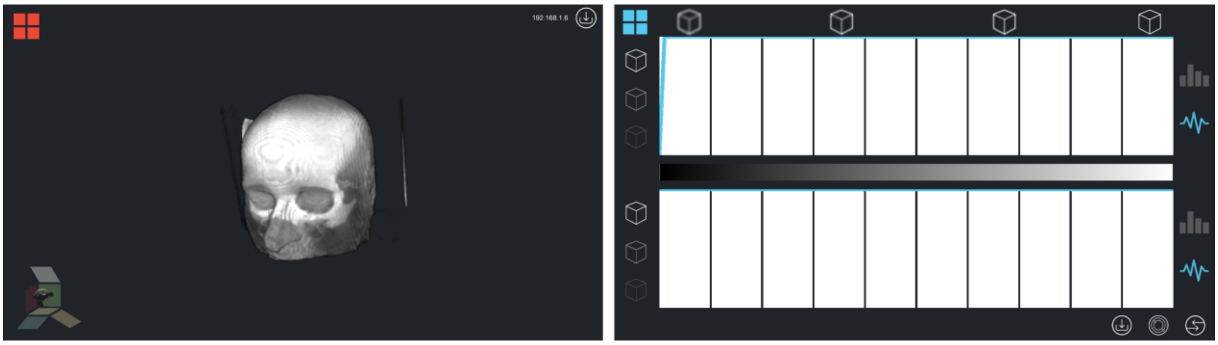


Figure 22 - Left image presents the new Voxel TIPS visualization and interaction display. Right image presents Voxel TACS interaction sketch-tool.

4.2.2. Functionalities

Voxel TIPS developed functionalities are synthetized in the following table. *Appendix G* contains visual insight of Voxel TIPS application in terms of user interface and possible interactions.

Functionality	Description
Image Loading	Loads 2D image slices used in current viewers into the system.
Voxelize	Out of the 2D slices loading renders a 3D volume.
Resolution	Changes the volume resolution, according to the system requisites.
Visibility	Removes undesired black voxels from the volume, making volume lines and edges more visible.
Manipulation	Touch interface for multi-finger volume manipulation, if displayed in a tabletop.
Open-Box Widget	Contains interaction shortcuts to obtain one of the six basic predefined orientations of the volume (front, back, up, down, left, right).

Table 2 - Voxel TIPS functionalities summary.

4.3. Touch

Voxel TACS main functionalities are centered on touch properties, since it runs on a tablet device great part of the experience relies in the interactive touch display. To develop all the standard interactions needed to manipulate, interact and sketch over the 3D volume, TUIO[15] framework for Unity3D was chosen. TUIO is an open framework that defines a common protocol and API for tangible multi-touch surfaces, making it possible to simplified and standardize all touch interactions. In addition, due to being considered a community standard, it allows programming abstraction for every platform that recognizes touches (e.g. sensor, display, etc.). In the next chapters, all the dynamics and functionalities developed, that required touch interaction, are covered with more detail.

4.3.1. Messaging – RPC

Communication between devices is a big part of the project setup, and since it was developed using Unity3D it was an easy decision to exploit its incorporated network functionalities, such as remote procedure calls (RPC[16]). Following a client-server model, using RPC for message exchanging makes it possible to establish a reliable and simple channel for communication between server (TIPS) and clients (TACS), this way it is we can invoke procedures from remote devices, which is essential for distributed computation. RPC is a form of client-server interaction (caller is client, executer is server), which was implemented via a request message-passing system, it is similar to calling a regular function and almost as easy but there are some important differences to stress out:

1. Parameters should be kept to a minimum in order to get the best performance (network latency);
2. Unlike a regular function call, an RPC needs to denote the recipients of the RPC request;
3. RPC function names should be unique across the scene;
4. RPC calls are always guaranteed to be executed in the same order as they are sent.

All network communications are handled by Unity3D *NetworkView* components, which must be attached to the object whose script declares the RPC functions. *NetworkView* guarantees that the above referenced characteristics are accomplished and that both, server and clients identify/discover the shared object that contains the RPC functions. In this system, message flow is unidirectional, which means that procedure calls are always initiated by the clients (TACS) and the consequent changes resulting of that call are applied to the server (TIPS). Every touch event that is performed in the tablet display that has an RPC call associated is sent through the network and reverberated in the server display.

15 http://www.tuio.org/
16 http://docs.unity3d.com/430/Documentation/Components/net-RPCDetails.html

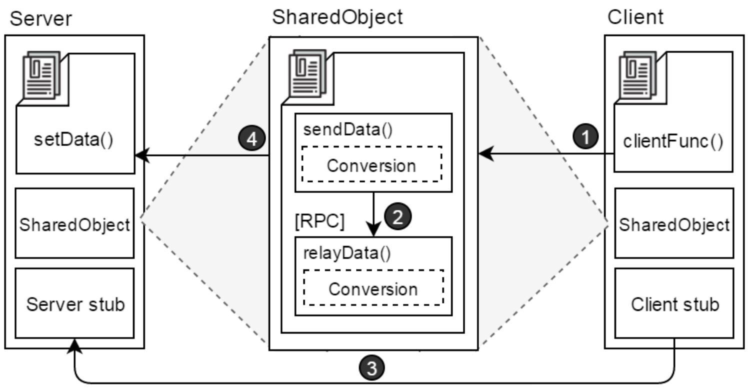


Figure 23 - Client and server applications interaction scheme through a network shared object.

As illustrated in **Figure 23**, both Client and Server applications contain a *SharedObject* that has attached to it a script with RPC functions. In a real use case scenario, the message exchange sequence of events is initiated by the user-client with a touch event that triggers a local function call:

1. After *clientFunc* is triggered, it locally calls its network shared object which invokes a specific RPC local function *sendData* (**1**) that converts the data to be transmitted to a parameter accepted by Unity3D RPC messaging;
2. The remote function *relayData* (which will be executed in the server side) is called from local client *sendData* function (**2**);
3. To execute the remote function on the server side, the client calls the *Client stub*. The call is a local procedure call.
4. The C*lient stub* packs the parameters (*marshalling*) into a message and makes a system call to send the message.
5. The client's local operating system sends the message from the client machine to the server machine (**3**).
6. The local operating system on the server machine passes the incoming packets to the *Server stub* that unpacks the parameters from the message (*unmarshalling*).
7. Finally, the *Server stub* calls the server procedure *relayData*, which is executed locally. This function once again re-converts the transmitted data to the type needed and triggers the required function (**4**) that applies the received changes, *setData*.

4.3.2. Manipulation

The manipulation of the volume data in the touch device (tablet) is made through multi-touch interaction. TUIO framework was used to deal with touch events, although there was still the need to define interaction movements that the user could associate to its experience of using touch devices or simple by interacting with the point and click peripheral (Ritter el al, 2015). Next figure contains the touch standard interaction for specific events that were implemented in this project.

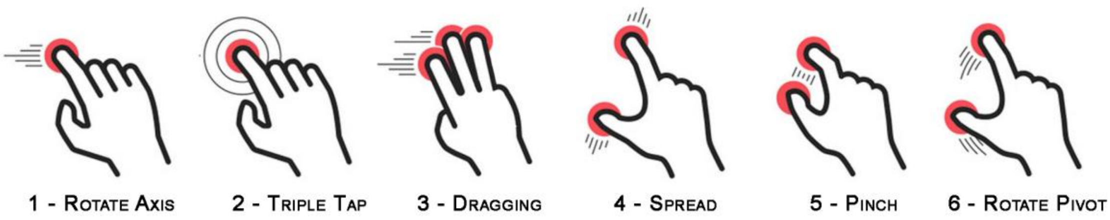


Figure 24 - Group of touch interactions and respective event response.

Dragging one finger across the touch surface (**1**) makes it possible for the user to rotate the volume in any direction. The finger movement direction selects the axis to rotate on, as well as the speed of rotation. To reset the volume to its initial position and rotation (**2**), three consecutive touches on the touch surface (summoning someone at the door analogy) achieves the desired result. If the user interacts with the surface using three or more fingers (touches) at the same time, the volume will follow the interaction movement, allowing to drag it to any point of the screen (**3**). When two fingers (touches) are recognized in the touch screen, it can mean one of three possible actions to be taken depending on which type of movement or direction is executed by the user. Having the two fingers engaged on the screen, the user is able to zoom in (**4**) or zoom out (**5**) (by moving the fingers away from – spread, or toward each other - pinch, respectively). Finally, if the user rotates a second finger (defines direction) over a fixed pivot finger (**6**), it is possible to rotate the volume around that pivot point. Since there is the need to calculate at the same time if the two fingers are moving closer or farther from each other, or even rotating, makes it possible to perform a zoom action while rotating. These controls resemble the ones usually employed in touch devices, such as smartphones, which represent metaphors for daily life tasks already perform by the users.

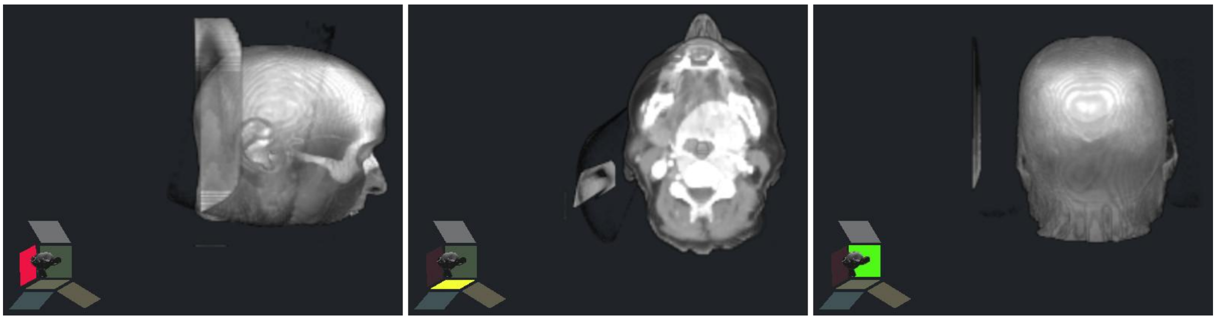


Figure 25 - Open-box widget shortcut for standard 3D image visualization. In the left image it is selected the left face of the widget which represent the left side of the volume. The middle image shows the under face of the volume and the right one the back of the head volume.

To assist volume manipulation, there is also an open box in the lower left corner of both applications that allows to obtain standard orientations of the volume (front, back, up, down, left, right), according to the cube selected faces. For example, by selecting the lower face of the cube (middle image in **Figure 25**), the activated cube face is highlighted in yellow and the volume is displayed on its underside view.

4.3.3. Sketch-based interface

This tool requires knowledge about imaging and transfer functions, it was developed for professionals and was adapted from Voxel TIPS original project to work remotely. The TACS sketch interface gives to the user the possibility to freely draw on the appropriate area of the screen, the resulting sketch is directly applied to the volume.

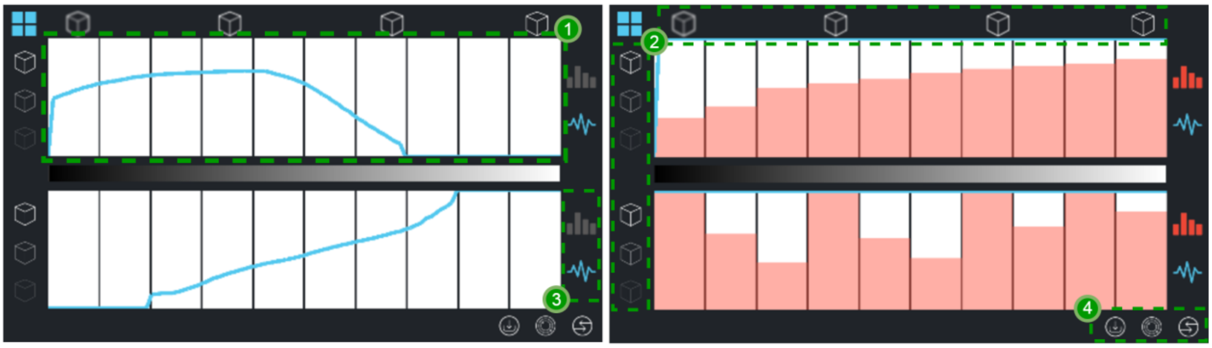


Figure 26 - Voxel TACS sketch-based interface.

Since transfer functions sketch it is an adaptation from another project related to transfer function design for medical images, and it will not be covered in this document, for further explanation on how transfer functions work (Mendes et al. 2015) master thesis offers a more detailed insight about the topic. The goal of this document is to maximize and develop novel interaction techniques, so transfer functions can be seen as a black box model (receives inputs and retrieves outputs).

Having in mind **Figure 26** it is possible for the user to sketch (**1**) in two specific areas for the effect, the superior sketch intractable rectangle is responsible to apply transfer functions that control the image intensity and the inferior one to control the image gradient.

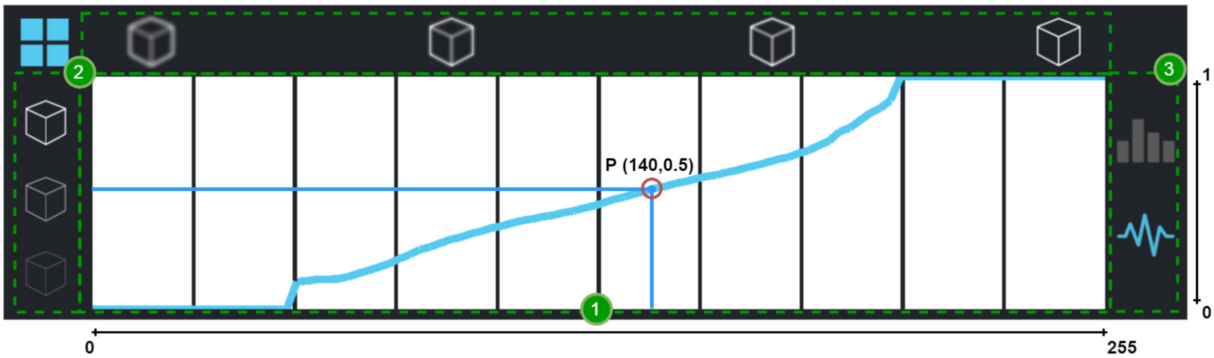


Figure 27 - Sketch line point mapping, interface sketch possibilities and visual subtitle.

The sketch area is a rectangle which maps points with the height range [0,1] and the width range [0,255], every line that is sketched/draw in this rectangle contains a group of points in those ranges. Those touch positions on screen are captured by TUIO framework. Once the line is draw, it is transformed into a direct transfer function to be applied to the 3D rendered volume.

This interface for sketch contains a visual subtitle (**2**) to understand how to model these transfer functions, in the horizontal one it is possible to observe the line edge definition between

structures, so drawing along the rectangle width reveals and defines specific medical structures. In the vertical one, it is possible to control the opacity of those medical structures that can be selected, so activating it (value 1 in the [0,1] range), which means sketching towards it, reveals a specific content, the inverse also occurs. As also shown in **Figure 26** and **Figure 27**, it is possible to switch (**3**) from sketch mode to a Disc Jockey analogy, by using a dragging bar mechanism (**Figure 26**, right image), which allows the user to visualize particular zones of the 3D image, simply by dragging up and down its fingers in a specific content layer. To access other functionalities such as touch and spatial manipulation or download images into the app the user toggles one of the available buttons (**4**).

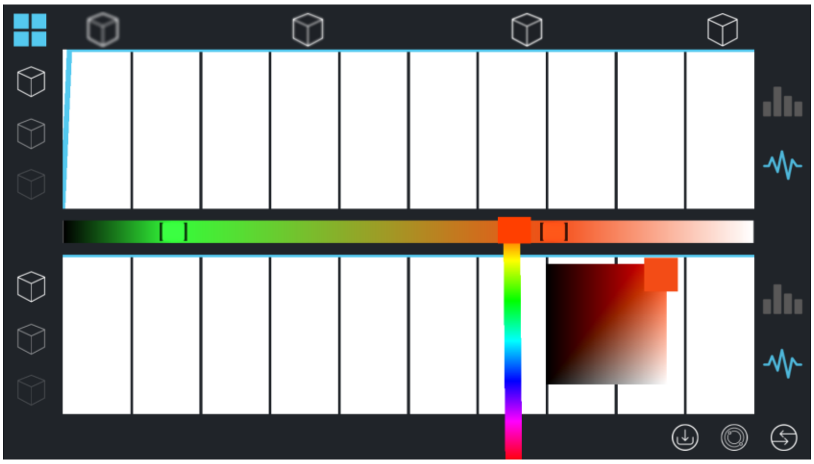


Figure 28 - Color bar and respective color picker used to coloring the 3D data.

In the process of 3D medical images analysis, by physicians, there is also the need of a color assignment tool. This is what allows to distinct tissues in a medical image (associated to the domain values) when they have the same opacities or when they are indistinguishable to the physician eye. To achieve this, a color bar was positioned directly above the gradient sketch area (**Figure 28**). The assignment of colors is done through interaction with the bar: when a double-tap is performed, this bar creates a small cursor with a given color that can be assigned with a color picker. The selected color is applied to the cursor and sent to the server in real time to be applied the volume. This approach follows the painter analogy also explored by (Piazza et al. 2013).

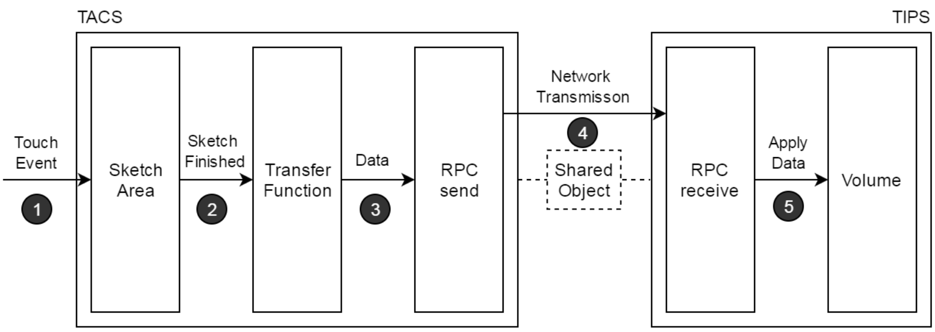


Figure 29 - Skektching flow of data through the Voxel system.

All the data produced in this sketch interface, as already mentioned, its processed, converted and remotely sent from the touch device (via Wi-Fi) to the display server, where its applied to each voxel of

the volume. These tasks that require real-time modification, i.e., when the user sketches or colors the volume it needs to see an instant feedback of what is happening, there was the need to use co-routines that can guarantee the real-time updates when interacting.

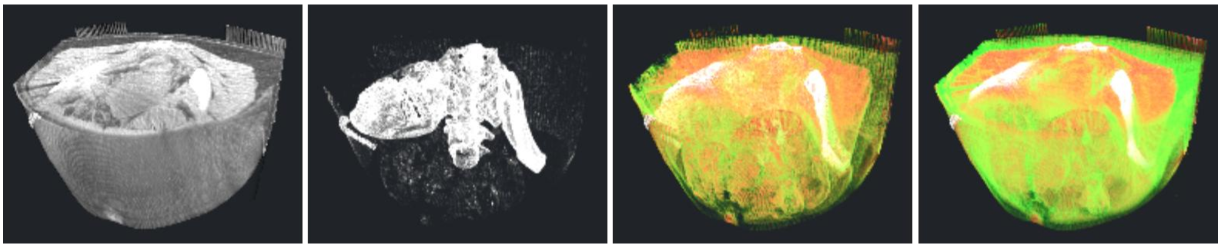


Figure 30 - Sketching capabilities to respectively: select anatomical content (bones) and coloring areas of interest (muscle – red; fat – green).

4.3.4. Clipping

One of the most important features in a medical tool, besides the volume rendering engine, is the capability to clip medical images, says Dr. Vitor Nunes (General Surgery Director of HFF). Medical image clipping follows the same implementation approach of the previous chapters, all data is processed in the tablet device and sent to the server.

In this interaction it is also introduced the widget approach explained in chapter **4.3.2**, making it possible for the user to easily select and center the desired volume orientation to clip. The users have the ability to clip the volume along a plane perpendicular to each axis. In the sequence of events shown in **Figure 31**, when an orientation is selected (**2**) through the open-box widget, it is possible for the user to navigate through the slices (forward and backward) in the chosen axis. For that, the user should move one or two fingers horizontally along the touch surface. Moving them to the right direction, it navigates forward in the volume slices (**3**). Moving them to the left, it navigates backwards in those same slices (**2**). After performing the cuts, it is possible to freely manipulate the volume orientation again (**4**) with the slicing applied.

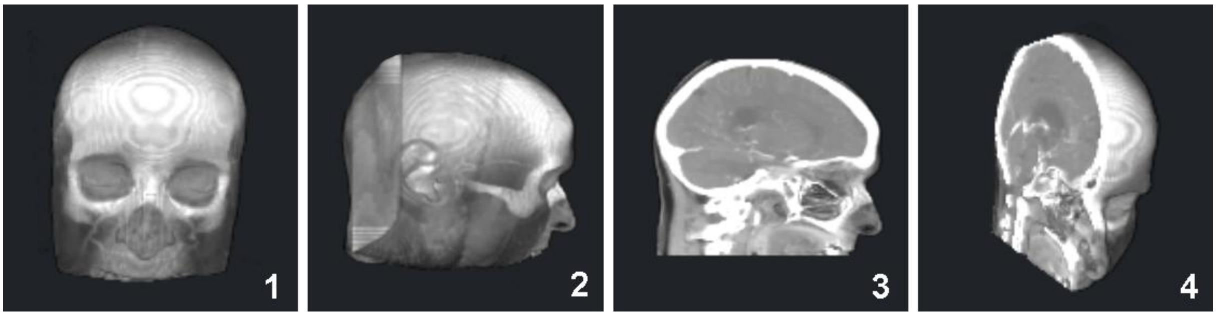


Figure 31 - Horizontal clipping sequence.

4.3.5. 2D Slicing

Image slicing is a common practice among physicians, even though performing this task in a 3D volume (as the previous topic) it is not an exercise that can be easily obtained in most of the traditional medical software. Most physicians still rely on mental representations of this 3D volumes through 2D images sequence navigation.

To provide the physicians with the same kind of interaction that is currently used in WIMP interfaces, it was developed a 2D slice viewer. The user must tap the button to download the 2D image slices that compose the 3D volume from TIPS server. Using this 2D medical image viewer it is possible to navigate, back and forth, through the image slices shown on the tablet screen. To achieve it, the user can drag the finger up or down the screen, in order to simulate the mouse wheel button, this way is possible to navigate throw the slices (remove or add slices). It is also possible to tap on the displayed navigation screen buttons (arrows) that offer a more precise navigation slice-by-slice, as shown on **Figure 32**.

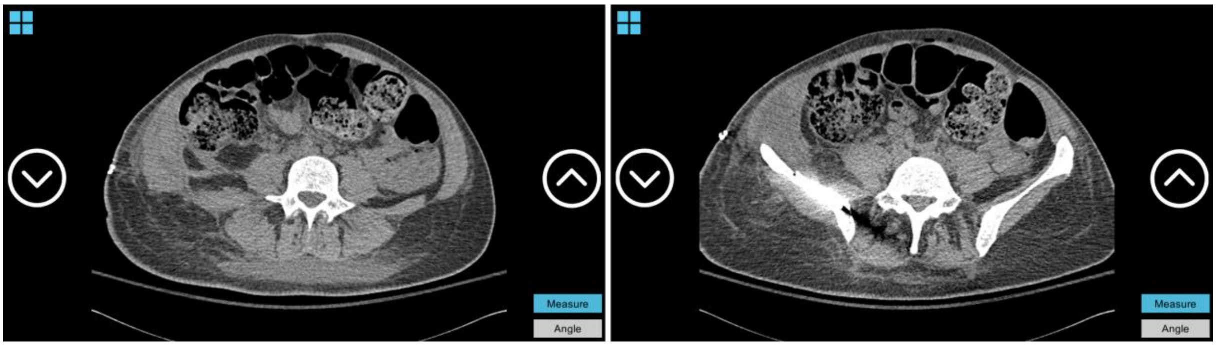


Figure 32 - 2D slice navigation interface, where it is possible to measure lengths and angles.

4.3.6. Measuring

Another tool that has an impact during surgical planning is the measuring of medical images that needs to be precise an exact. In (Parreira et al. 2015) thesis, introducing novel gestural interactions, it was featured the possibility to make measurements over the faces of the volume or over any of the clipping planes, canonical or free. Even though it was an interesting feature, in the interaction point of view, it lacks the accuracy needed and it is not that useful and perceptible for physicians to take measurements over a 3D volume (as shown in Parreira master thesis results). Having this in mind, it was also recreated the point-and-click measuring functionality in the point-and-tap device, which does not bring nothing new in the interaction chapter, but makes is possible for a smooth transition between mechanical and touch peripherals. Users have the ability to tag, make measurements and take angles over the 2D slices of the volume as they do in traditional software.

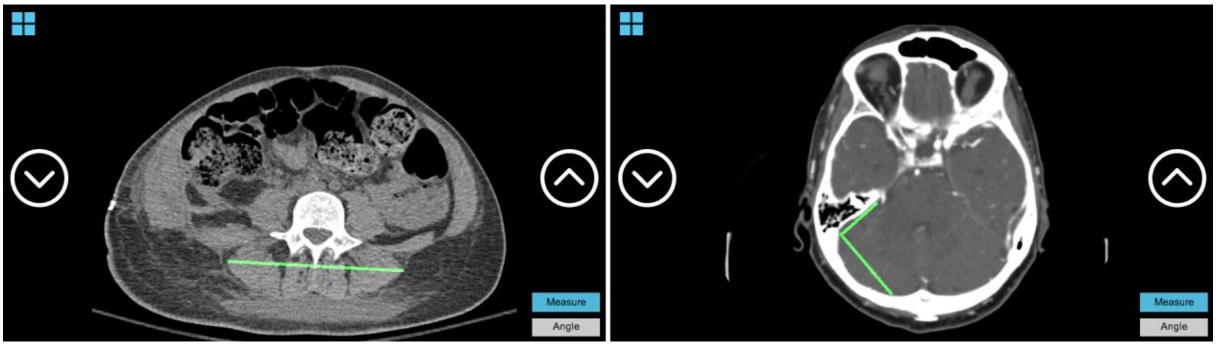


Figure 33 - At the left image, it is possible to visualize the length measuring option, and the angle measuring option at the right image.

After selecting the desired option (tag, measure or angle) and when a touch is detected, a ray is casted forward from the touch position and it is checked for collision with the medical image. If a collision is detected, a marker is created in the exact collision point. In order to measure lengths, two markers need to be set, and a line connecting the two markers is draw after the second marker is placed. The length value between the two markers, displayed midway between both markers, is displayed in centimeters, since it is the same order of magnitude as the volume displayed. Angles are determined in a similar way, with the need for three markers instead of two. The measured angles appear over the second positioned marker, which are presented in degrees. Finally, to simply tag a point of interest in the displayed image, there is just the need to tap on the desired position and the marker is set.

4.4. Spatial

Spatial awareness is provided to Voxel TACS project through the usage of OptiTrack motion capture hardware. A set up of 20 motion capture cameras and three reflective markers placed on the tablet device allow it to recognize its own position and orientation in space. In the next chapters, all the spatial content developed, such as interactions and communication is covered in detail.

4.4.1. Motion capture

Motion capture technology was used to track the tablets position and orientation in space. OptiTrack system was chosen to detect the tangible touch device, due to its low latency in data transmission and high precision of movement detection.

Figure 34 - Tablet device equipped with reflective markers (2) that can be detected and captured by motion capture cameras (1).

The tablet devices are equipped with reflective markers (**2**) that can be detect by the depth sensor cameras (**1**) attach to the ceiling of the laboratory. After the markers attachment to the tablet, the system is calibrated for the user comfort position with the device, which sets the initial coordinates and orientation in 3D referential space. Motive software is responsible for detect, collect and broadcast the tablet position and orientation in space to be sent to Voxel TIPS software and subsequently applied to the 3D volume (matching tablet position and orientation).

4.4.2. Messaging – UDP

To provide spatially awareness to the handheld devices there was the needed to establish a simple connection without any complex mechanisms and agreements to send smalls chunks of data to the devices. Using OptiTrack system, Motive, which already works with integrated UDP message broadcasting, makes it possible to communicate with other systems, even though it was necessary to build at the receptor endpoint (TACS) a structure to process the received broadcasted data.

Time-sensitive applications often use UDP because dropping packets is preferable to waiting for delayed packets. Using a simple connectionless transmission model with a minimum of protocol mechanisms, where error checking and correction is not necessary avoids processing overhead.

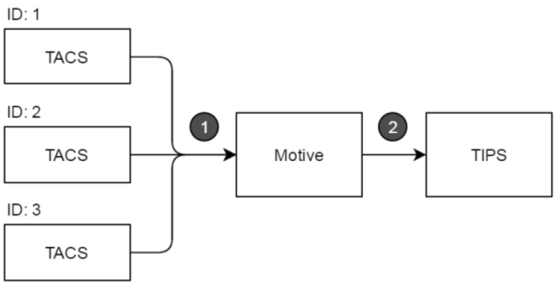


Figure 35 - Spatial interaction flow. TACS markers are single captured by Motive software and sent to TIPS server application.

After the socket creation and binding, with the Motive server, in the appropriate multicast address and port for data transmission a channel of communication is created. The simple schematics in **Figure 35** shows that Motive software broadcasts (**2**) to TIPS server machine all the TACS spatial data that is collecting in real-time (**1**). All the spatial content is sent to TIPS server through the Motive UDP broadcast, but only one TACS device, at a time, can spatially interact with the 3D volume. Since every rigid body (TACS) has an ID associated to it, it is possible for the TIPS server to recognize which TACS device is active for interaction.

4.4.3. Manipulation

Spatial volume manipulation is achieved through direct manipulation of the tablet device in space. Being a 3D cursor, with position and orientation, the real-world handheld device controls the virtual volume as if it was himself.

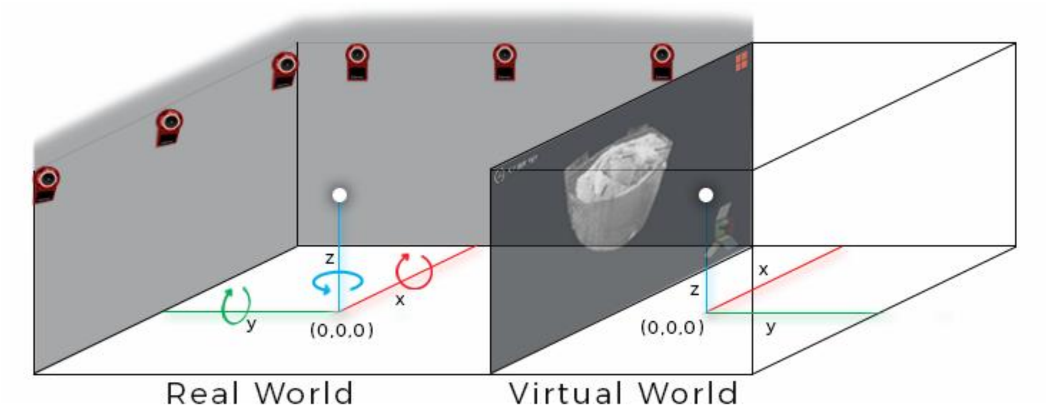


Figure 36 - Schematics for tablet position in space mapped in the virtual world.

The Optitrack system composed by 20 depth sensor cameras, represented by the 6 red cameras on **Figure 35** in the *Real World* section, is responsible to detect the *white dot* that represents the tablet device in space. Being detected by the motion capture cameras, the tablet device is represented in a

three-dimensional referential as illustrated. Every movement performed by the user on the handheld device, including axis rotations, are detected and directly mapped into the *Virtual World* section. The tablet position and orientation in *Real World* is directly mapped in the *Virtual World white dot*, which represents the 3D volume rendered in the TIPS application. To transmit data (position and rotation) is used UDP protocol as already mentioned. This approach follows the concept developed in (Dorta et al. 2015) related to 3D cursors in space.

4.4.4. Clipping

Volume clipping is also performed in the spatial component of the project. For that, the spatial data is complemented by touch mechanisms to select the volume face to clip. Similar to the touch clipping, the user must switch between spatial manipulation and the use of the open-box widget concept.

The main problem in this interaction was the need to switch from free manipulation, which is constant while the tablet moves, to a static interaction to clip the volume. While spatially interacting with the volume using the tablet device, if the user wants to perform a clip in a certain face, one of sides of the open-box must be selected, which immediately deactivates the free manipulation. After that, and having in mind **Figure 36** and **Figure 37**, the user just needs to move the tablet device along the y axis to perform the clip. Moving the tablet further from the center position, along the y axis, navigates forward in the volume slices (removes slices). Moving it closer, navigates backwards in those same slices (adds slices). After performing the clipping, it is possible for the user to freely manipulate the volume again.

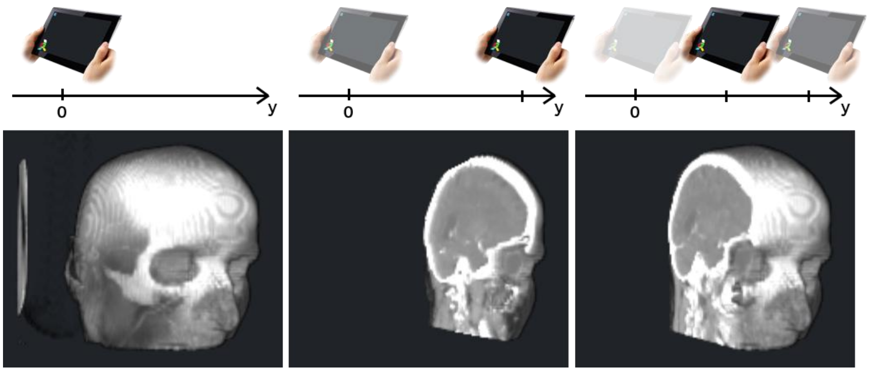


Figure 37 - User horizontal movement dynamics with a handheld device in order to perform a clipping task.

4.5. Collaborative Setup

The collaborative environment is provided with the sum of all the functionalities developed. Almost no mechanism were implemented to provide the users with the ability to perform tasks together, at the same time. A user with a device running Voxel TACS is able to connect to the running Voxel TIPS application and immediately interact with it. Every person connected is able to modify the state of the server. Although, if interacting all at the same time the volume will receive every update. Coordination is obtain through person-to-person communication (Spindler et al. 2014), if a user is manipulating the volume another user can join and also manipulate but will interfere with the first user interaction (Alexander 2014). In this application scenario this is not seen as a problem, since it should work in a medical scenario where physicians discuss and interact to show its own perspective of the content, for others to see. We decided not to follow a token approach (Lamberti & Sanna 2007) that can deprecate the naturalness of the system interaction. Taking into account (Marquardt et al. 2011) work we provided a device to control other displays, a universal input device (tablet) for all activities that smooths the transition between activities.

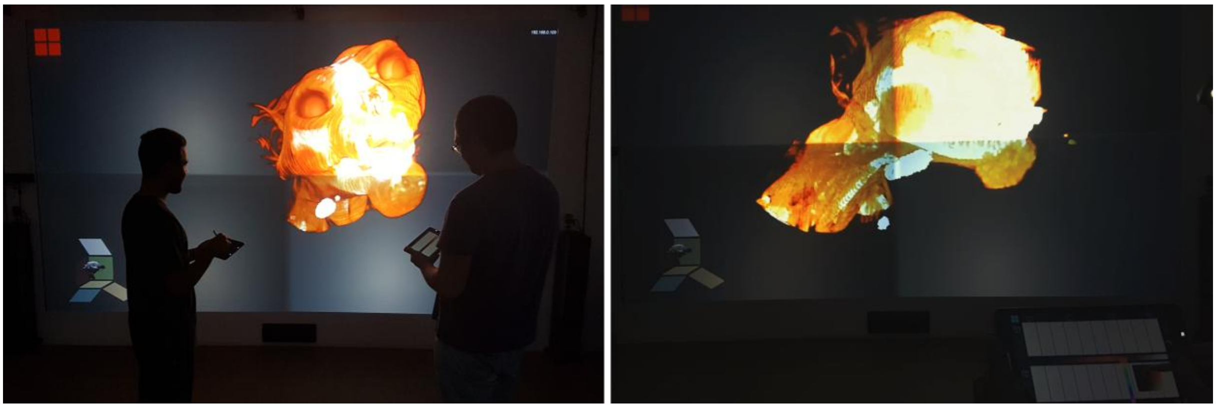


Figure 38 - Collaborative interaction with two Voxel TACS machines performing manipulation and sketching over the volume, at the same time.

Chapter 5

5. Evaluation

In order to evaluate Voxel TACS we proceeded with some standard system, user and task performance tests, based on the general metrics of usability to measure the characteristics of a 3D environment, similar to what other authors have done. Our 3D user interface will be usable if the user can reach the proposed goals, when important tasks can be done better, easier or faster than with another system, and when users do not become frustrated or uncomfortable using the system. To find the answer to these conceptions we need to take into account:

- **System Performance Metrics**

System performance refers to typical computer or graphical system performance, so metrics such as average frame rate, average latency and network delay need to be taken into account. From the interface point of view, system performance metrics are not important, only if they affect the user's overall experience or tasks. System interaction it is not limited by network latency or package delay, real-time frame rates are provided to the user when interacting, usually 24 fps is the minimum the human eye needs to create the illusion of movement, and the system can reach 50-60 fps. Also, in a collaborative setting, such as in this project, task performance will be negatively affected if there is too much network latency. So based on Jacob Nielson (Nielsen 1994) work in HCI and usability we can achieve time response intervals between the following research results:

- 100 milliseconds is the maximum time limit for having the user feel that the system is reacting instantaneously;
- 1000 milliseconds is the maximum limit for the user's flow of thought to stay uninterrupted, even though the user will notice the delay, the user does lose the feeling of operating directly on the data.

- **Task Performance Metrics**

User task performance refers to the quality of performance of specific tasks in the 3D application, such as the time to navigate to a specific location or the accuracy of object placement. These tests are domain-specific, and metrics were defined accordingly to this project interest and further explained.

- **User Performance Metrics**

User preference refers to the subjective perception of the interface by the user (ease of use, ease of learning, satisfaction, etc.). These preferences are often measured via questionnaires or interviews. For 3D user interfaces (UI) in particular, presence and user comfort are important metrics that are not usually considered in traditional UI evaluation. To measure these results, surveys were delivered to the users containing a wide variety of specifically design, comfort and interaction questions. To achieve palpable rating results we used 4 points *Likert* scales, to avoid neutral answers and get specific answers, since this way the user needs to form an opinion.

5.1. Participants profile

The user tests were carried out with 15 people, age 18 to 35 years, belonging to Informatics, Electronics, Biomedical and Food Engineering courses, and also Cinema, Video and Multimedia courses. From these, 13 were men and 2 were women. All users had touch devices, such as smartphones or tablets, and the great majority (75%) of the users already took advantage of the built-in device accelerometer to interact. Although, only 4 users had some experience with systems that allow visualization and manipulation of 3D content. *Appendix C* contains the survey used to analyse the participants profile.

5.2. Tests Setup

To determine and validate if Voxel TACS can be a complementary tool or even a suitable alternative to traditional WIMP interfaces in medical software, three major questions needed to be answered:

1. Is this kind of interaction capable of accomplishing the same basic and essential tasks as the traditional medical interaction software?
2. Can these tasks be accomplished in a similar execution time when compared to the traditional software?
3. Can this setup provide a substantial benefit over mouse controls? Is it viable?

The tests were designed to evaluate the system performance while executing several standard tasks (done by physicians) using Voxel TACS (touch and spatial), traditional WIMP software and Voxel Explorer, a novel gestural manipulation interface (Parreira et al. 2015). For the purpose of these tests evaluation, the interactive system for image visualization VolView[17] was chosen (WIMP software), since it is capable of perform the same tasks of professional medical software.

Table 3 synthetizes the performed tests in the following away: For each system (total of 4) the tests were divided in two parts, each one composed by 5 time measured tasks (10 task per system).

[17] http://www.kitware.com/opensource/volview.html

In *Part One* it is intended to test the user's ability to translate (T), rotate (R) and scale (S) the 3D content. At every tasks it was introduced a new interaction element, minimizing the learning curve. In *Part Two* the clipping functionality is introduced, asking the users to vertically (VC) and horizontally clip (HC), combined with previous interactions, increasing the interaction complexity. At the beginning of each task an image was presented with the result that the user would have to obtain using the tools provided and their performance was measured by the time they needed to complete each task.

Task #	T	R	S	VC	HC
Part One					
1	×				
2		×			
3	×	×			
4	×	×			
5	×	×	×		
Part Two					
1				×	
2					×
3	×	×		×	
4	×	×			×
5	×	×	×	×	

Table 3 - Interaction content of each test task.

To avoid bias of results caused by the order in which the tests were presented, due to familiarity with the data set, the tests order were randomized for each group of five users. Each task had a limit of 60 seconds to be finished, at the end of each system test the user was presented with a survey to collect perceptive data about the interactions performed. A complete user tests guideline is available for consultation in *Appendix A*.

5.3. Systems Setup

The systems being tested: Voxel TACS (touch and spatial), Voxel Explorer and VolView were setup with two anatomically similar 3D volumes to provide interaction resemblance, with one volume being used for user adaptation and training and another one for the effective test tasks.

The training volume for VolView was a standard thoracic and lombar MRI obtained from OsiriX image database (MRIX), and the two Voxel projects a similar anatomical structure obtained from **Hospital Professor Doutor Fernando Fonseca, EPE (HFF)**. The test volume for VolView is a human head obtained from OsiriX image database (BRAINIX), while the volume head loaded into Voxel TACS and Voxel Explorer is a resource from **HFF**. All volumes from the Hospital where obtained anonymously, to protect the identity of the patients.

5.3.1. Touch & Spatial

The Voxel TACS application setup for touch and spatial interactions is composed by an interaction device (tablet) and a display (Wall) to run Voxel TIPS. In the spatial setup where also used 20 OptiTrack motion capture cameras. Voxel TIPS ran on a capable desktop machine (RAM: 12.00GB; VRAM: 6362MB; Processor: 3.3GHz) and a LAN Wireless router 802.11n with 150 Mbps of upload and download rate to connect the machines. The connectable devices possess an upload Wi-Fi connection with 6Mbps that establishes the maximum bandwidth for communication (Samsung Galaxy Tab 10.1 and Galaxy S GT-I9000).

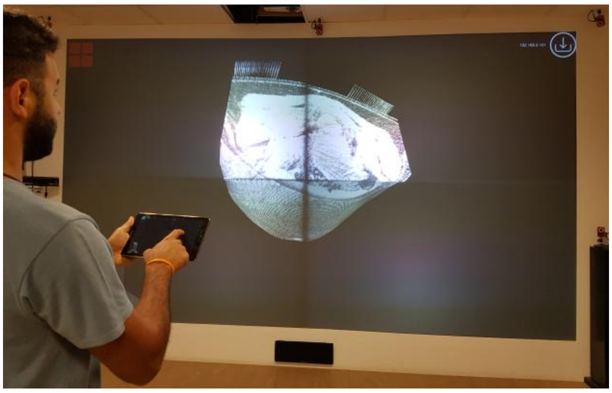


Figure 39 - Voxel TACS interaction setup.

5.3.2. VolView

The Volview setup was composed by a PC (RAM: 8Gb, VRAM: 2811Mb; Processor: 3:20Ghz) running VolView version 3.4. Since the type of interaction in this system is WIMP, the users were provided with a mouse and keyboard for task completion.

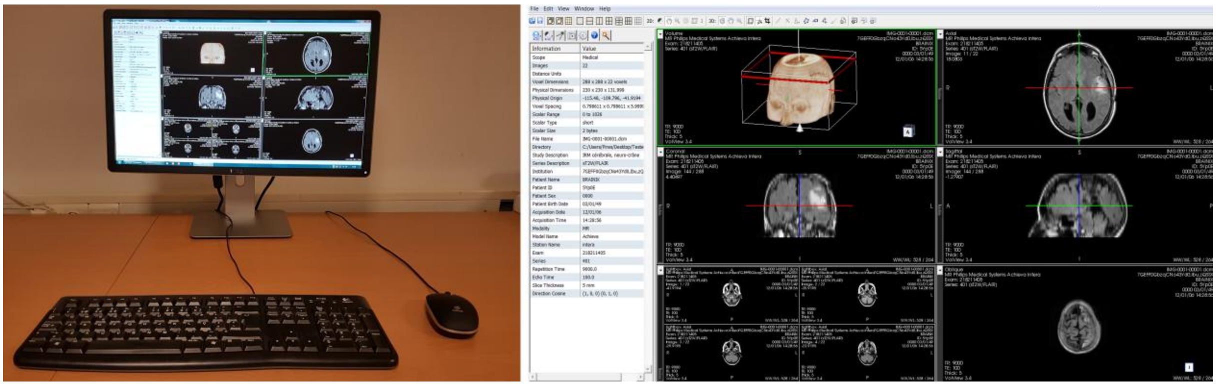


Figure 40 - VolView interaction setup.

5.3.3. Explorer

The Voxel Explorer (Parreira et al. 2015) application setup is composed by a single Microsoft Kinect for gesture recognition and a Wall display. Voxel Explorer ran on a capable desktop machine (RAM: 12.00GB; VRAM: 6362MB; Processor: 3.3GHz). The user was positioned in front of the Kinect camera, interacting through the use of gestures with the rendered volume.

Figure 41 - Voxel Explorer interaction setup.

Chapter 6

6. Results

In this chapter, it will be presented a comprehensive set of results obtained from the timed system tasks and the user interaction experience data collected from surveys. A short discussion about the collected data and the attained results is provided. In addition, the professional feedback obtained from different sources is presented and discussed.

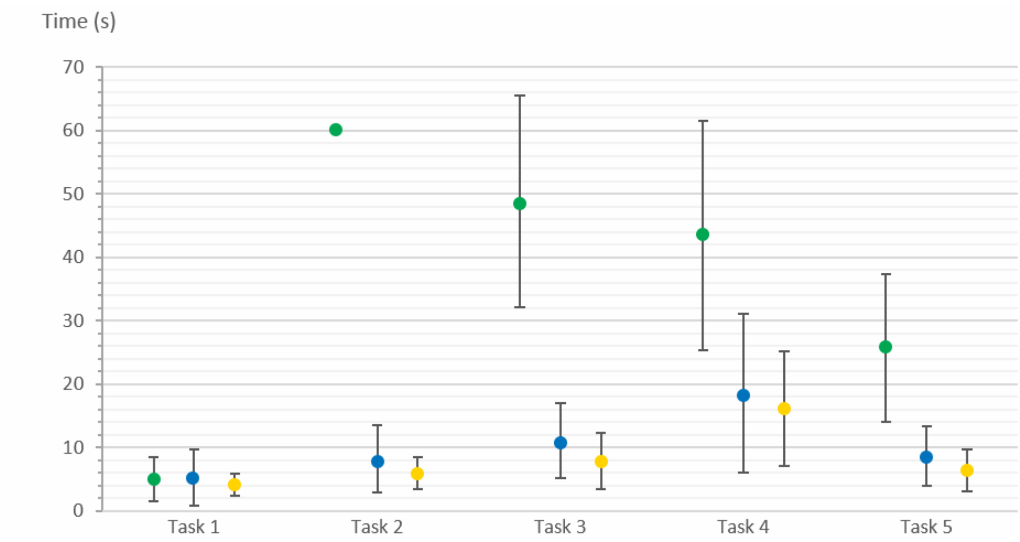
6.1. Task Results

In order to evaluate users' performance when interacting with the four system interfaces, the timed interaction data collected from users while performing each task for each system was gathered and compared. The following results from task execution will be used to determine which interface can achieve the desired results for task completion in the least amount of time. This will be useful to comprehend if the interaction techniques developed for Voxel TACS can play a role in the future of medical interface interaction or in the future of virtual object manipulation.

As expressed in the previous chapter **Table 3** the developed test package is composed by two parts, the first one centred in basic interaction techniques and the second one based in clipping tasks usually performed by physicians. Next topics contain the results and analyses of both parts.

- **Part One**

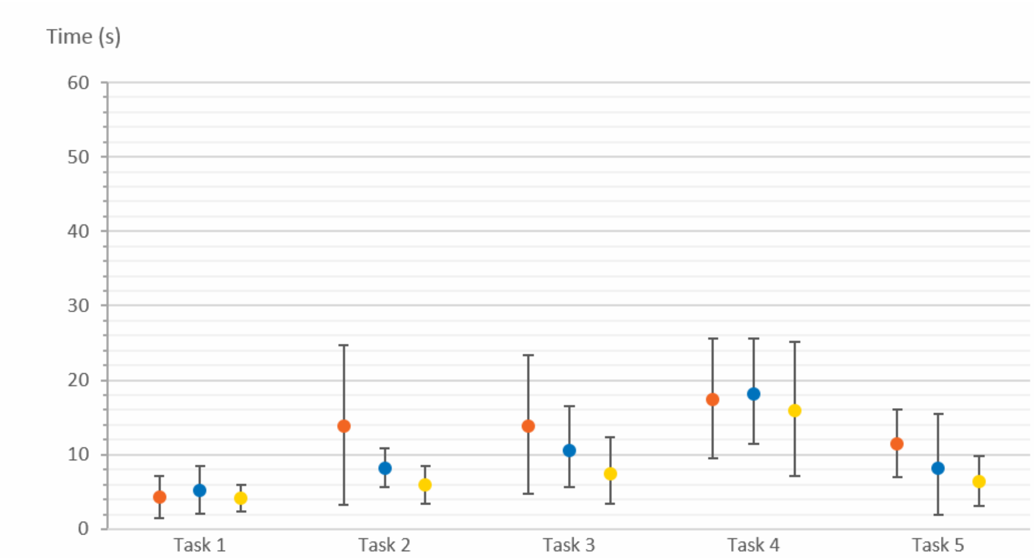
The following results correspond to the first group of five system tasks. The first analyses that needs to be made, to verify that this project touch and spatial interactions are a step up compared to gestural interaction interfaces, is between Voxel Explorer and Voxel TACS.



	Task 1	Task 2	Task 3	Task 4	Task 5
Explorer	4,96	60,00	48,78	43,43	25,72
Touch	5,28	8,25	11,13	18,56	8,68
Spatial	4,14	5,96	7,88	16,12	6,47

Figure 42 - User time performance comparison in the five tasks from *Part One*, with Explorer and TACS systems.

Comparing users' performance in both systems (Explorer and TACS - Spatial and Touch) with **Figure 42**, we can observe that there is a huge gap between the values obtained with those systems. Results are only balanced in the basic translation task (*Task 1*). It is possible to infer that in tasks that contain more complex geometric transformations (*Task 2*, *Task 3* and *Task 4*), Voxel Explorer does not suit the purpose to achieve quick interaction results. An interesting result was achieved in *Task 2* with Voxel Explorer, being impossible to turn the 3D volume upside down with precision, resulting in a time limit task value of 60 seconds with no standard deviation.



	Task 1	Task 2	Task 3	Task 4	Task 5
Volview	4,27	14,01	14,05	17,54	11,59
Touch	5,28	8,25	11,13	18,56	8,68
Spatial	4,14	5,96	7,88	16,12	6,47

Figure 43 - User time performance comparison in the five tasks from Part One, with VolView and TACS systems.

Furthermore, in Voxel TACS (Spatial and Touch) in **Figure 43** we can observe a slight decrease in the time required to perform each task (*Task 2*, *Task 3*, *Task 4*), compared to standard visualization software (VolView). One thing to notice is that standard deviation in Voxel TACS is always smaller in one of the interaction interfaces than the traditional software used. In tasks with no improvement to traditional software, mainly by the touch interface, the difference obtained, it is not evident (*Task 1* and *Task 4*) when compared to the conventional software. However, there was a noticeable decrease in the amount of time necessary to, once again, rotate with precision the volume upside down (*Task 2*). Important to notice that in almost every complex task (*Task 2, Task 3, Task 5*) the execution time of the spatial Voxel TACS is almost half than the traditional software.

In VolView software the standard deviation is always much relevant than the one found in the TACS interfaces, this is specially noticed in intense rotation tasks (*Task 2* and *Task 3*), due to the fact that the rotation used in traditional software does not use a rotation axis inside the volume, but rotates around a fixed point in space. This way, users often relied on luck to obtain the desired result, rotating it in a disordered and uncoherent way to achieve the goal.

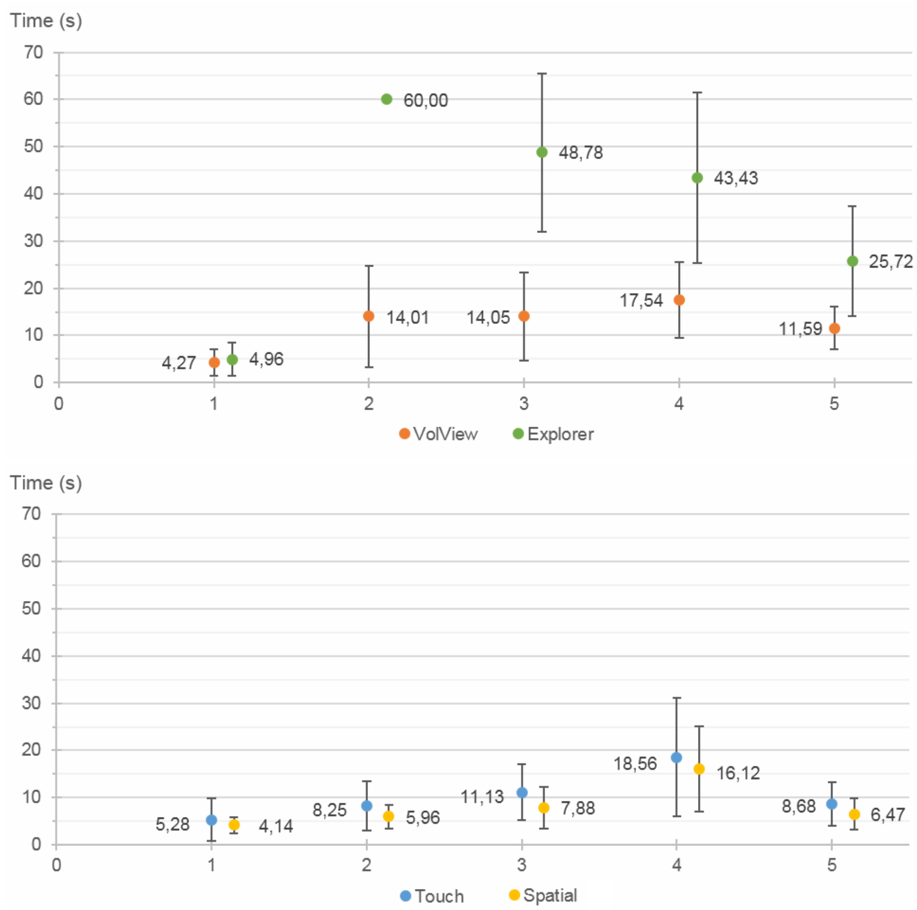


Figure 44 - User performance comparison in the five tasks from *Part One*. The top figure compares VolView and Voxel Explorer task performance. The one below compares the two Voxel TACS interfaces.

As a final study, **Figure 44** compares in the top image the traditional software VolView with the novel gestural interface of Voxel Explorer. This task results create an opposition statement to the results obtained in (Parreira et al. 2015) master thesis with Voxel Explorer free rotation tool. In his work, it was

verified that Voxel Explorer techniques were in some way similar, or even better (in terms of performance times), to the ones used in traditional software. However, the tests performed in Parreira's work do not implied difficult rotation tasks that forced the user to achieve uncomfortable anatomical positions. In terms of rotation tasks, it is possible to deny that Voxel Explorer previous analyse is coherent, since the setup test mounted for this document did not took into account possible interaction limitations in the systems tested. It is important to underline that the translation results (*Task 1*) obtained in every interface tested are similar to traditional software, including Voxel Explorer.

In **Figure 44**, the image below compares the touch and spatial interfaces outcomes, and surprisingly the spatial interface overcomes in every task the results obtained with touch interaction. This can be explained by the simplicity of the spatial interface to achieve translations and/or rotations. The user just needed to move and orientate the tablet accordingly to the desired goal.

- **Part Two**

The following results correspond to the second group of five system tasks. To analyse the second group of tasks it will be used the same discussion sequence from *Part One*. We will start by verifying that this project touch and spatial clipping interactions are a step up compared to gestural clipping interactions.

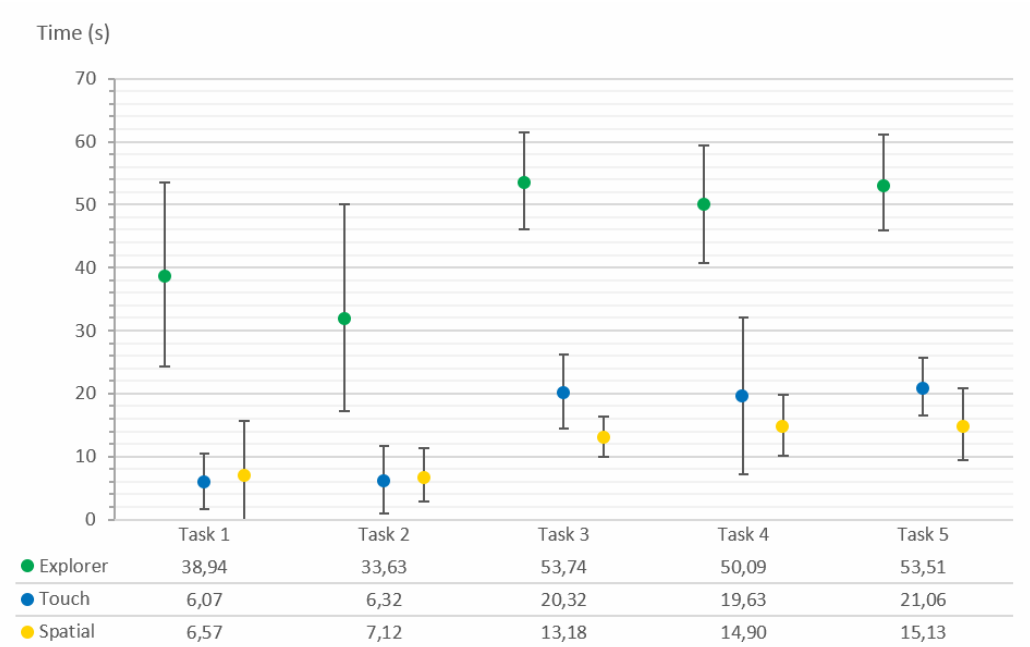
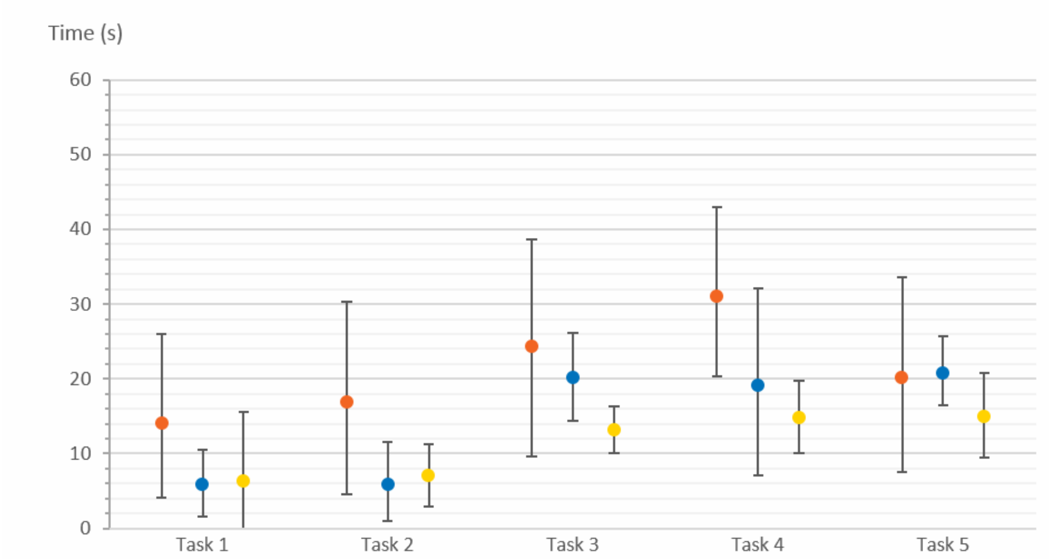


Figure 45 - User performance comparison in the five tasks from *Part Two*, with Explorer and TACS systems.

Comparing users' performance in both systems (Explorer and TACS - Spatial and Touch) with **Figure 45**, we can observe that there is a huge gap between the values obtained with those systems. Voxel Explorer set of gestural interactions, intense menu navigation and limitations to choose the volume clipping face, is expressed in every test task result, which took considerably longer when compared with the measured times obtained with Voxel TACS platform.



	Task 1	Task 2	Task 3	Task 4	Task 5
Volview	15,04	17,43	24,09	31,64	20,52
Touch	6,07	6,32	20,32	19,63	21,06
Spatial	6,57	7,12	13,18	14,90	15,13

Figure 46 - User performance comparison in the five tasks from *Part Two*, with VolView and TACS systems.

When comparing, in **Figure 46**, VolView with Voxel TACS (Spatial and Touch) we can observe a slight improvement in this kind of tasks compared to the ones performed in *Part One*. The simplified manner that the user could select the face to clip in both TACS interfaces, is demonstrated in the measured time results. The more complex tasks (*Task 2* and *Task 4*), that involved a more complex thinking and navigation through the system, are an example on how well the simplification of face selection through the open-box widget was well received and understood by the users. This technique compared to the standard visualization software (VolView) shown great progress, since there is no need to rotate, translate and select imaginary planes to clip as it happen in VolView. One thing to notice is that, once again, standard deviation in Voxel TACS is always smaller than the traditional software used. In *Task 5* the average systems results are more similar because the original starting position of the 3D volume favours the achievement of the orientation and the selection of the clipping plane over the volume.

In VolView software the standard deviation is always much relevant than the one found in the TACS interfaces. This is even more noticed in tasks that involved horizontal clipping or vertical clipping with rotations (*Task 2*, *Task 3* and *Task 5*), due to the need for the user to rotate and translate the volume to achieve the right position to clip.

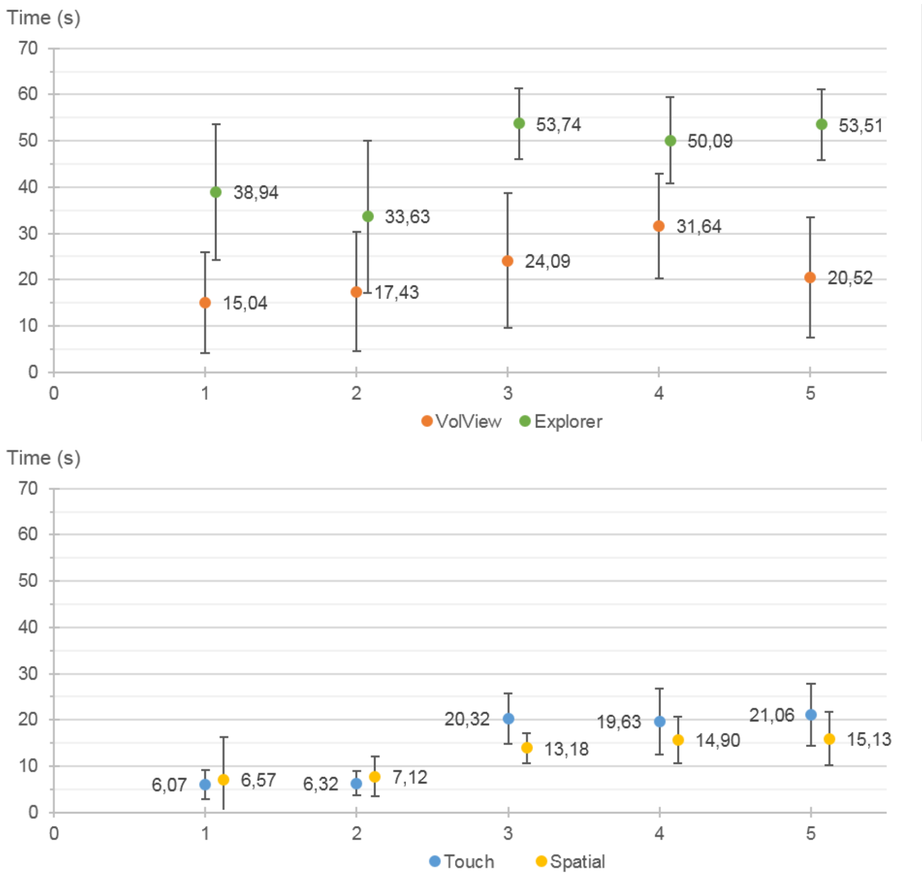
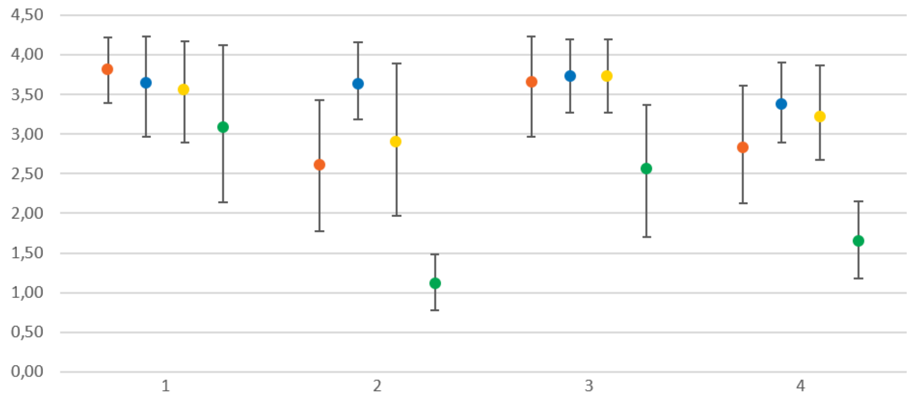


Figure 47 - User performance comparison in the five tasks from *Part Two*. The top figure compares VolView and Voxel Explorer task performance. The one below compares the two Voxel TACS interfaces.

As a final analyses, **Figure 47** compares in the top image the traditional software VolView with Voxel Explorer. This task results meet the results obtained in (Parreira et al. 2015) master thesis with Voxel Explorer clipping tool. The problems with Kinect recognition, adding to the poor interface design made Voxel Explorer a difficult tool to quickly perform clipping tasks. The image below compares the touch and spatial interfaces outcomes, and an interesting but predictable result was found, in the first two tasks where the users only needed to perform a clip over a volume face, the results become similar in both spatial and touch interfaces, with the touch interface being slightly better. However, when the tasks implied a combination of clipping, translation and rotation, the spatial interface overcomes the touch interface. This can be explained by the simplicity of the spatial interface to switch from clipping to free manipulation, which did not happen in the touch interface. In the TACS touch interface, after the user performed the clip and to be able to manipulate the volume again, there is the need to navigate through menus to achieve it, which is notably shown in the slightly worst results obtained.

6.2. Survey Results

In order to evaluate user experience, multiple choice answers were presented in a scale between 1 and 4, where 1 represents the most negative answer and 4 represents the most positive answer. *Appendix D* and *Appendix E* contain the surveys used to evaluate the user experience when interacting with every system tested.



	1	2	3	4
Volview	3,80	2,60	3,60	2,87
Touch	3,60	3,67	3,73	3,40
Spatial	3,53	2,93	3,73	3,27
Explorer	3,13	1,13	2,53	1,67

Figure 48 - Difficult felt by the user when: 1- Translating the volume; 2- Rotating the volume; 3- Scaling the volume; 4- Using all controls combination.

To answer to the first four questions related to geometric transformations, **Figure 48** statistically sums the users' responses to the difficulty felt when performing standard medical tasks related to: translation (**1**), rotation (**2**), scaling (**3**) and combining all the controls at once (**4**). Users were asked to classify from 1 (Very Hard) to 4 (Very Easy) the performed tasks. Starting with the first question (**1**), all systems obtained a close response, which is supported by the timed results obtained in the previous topic. Translation tasks were well received and executed by the users. To note that the users preferred to use the traditional point and click strategy (m=3,80; sd=0,41), although both touch (m=3,60; sd=0,63) and spatial (m=3,53; sd=0,64), also obtained satisfactory interaction results. Voxel Explorer results were still acceptable, but there is clearly a differentiation from the other systems.

Regarding question number two (rotation - **2**), users clearly find it hard to achieve the desired results with Voxel Explorer which will not need further analysis from now on, since it is far away from being matter for comparison. This question about how the user felt using rotation triggered interesting results. Touch interface was clearly the most easy to use (m=3,67; sd=0,49), even though the users obtained faster timed results with the spatial interface, as verified in timed tasks analyses (**Figure 43**). This can be explained by the fact that users needed to manipulate and rotate the tablet in their hands in order to rotate the volume, which could not be a comfortable position to be at. Both touch and spatial performed better in terms of ease to use than the standard software, which presented some challenges for the users to understand where the rotation axis was. Scaling (**3**) was a really easy to use tool in VolView (m=3,60; sd=0,63) but so it was with both TACS interfaces. Touch and Spatial

obtained the same exact result (m=3,73; sd=0,46) which evidences the volume scaling easiness. Finally, the combination of all controls (**4**) was easier to use with the touch interface (m=3,40; sd=0,51), the spatial interface (m=3,27; sd=0,59) was closer to the touch one, but due to users lack of familiarity with spatial navigation it did not performed as good the recognizable touch mechanisms. Traditional software, VolView (m=2,87; sd=0,74), scored lower than Voxel TACS interfaces mainly due to the need to constantly '*point and click'* to achieve the desired position and orientation.

When asked about the difficulty of performing clipping tasks with VolView, 70% of the users find it easy to select the clipping plane, although manipulating it divided the users opinion with 53% answering that was difficult or very difficult to move the clipping plane along the axis. With the touch interface 80% of the users find it easy or very easy (50%) to select the clipping plane, in contrast with VolView, all the user find it easy or very easy to move clipping plane, which was an improvement to this kind of interaction. In the spatial interface 50% of the users find it very easy to use, and 73% found it easy or very easy to use, which was better than traditional software but not as good as the touch interface. Once again, this results contrast with the timed task, since the touch interface was slightly worst in terms of performance compared to the spatial interface. These results happened because, even though the user was faster moving its tablet around space it had to perform more physical effort during the tasks, which did not happen with the touch Voxel TACS. The following figure confirms this problem when users were asked how comfortable they felt when interacting with the volume. To conclude the analyses Voxel Explorer united 80% of the people to answer that the clipping plane selection was hard or very hard and 70% of the people found it very hard to manipulate it.

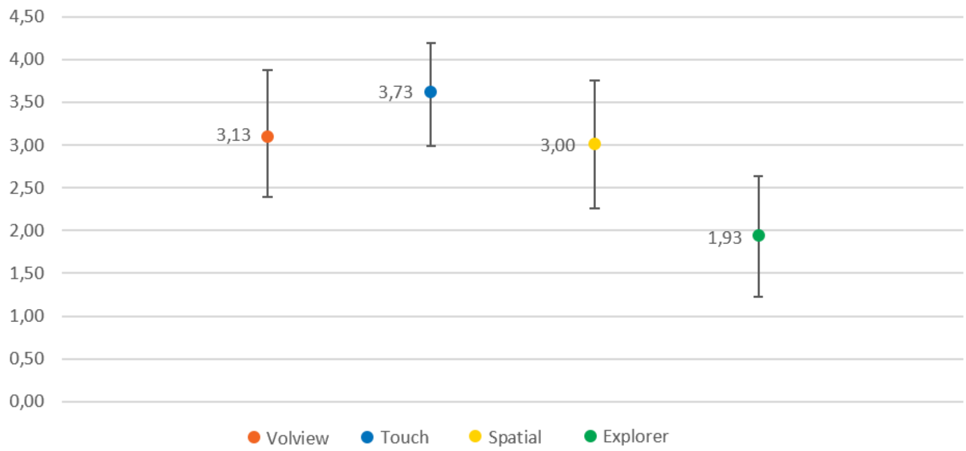


Figure 49 - Comfort felt by the user while interacting with the volume.

To understand if the user felt mentally and physically comfortable/tired while interacting with the volume the users were asked to classify their experience from 1 (Being Very Tired) to 4 (Not Tired at All). The results demonstrate that using a tablet, which is ergonomically designed, do not make the user tired or uncomfortable. Spatial and traditional software scored similar, but these identical scores had different causes. In the spatial interface, the users felt mainly uncomfortable with certain tablet positions, but with the WIMP interface the users felt frustrated (47%) since the system not always cooperated as it was supposed when dealing with rotation. Most of the users, also stressed that clipping was confused and complex.

6.3. Discussion

After the performed tests and data collected from users interaction feedback and surveys it is now possible to reason if touch and tangible user interfaces can improve users' ability to manipulate 3D volumes when compared to the traditional WIMP approach. The kind of interactions developed in TACS application are more than capable to accomplish the same basic tasks than traditional interaction software, furthermore, it can achieve better results in rotations and clipping tasks. The new paradigm developed confirms its viability with surprising results obtained in spatial interaction timed tasks. In a bigger time window frame of interaction, and not only performing simple and complex tasks as a goal, Voxel TACS could demonstrate a bigger viability with the precision that touch offers and the quickness of the spatial execution. With the data collected, it will be possible to combine both touch and spatial capabilities in order to achieve the perfect interaction tool for specific tasks.

Figure 50 - Clipped volume in VolView, Explorer and TACS display, respectively.

The main problems that users pointed out in VolView interaction are related to the complex combination of controls to perform clipping tasks. Although, the main cause of frustration and confusion was the volume rotation that is not performed in a fixed rotation center point, which made the users guess when rotating. Important interaction problems reside with the clipping and rotation functionalities in traditional software. As **Figure 50** shows, the VolView clipping interface displays an imaginary red plane that needs to be selected in order to be moved, which not only is difficult, but forces the user to be precise. If the red plane is not well selected the user can unintentionally move or rotate the volume. With the open-box widget approach, the user is just one tap away from clipping the volume, which is explicit in the timed tasks results.

The overall results obtained from timed tasks and surveys suggest that touch interface is the most natural for users to obtain the desired results, as well as the most comfortable and less frustrating, being able to mitigate many limitations observed in several approaches that are currently to deal with volumetric data. The simplicity of spatial and touch interfaces that scored an average satisfaction of 3,80 and 3,73, respectively, out of 4, compared to the VolView result of 2,53 and Voxel Explorer 2,60, shows that current WIMP interfaces do not suit the user needs for interaction.

The users overwhelmingly preferred touch interaction to perform all the tasks, which can be explained by the fact that touch mechanisms do a better job at translating users intentions, when compared to the traditional WIMP approach using a mouse. Even though the results obtained show that users were much quicker when spatially interacting, they also demonstrate that some of the interactions were not preferable to the same touch interactions in an anatomically point of view (mainly

rotation and translation). Spatial interface also depends on a much-restricted setup and can be affected by occlusion, which is a disadvantage to integrated touch displays. A deeper analysis of the data reveals that touch and spatial approach gives the user the ability to perform a trial and error procedure at a much faster rate. This means that even if the user fails to obtain the desired orientation of the volume in a certain attempt, attempting again is an easy and quick task to accomplish.

The main suggestions pointed by users to the touch interface were related to possible improvements to the clipping mechanism, through the possibility of receiving visual feedback of the clipping plane while performing it. Also, the need to navigate from the manipulation menu to the clipping menu was pointed out by the users, that would prefer to do both tasks in the same interface, as they did with the spatial interactions.

6.3.1. Study Limitations

A set of comprehensive tests was arranged, making it possible to compare and analyse 4 different types of interaction (WIMP, Touch, Spatial and Gestural) in medical software. Even developing an extended temporal setup of tests that extensively obligated the users to interact and think, during more than an hour, with different interaction techniques, there are still some gaps that need to be covered.

It was possible to cover standard medical tasks performed by users with different background, which offers a bigger variety of data, although there is still the need to test it cooperatively in a surgical planning environment, so that the user performance results can be properly evaluated within a medical context. It is possible to infer from the tasks performed by users can, in fact, achieve the same or better results using novel interaction, and even though the system is capable to perform those same tasks in a collaborative way it lacks the statistical data. The professional feedback obtained from medical staff makes it possible to understand that a collaborative tool like this can add value to the job, as stated in the next chapter. We are still trying to validate the idea in a real use case scenario, to develop better collaborative dynamics within the software.

6.4. Professional Feedback

Along with the user tests and as part of this thesis, Voxel TACS was presented to professionals that depend and/or use this type of tools, including medical staff, in order to obtain professional opinion and feedback on the application and its usefulness in a medical context.

6.4.1. Hospital Professor Dr. Fernando Fonseca

Dr. Vitor Nunes (General Surgery Director of Hospital Professor Doutor Fernando Fonseca) was presented with a real-time demo of the Voxel project conducted by us. He had the opportunity to interact '*in loco'* with the rendering engine used in this project, as well as with some interaction techniques that were developed for this project. This demo was of extreme importance to notice some gaps in the tools used in surgical planning and to understand the valuable addition that this project can be to medical education and collaborative medical review. It was also stressed that this type of interactive systems would upgrade the way medicine is taught, offering a great variety of exemplificative anatomical structures and manipulation that books cannot offer.

- **Surgical Planning**

A strong issue emphasized by Dr. Vitor Nunes was how surgical planning occur in hospitals. Physicians from different specialty fields group around a fixed screen display interacting once at a time with the available images, sharing a mouse and keyboard connected to a workstation. The usage of a tool such as we present in a surgical collaborative environment would be relevant and a synonymous of improvement. There was the possibility to visit a true surgical planning scenario and do a real requirement analysis of how physicians work while preparing for the operatory scenario. During this visit to the planning room, it was possible to understand that the images provided to the physicians were static and limited to what imaging specialist had previously selected. Most of the time surgeons who do not specialize in medical images are often unable to read those images effectively, which may cause inefficiencies during surgery. The ability to interactively explore the images beforehand becomes a valuable tool for surgeons to understand the whole scenario, as well as train interns as part of their education.

During this planning session Dr. Vitor Nunes made some comments and suggestions to what would possible be a major improvement in medical planning practice. A tool like Voxel TACS would definitely had impact in surgical planning and doctor-patient communication, said Dr. Vitor Nunes. Although, it is necessary to find the kind of surgery in which the use of images is constant and relevant during operation. This lead to an invitation for requirement analysis in a real operatory scenario, as explored in the next topic. Interfaces and interactions like this would be vital in pancreas and liver operations, since there is the need to select and isolate specific blood strains from the remaining tissues. After this discussion, the possibility to navigate and annotate through 2D medical images was introduced in the Voxel TACS system, since it is of extreme importance to communicate with medical

staff. We are still in conversations with **HFF** to arrange a real world use case scenario, in order to use and test the developed tool. Dr. Vitor Nunes also stressed out the need and importance for a future technology room in the Hospital where imaging experts, technology technicians and physicians could interact.

- **Operatory Scenario**

In order to understand the dynamics and possible needs during surgical operations, the team was invited to assist a real surgery inside the sterile operatory room. It was a good opportunity to observe real medical interactions and take notes of how the staff works, reads and manages data. This was useful to find possible solutions to simplify technological processes during surgery. The surrounding environment of the operation room makes it possible, due to its ample space, to use projections and sterile touch interfaces. Every data related to the state of the patient, as well as small reports, are registered and inserted in real time by the staff through confusing and obsolete WIMP interfaces during the surgery.

Figure 51 - Requirements analysis in a surgery scenario, at **HFF**.

6.4.2. Egas Moniz Dental Clinic

The visit to the dental clinic, guided by Prof. Dr. Alves de Matos, was a great opportunity to understand how dentists work and the tools that are currently used in this specialty. It was possible to find some important clinic scenarios where the technology developed could have an impact. In specific endodontics scenarios, such as root canal treatment, a navigable 3D volume would be of extreme usefulness to analyze the canal with precision. Also, in dental health measuring lengths and angles, is of extreme importance during surgery planning for implants and endodontics. Once again, oral health doctors work around a fixed workstation with WIMP interfaces when planning surgeries.

Ideas for future work were also debated, which include the possibility to visualize images collaboratively online (for conferences and planning with other doctors). A secure image download feature for doctors and patients to share content (Birr et al. 2011). The development of standard volumetric images for dental studies and to use during appointments with patients to elucidate them.

6.4.3. Hospital Escolar Veterinário - HEV, FMV

Prof. Dr. António Ferreira[18], Clinic Director of HEV and Imaging Specialist, had the time to experiment the Voxel TACS system and compare it with traditional imaging software used in the Hospital. It was discussed the possibility to provide a functional setup in the planning room for vets to interact, explore and give feedback. An interesting proposal made by Dr. António was to arrange a TACS software release installed in the University laboratories with the mobile application made available for download to all the students.

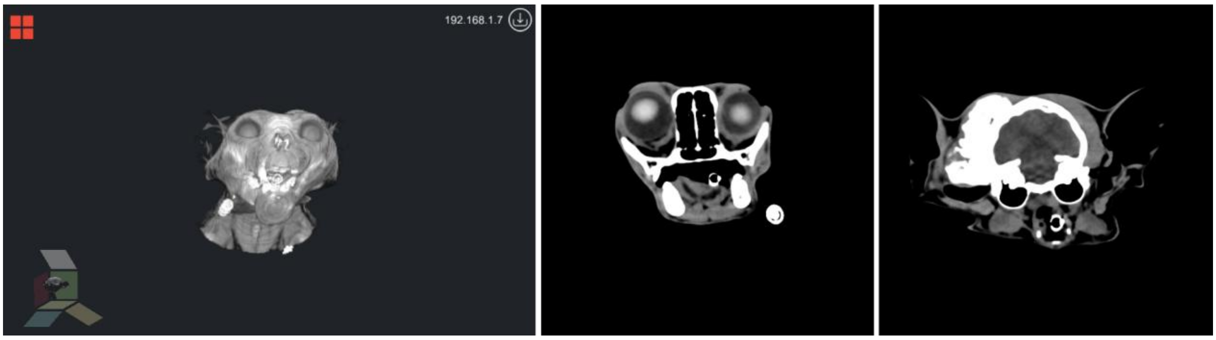


Figure 52 - A volume rendered MRI running on Voxel TIPS, made available by Dr. António Ferreira, and two individual slices from the same 3D volume.

6.4.4. Illustrators

- **Diana Marques**

Feedback received from Diana Marques[19] - notorious illustrator - immediately recognized that the possibility to intuitively and naturally manipulate volumes can stand as an advantage for visualization and creation of medical animations and illustrations. Although some problems emerge in the domain of image access and edition. Currently the system only allows the volumes to be visualized and manipulated, so by itself does not offer the means to create a complete medical illustration. Medical illustration is not usually composed by coloured and real volumetric data, these kind of illustrations tend to transmit more complex scenarios, such as surgical procedures, diseases in anatomical structures, etc.

The current tool can be of extreme importance to create, manipulate and explore 3D images and later export to 3D edition software: Autodesk Maya, Cinema 4D or 3D Studio Max. To add value to the solution the possibility to export *obj*, *stl* or *fbx* files, would be a relevant tool to the pipeline of illustration.

[18] http://hospital.fmv.utl.pt/index.php/hospital/corpoclinico/item/362-antónio-josé-almeida-ferreira
[19] http://www.dianamarques.com/

- **Guida Casella**

Guida Casella[20], recognized scientific illustrator, had the time to participate in a feedback demo session to provide insight about the developed interactions. Guida Casella noticed that this tool was important to isolate tissues and other structures, and coherently follows the same interaction mechanisms used by touch manipulation pads. Guida pointed out that the interface still lacks visual feedback while interacting, which was added after this feedback. It was suggested the use of flashcards, cheat sheets and *'how to's'* to create a product tool. During sketching, and being an illustrator, the layer activation mechanism was referred multiple times, so there is the need to create previews of the volume (thumbnails) to activate or deactivate pre-created views.

[20] https://guidacasella.wordpress.com/

Chapter 7

7. Conclusions

In this document, we presented an exciting interaction design for tangible displays in a possible collaborative tabletop or wall environment. We believe that the proposed novel techniques will improve the naturalness of interaction with 3D volumetric images, especially in medical visualization techniques that play an essential role in current and future healthcare systems.

Interactive tabletops can support 3D virtual model review tasks, although, there are still challenges to address in order to improve interactions around such devices. The setup proposed makes it possible to gather around the tabletop and discuss 3D virtual models while providing each user his own spatial tablet device. A set of new interactions possibilities can emerge from this type of symbiosis. We believe that our solution can enhance the current 3D interaction solutions and promote future research and analysis. The ultimate goal of bringing touch and spatial techniques together is to create a platform that can provide a novel interactive way of exploring 3D medical volumes for students and a robust yet easy to use tool for imaging specialists and surgeons to use before and during surgery. Although there is still the need of intimate collaboration with medical staff to determine the best interaction approaches to upgrade this project.

Voxel TACS has shown to introduce several aspects that result in improvement upon WIMP interfaces, providing an easy to use tool for 3D volume manipulation. It was shown that users prefer Voxel TACS, which takes advantage of a touch and spatial interface, instead of the conventional software that takes advantage of WIMP approaches. Touch interfaces should be the new standard for interaction, and the results obtained are an evidence in terms of productivity. Users' naturalness to interact with touch screens makes it possible for them to improve its interaction skills with machines. The versatility, simplicity and user-friendly interface of this project, opens up a wide range of possible applications in several areas, not all of them limited to medical content. The usage of non-related medical people was important to test singular interaction techniques with 3D data since it provided different feedback from different backgrounds, which is relevant for manipulation and exploration systems. Different users have different experiences and behave differently to different stimulus. Spatial interaction is still a sci-fi theme but will have a huge impact on how people perceive and explore content. The results obtained make us predict that there will come the time where touch interfaces will stand as obsolete as WIMP interfaces. People are great with spatial references and associations and the obtained results in a confined and control environment were astonishing and demonstrate the potential of 3D interactions in space. Nevertheless, the relevance of spatial interfaces in the history of human and machine interaction is still a mirage that step-by-step (study-by-study) can turn into reality.

7.1. Future Work

The work presented leaves room for both improvements and new study subjects. The VIMMI group with IT-MEDEX project is already taking advantage of the developed project to develop new study branches related to neuroscience, radio diagnostic and Virtual Reality for medical image visualization (Edirisinghe & Crossette 2012). The work developed by fellow colleagues produced relevant interaction content to be submitted to important conferences. The results obtained in this project will also be subject to produce pertinent novel interaction data to be submitted. The next stage of this project is to gather relevant medical interaction data to complement the already collected data. The collaborative setup developed needs to be tested and corrected to fulfil the physicians needs during surgical planning.

7.1.1. Improvements

General improvements need to be done in terms of the system interaction having in mind the goal to turn this project, even more, into a viable product. Interface feedback and '*how to use'* tutorials that were out of the scope of this project, even though some were developed, need to be enriched and improved or created from scratch. The sketching tool developed needs to be enhanced in order to support the drawing of smother lines (more *dpi*). It should be possible to adjust dynamically with the tablet interface the settings related to the spatial interaction for each user to be able to it without a technician.

7.1.2. Surgical Scenarios

An important step to take this project to another level is to use it in a real use case scenario. Find a simple surgical case study in which the project can be used throughout all surgical processes. Some limitations pointed in (Mendes et al. 2015) work that limited the experience of surgeons are now solved which makes it possible to create a real world experience. Furthermore, the system created is totally portable which is ideal for real-time demos and to be used the clinicians.

Bibliography

Alexander, N., 2014. *Context-Aware 3D Rendering for User-Centric Pervasive Collaborative Computing Environments*. University of Geneva.

Aziz, S.R. & Ziccardi, V.B., 2009. Telemedicine Using Smartphones for Oral and Maxillofacial Surgery Consultation, Communication, and Treatment Planning. *Journal of Oral and Maxillofacial Surgery*, 67(11), pp.2505–2509. Available at: http://www.ncbi.nlm.nih.gov/pubmed/19837324.

Birr, S., Dachselt, R. & Preim, B., 2011. Mobile Interactive Displays for Medical Visualization. *Data Exploration for Interactive Surfaces (Workshop)*, pp.28–31.

Bowman, D.A. et al., 2011. *3D User Interfaces - Theory and Practice* Addison-Wesley, ed.,

Correa, C.D. et al., 2006. Feature Aligned Volume Manipulation for Illustration and Visualization. *Visualization and Computer Graphics, IEEE Transactions*, 12(5).

Coughlan, T. et al., 2012. The Conceptual Framing, Design and Evaluation of Device Ecologies for Collaborative Activities. *International Journal of Human-Computer Studies*, 70(10), pp.765–779. Available at: http://www.sciencedirect.com/science/article/pii/S1071581912000973.

Dam, A. Van, 1997. Post-WIMP User Interfaces. *Communications of the ACM*, 40(2), pp.63–67.

Dorta, T., Kinayoglu, G. & Hoffmann, M., 2015. Hyve-3D and rethinking the 3D Cursor: Unfolding a Natural Interaction Model for Co-Design in the VR. *SIGGRAPH '15 SIGGRAPH 2015: Studio*, p.2785586.

Edirisinghe, Y. & Crossette, M., 2012. Accuracy of using a tablet device for the use of digital radiology manipulation and measurements. *Journal of Mobile Technology in Medicine*, (2), pp.23–27. Available at: http://www.journalmtm.com/2012/accuracy-of-using-a-tablet-device-for-the-use-of-digital-radiology-manipulation-and-measurements/.

Hachaj, T., 2014. Real time exploration and management of large medical volumetric datasets on small mobile devices—Evaluation of remote volume rendering approach. *International Journal of Information Management*, 34(3), pp.336–343. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0268401213001503.

Hinckley, K. & Goblel, J.C., 1994. A Survey of Design Issues in Spatial Input. *User Interface Software and Technology*, pp.213–222.

Information, H. & Society, M.S., 2012. Everything in medicine is going mobile (HIMSS meeting).

Isenberg, P., Carpendale, S. & Hesselmann, T., 2012. Workshop on Data Exploration for Interactive Surfaces DEXIS 2011. , (May).

John, S. et al., 2012. The iPad Tablet Computer for Mobile On-Call Radiology Diagnosis ? Auditing Discrepancy in CT and MRI Reporting. *Journal of Digital Imaging*, pp.628–634.

Katzakis, N. et al., 2015. INSPECT: extending plane-casting for 6-DOF control. *Human-centric Computing and Information Sciences*, 5(1), p.22. Available at: http://www.hcis-journal.com/content/5/1/22.

Lamberti, F. & Sanna, A., 2005. A solution for displaying medical data models on mobile devices. *Sepads*. Available at: http://www.wseas.us/e-library/conferences/2005salzburg/papers/492-354.pdf.

Lamberti, F. & Sanna, A., 2007. A streaming-based solution for remote visualization of 3D graphics on mobile devices. *IEEE transactions on visualization and computer graphics*, 13(2), pp.247–60. Available at: http://www.ncbi.nlm.nih.gov/pubmed/17218742.

Larrosa, F.. et al., 2013. Rhinoplasty planning with an iPhone app: Analysis of otolaryngologists response. *European Archives of Oto-Rhino-Laryngology*, 270(9), pp.2473–2477. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84881311096&partnerID=40&md5=44d529617aba53bcf8fe765605a907d1.

Malik, S. & Laszlo, J., 2004. Visual touchpad: a two-handed gestural input device. *Hand The*, pp.289–296. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.64.4689&rep=rep1&type=pdf.

Marquardt, N. et al., 2011. The continuous interaction space: Interaction techniques unifying touch and gesture on and above a digital surface. *Proceedings of the 13th IFIP TC 13 International Conference on Human-Computer Interaction*, pp.461–476. Available at: http://link.springer.com/10.1007/978-3-642-23765-2_32.

McGrath, W. et al., 2012. Branch-explore-merge. *Proceedings of the 2012 ACM international conference on Interactive tabletops and surfaces - ITS '12*, p.235. Available at: http://dl.acm.org/citation.cfm?id=2396673\nhttp://dl.acm.org/citation.cfm?doid=2396636.2396673.

Mendes, A., Jorge, J. & Lopes, D., 2015. *Transfer Function Design for Three-Dimensional Medical Images Using Sketches Biomedical Engineering October 2015*.

Mendes, D., Sousa, M., et al., 2013. Collaborative 3D Visualization on Large Screen Displays. *POWERWALL: International Workshop on Interactive, Ultra-High-Resolution Displays, Part of the SIGCHI Conference on Human Factors in Computing Systems*, pp.1–6.

Mendes, D., Ferreira, A. & Jorge, J., 2013. Envisioning Multi-Surface Collaborative Review of 3D Virtual Models. *CmIS Workshop*. Available at: https://615cca70-a-62cb3a1a-s-sites.googlegroups.com/site/oilcedar/file-cabinet/CmIS_Envisioning_Multi_Surface_Collaborative_Review_of_3D_Virtual_Models.pdf.

Meng, Q. & Heng, P., 2011. WYSIWYF : Exploring and Annotating Volume Data with a Tangible Handheld Device. *Small*, D, pp.1333–1342. Available at:

http://doi.acm.org/10.1145/1978942.1979140.

Nielsen, J., 1994. *Usability engineering*, Elsevier.

O'Neill, K. et al., 2013. Applying surgical apps: Smartphone and tablet apps prove useful in clinical practice. *Bull Am Coll Surg*, 98(11), pp.10–18.

Parreira, P., Mendes, A., et al., 2015. Design de Funções Transferência para Imagens Médicas 3D recorrendo a uma Interface baseada em Esboços. *SciTecIN'15*.

Parreira, P., Jorge, J. & Lopes, D., 2015. Novel Spatial Interaction Techniques for Exploring 3D Medical Images Biomedical Engineering October 2015. , (October).

Pasha, M.F. et al., 2012. An Android-based Mobile Medical Image Viewer and Collaborative Annotation: Development Issues and Challenges. *International Journal of Digital Content Technology and its Applications*, 6(1), pp.208–217.

Piazza, T. et al., 2013. Holy smartphones and tablets, Batman! *Proceedings of the 11th Asia Pacific Conference on Computer Human Interaction - APCHI '13*, (Table 1), pp.63–72. Available at: http://dl.acm.org/citation.cfm?id=2525194.2525205.

Ponto, K. et al., 2011. CGLXTouch: A multi-user multi-touch approach for ultra-high-resolution collaborative workspaces. *Future Generation Computer Systems*, 27(6), pp.649–656. Available at: http://www.sciencedirect.com/science/article/pii/S0167739X10002463.

Rateau, H., Grisoni, L. & Araujo, B. De, 2014. Exploring Tablet Surrounding Interaction Spaces For Medical Imaging. *Proceedings of the 2nd ACM symposium on Spatial user interaction*, pp.150–150.

Ritter, F. et al., 2015. Combining Mobile Devices and Workstations for the Reading of Medical Images. *H. Reiterer, & O. Deussen (Eds.), Mensch & Computer Workshopband*, (SEPTEMBER 2012), pp.231–240.

Scott, S., 2014. Cross-device transfer in a collaborative multi-surface environment without user identification. *Ieee*, pp.219–226.

Scott, S., Grant, K. & Mandryk, R., 2003. System guidelines for co-located, collaborative work on a tabletop display. *Ecscw 2003*, (5), pp.1–20. Available at: http://link.springer.com/chapter/10.1007/978-94-010-0068-0_9.

Scott, S., Sheelagh, C. & Inkpen, K., 2004. Territoriality in collaborative tabletop workspaces. *Proceedings of the 2004 ACM conference on Computer supported cooperative work - CSCW '04*, pp.294–303. Available at: http://dl.acm.org/citation.cfm?id=1031655.

Seyed, T. et al., 2014a. Medical Imaging Specialists and 3D: A Domain Perspective on Mobile 3D Interactions. *Chi 2014*, pp.2341–2346.

Seyed, T. et al., 2014b. Poster: Exploring 3D volumetric medical data using mobile devices. *2014 IEEE*

Symposium on 3D User Interfaces (3DUI), pp.173–174. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6798876.

Seyed, T. & Sousa, M.C., 2013. SkyHunter: a multi-surface environment for supporting oil and gas exploration. *Proc. ITS*, pp.15–22. Available at: http://dl.acm.org/citation.cfm?id=2512798.

Sharma, R., Pavlovic, V.I. & Huang, T.S., 1998. Toward multimodal human-computer interface. *Proceedings of the IEEE*, 86(5), pp.853–869. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=664275.

Souza, M. De et al., 2010. Using acceleration data from smartphones to interact with 3D medical data. *Graphics, Patterns and Images (SIBGRAPI), 2010 23rd SIBGRAPI Conference*.

Spindler, M. et al., 2014. Tangible displays for the masses: Spatial interaction with handheld displays by using consumer depth cameras. *Personal and Ubiquitous Computing*, 18(5), pp.1213–1225.

Spindler, M., Stellmach, S. & Dachselt, R., 2009. PaperLens: Advanced magic lens interaction above the tabletop. *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*, pp.69–76. Available at: http://doi.acm.org/10.1145/1731903.1731920\nhttp://portal.acm.org/citation.cfm?doid=1731903.1731920.

Subramanian, S. & Ijsselsteijn, W., 2000. Survey and Classification of Spatial Object Manipulation Techniques. *Proceedings of OZCHI 2000*, pp.330–337.

Székely, A., Talanow, R. & Bágyi, P., 2013. Smartphones , tablets and mobile applications for radiology. *European Journal of Radiology*, 82(5), pp.829–836. Available at: http://dx.doi.org/10.1016/j.ejrad.2012.11.034.

Tang, A. et al., 2006. Collaborative coupling over tabletop displays. *Proceedings of the SIGCHI conference on Human Factors in computing systems - CHI '06*, p.1181. Available at: http://portal.acm.org/citation.cfm?doid=1124772.1124950.

Tang, A. & Irani, P., 2011. Interstitial Space in MDEs for Data Analysis. *Data Exploration for Interactive Surfaces (Workshop)*, pp.9–11.

Ward, J.P.T. et al., 2001. Communication and information technology in medical education. , 357, pp.792–796.

Yang, X. et al., 2010. LensMouse. *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, p.2431. Available at: http://portal.acm.org/citation.cfm?doid=1753326.1753695.

Appendixes

Appendix A – User Tests Guidelines

Guia de Testes de Utilizador

Em cada sessão de testes a ordem dos sistemas onde executar as tarefas é alternada, de forma a não existir influência nos resultados. As 10 tarefas (Parte 1 e parte 2) são realizadas para todos os sistemas em teste, pela mesma ordem. São utilizados dois volumes em cada plataforma, sendo o o primeiro volume utilizado para interagir um volume para tarefas de treino e habituação.

Perfil de Utilizador Survey - Appendix C

No início de cada sessão de testes cada utilizador é informado sobre o conjunto de sistemas que vai testar, bem como o propósito dos testes e do estudo a realizar. Seguidamente preenche o User Profile Survey , disponibilizado no Appendix C.

Teste de Sistema - Appendix D

Para cada sistema testado [VolView, Voxel Explorer e TACS (Spatial e Touch)] o utilizador é a sujeito a um:

1. **Período de habituação:** Explicação do ambiente de trabalho, ferramentas e controlos. É pedido ao utilizador para interagir com o volume de teste realizando algumas operações sobre o mesmo.

2. **Período de testes:** É efectuado o pacote de testes desenvolvido para estudar o sistema, constuído por duas partes:

   - **Parte Um**: O utilizador realiza 5 tarefas que envolvem respectivamente:

     • Translação; • Rotação; • Translacção e rotação (2); • Translação, rotação e scaling.

   - **Parte Dois**: O utilizador realiza 5 tarefas que envolvem respectivamente: • Corte vertical; • Corte horizontal; • Corte vertical, rotação e translação; • Corte horizontal, rotação e translação; • Corte horizontal, rotação e translação e scaling.

3. **Preenchimento de questionário:** No fim de cada sessão de testes de um sistema, é preenchido um questionário para avaliar o sistema em teste. O questionário é disponibilizado no Appendix D.

Nota: *Foi estabelecido um limite máximo de 1 minuto por tarefa, sendo o conjunto de testes constituido por 10 tarefas a realizar por cada sistem (4) estabelece um máximo de 40 minutos para a realização das tarefas de teste. Este tempo não incluí explicações, tempo de habituação nem preenchimento de questionários.*

Estudo Comparativo - Appendix E

No final da sessão de testes, depois do utilizador ter realizado as mesmas tarefas em todos os sistemas, é pedido para preencher um questionário final que serve como estudo de comparação, disponível no Appendix E.

Appendix B – Related Work: Comparison Table

Reference	Md	NT	Mobile				Collaborative				Spatial				Interface			
			Ct	Cn	Rd	Ac	St	Tb	Sp	Tbt	W	K	SDC	Mb	SA	SB	2D	3D
(Aziz & Ziccardi 2009)	×	×		×			×		×								×	
(Birr et al. 2011)	×			×				×	×	×				×				×
(Coughlan et al. 2012)				×			×	×	×	×	×						×	×
(Dorta et al. 2015)			×	×	×			×	×		×		×	×	×		×	×
(Edirisinghe & Crossette 2012)	×			×	×			×									×	×
(Hachaj 2014)	×			×			×	×	×								×	
(John et al. 2012)	×			×			×										×	
(Lamberti & Sanna 2005)	×			×			×										×	
(Lamberti & Sanna 2007)				×			×										×	
(Larrosa et al. 2013)	×			×													×	
(Malik & Laszlo 2004)			×	×														×
(McGrath et al. 2012)				×				×		×							×	×
(Mendes, Sousa, et al. 2013)			×	×				×			×	×			×		×	×
(Meng & Heng 2011)	×		×	×		×								×			×	×
(Parreira, Mendes, et al. 2015)	×									×						×	×	×
(Pasha et al. 2012)	×			×	×			×	×								×	
(Piazza et al. 2013)			×	×				×	×	×						×	×	×
(Ponto et al. 2011)			×	×			×	×	×	×	×					×	×	×
(Ritter et al. 2015)	×		×	×				×									×	
(Seyed et al. 2014a)	×		×			×								×			×	×
(Seyed & Sousa 2013)			×	×				×		×		×					×	×
(Souza et al. 2010)	×	×		×		×								×			×	
(Spindler et al. 2014)				×				×	×	×		×		×	×			×
(Székely,Talanow,and Bágyi 2013)	×				×												×	

Subtitle:
Md – Medical;
NT – Not touch;
Ct – Controller; **Cn** – Connectivity; **Rd** – Rendering; **Ac** - Accelerometer; **St** – Stream;
Tb – Tablet; **Sp** – Smartphone; **Tbt** – Tabletop; **W** - Wall;
K – Kinect; **SDC** – Sensor-depth Cameras; **Mb** – Mobile; **SA** – Spatially Aware;
SB – Sketch-Based;

Appendix C – User Profile Survey

Perfil de Utilizador

Os testes de utilizador realizam-se no âmbito da tese de mestrado: Interactive Tablets for 3D Image Colaborative Exploration. Estará a interagir com ferramentas de visualização de imagens médicas, não sendo contudo necessários conhecimentos de anatomia.
O objectivo destes testes centram-se na análise e percepção do ponto de vista do utilizador, no que diz respeito à utilização de software para interacções 2D em espaços de visualização 3D, bem como interacções 3D em espaços de visualização 3D.
As respostas a este questionário são anónimas.

*Obrigatório

Informação Pessoal

Sexo: *

- ○ Feminino
- ○ Masculino

Idade: *

- ○ 18 - 24
- ○ 25 - 35
- ○ 36 - 50
- ○ > 50

Habilitações Académicas: *

- ○ Secundário
- ○ Licenciatura
- ○ Mestrado
- ○ Outro: ________

Conhecimentos Tecnológicos

Tem smartphone ou tablet? *

- ○ Sim
- ○ Não

Tem facilidade em utilizar aplicações de software através de ecrãs tácteis? *

	1	2	3	4	
Nenhuma	○	○	○	○	Muita

Já tirou proveito do acelerómetro ou giroscópio do seu smartphone para interacções espaciais? *
(Ex: Jogos, Visualização 3D, etc)

- ○ Sim
- ○ Não

Já utilizou sistemas de detecção de movimento ou gestos? *
(Ex: Wii Remote, PS Move; Xbox Kinect, etc)

- ○ Sim
- ○ Não

Com que frequência utiliza sistemas de detecção de gestos ou movimentos? *

- ○ Casualmente
- ○ Mensalmente
- ○ Semanalmente
- ○ Diariamente

Como classifica o seu nível de conhecimento (ao nível de itneracção) com sistemas de visualização e exploração de imagens 3D ou modelação 3D? *
(Ex: OsiriX, Volview, Maya, Blender, ZBrush, etc)

	1	2	3	4	
Nenhum Conhecimento	○	○	○	○	Total Conhecimento

Appendix D – System Survey

System Survey

Questionário

*Obrigatório

Transformações Geométricas

Qual a dificuldade sentida ao fazer a translação do volume? *

	1	2	3	4	
Muito Fácil	○	○	○	○	Muito Difícil

Qual a dificuldade sentida ao fazer a rotação dos volumes? *

	1	2	3	4	
Muito Fácil	○	○	○	○	Muito Difícil

Qual a dificuldade sentida ao fazer scaling dos volumes? *

	1	2	3	4	
Muito Fácil	○	○	○	○	Muito Difícil

Qual o nível de dificuldade que atribuiria à combinação de controlos? *

	1	2	3	4	
Muito Fácil	○	○	○	○	Muito Difícil

Funcionalidades

Qual a dificuldade que sentiu ao realizar as seguintes tarefas: *

	Muito Fácil	Fácil	Difícil	Muito Difícil
Selecção do plano de corte	○	○	○	○
Manipulação do plano de corte	○	○	○	○

GUI - Graphics User Interface

O que sente em relação à quantidade de botões na interface? *

	1	2	3	4	
Simplicista	○	○	○	○	Complicado

O que sente em relação à disposição e utilização dos menus? *

	1	2	3	4	
Fácil de utilizar	○	○	○	○	Difícil de utilizar

Considera a combinação de controlos/botões/movimentos para atingir o resultado pretendido tedioso ou desnecessário? *

○ Sim

○ Não

Geral

Sentiu-se confortável a interagir com o volume? *
(i.e sem grande fatiga/esforço fisico ou mental)

	1	2	3	4	
Nada Cansativo	○	○	○	○	Muito Cansativo

Sentiu-se frustrado ao tentar atingir as tarefas propostas? *

○ Sim

○ Não

Quais foram as tuas maiores dificuldades ao utilizar o programa? *

Sua resposta

Appendix E – Final Survey

Estudo Comparativo

Seleccione uma ou mais opções, de acordo com as suas preferências.

*Obrigatório

Que controlo(s) prefere ao manipular a posição, orientação e dimensão do volume? *

- [ ] Periféricos (Rato + Teclado)
- [ ] Gestual
- [ ] Toque
- [ ] Espacial

Que controlo(s) prefere ao manipular os planos de corte sobre o volume? *

- [ ] Periféricos (Rato + Teclado)
- [ ] Gestual
- [ ] Toque
- [ ] Espacial

Num balanço geral qual o sistema(s) que teria preferência de interacção regular para realizar as tarefas propostas? *

- [ ] Periféricos (Rato + Teclado)
- [ ] Gestual
- [ ] Toque
- [ ] Espacial

Em qual dos sistemas sentiu uma maior naturalidade de interacção? *
(i.e movimentos realizados e resposta do sistema)

- [ ] Periféricos (Rato + Teclado)
- [ ] Gestual
- [ ] Toque
- [ ] Espacial

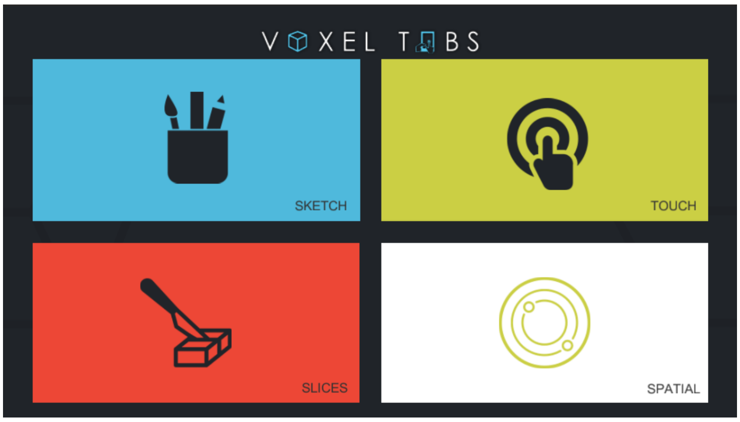
Qual dos sistemas lhe ofereceu maior confiança e à vontade para explorar e alcançar as tarefas pretendidas? *

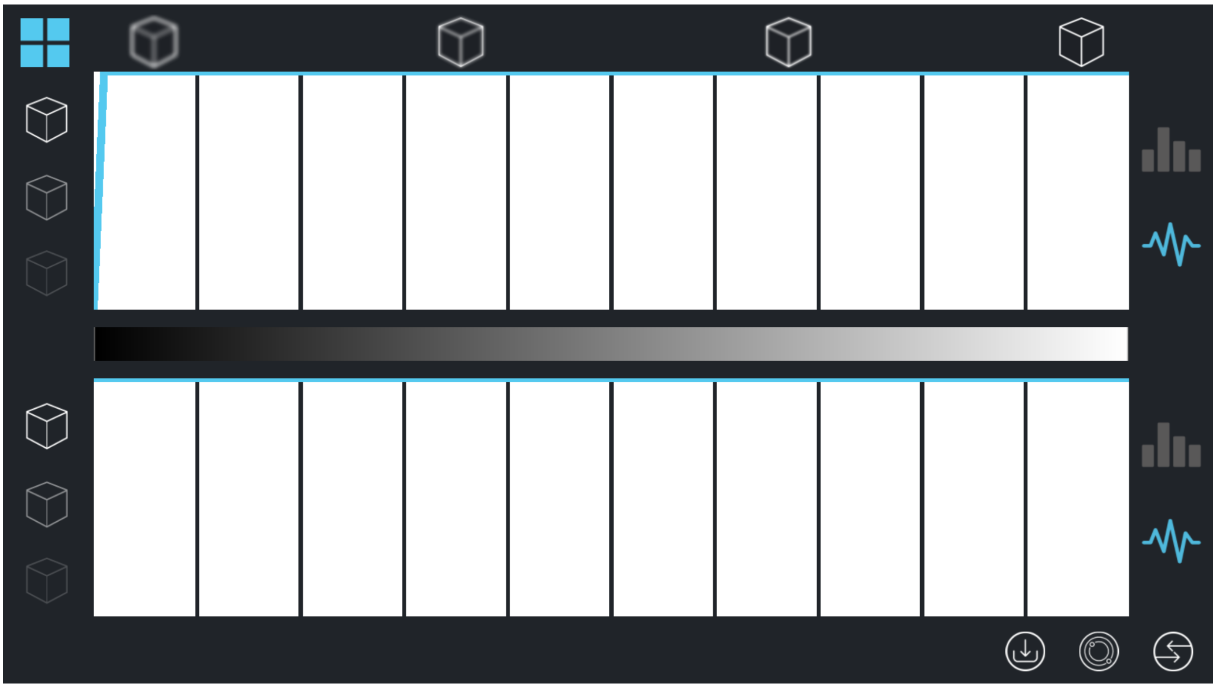
- [ ] Periféricos (Rato + Teclado)
- [ ] Gestual
- [ ] Toque
- [ ] Espacial

Achou que a utilização do tablet para a realização das tarefas é significativamente mais fatigante que a utilização de periféricos? *

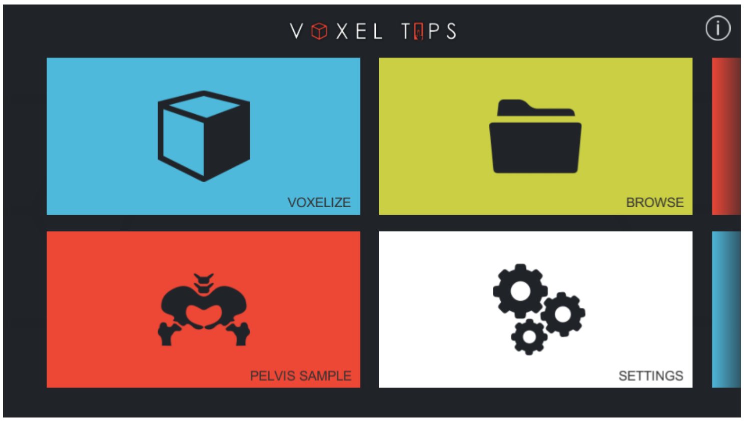
- ○ Sim
- ○ Não

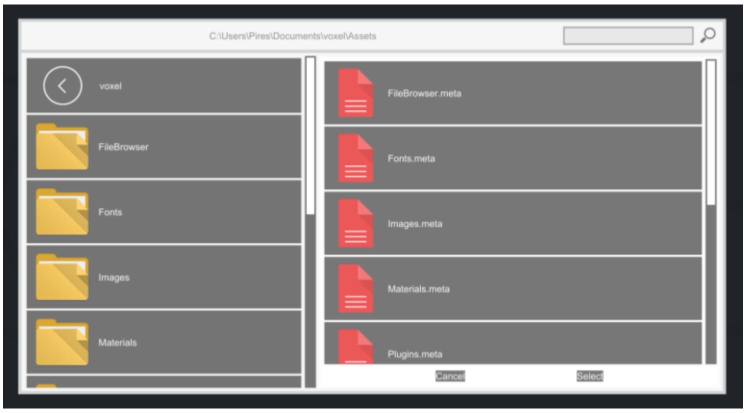
Appendix F – Voxel TACS Functionalities

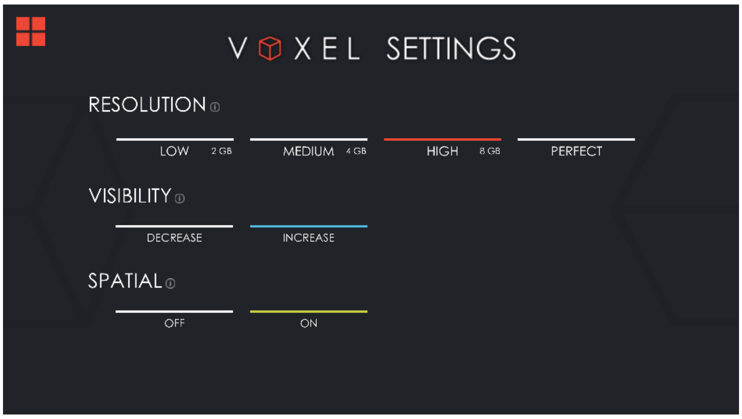


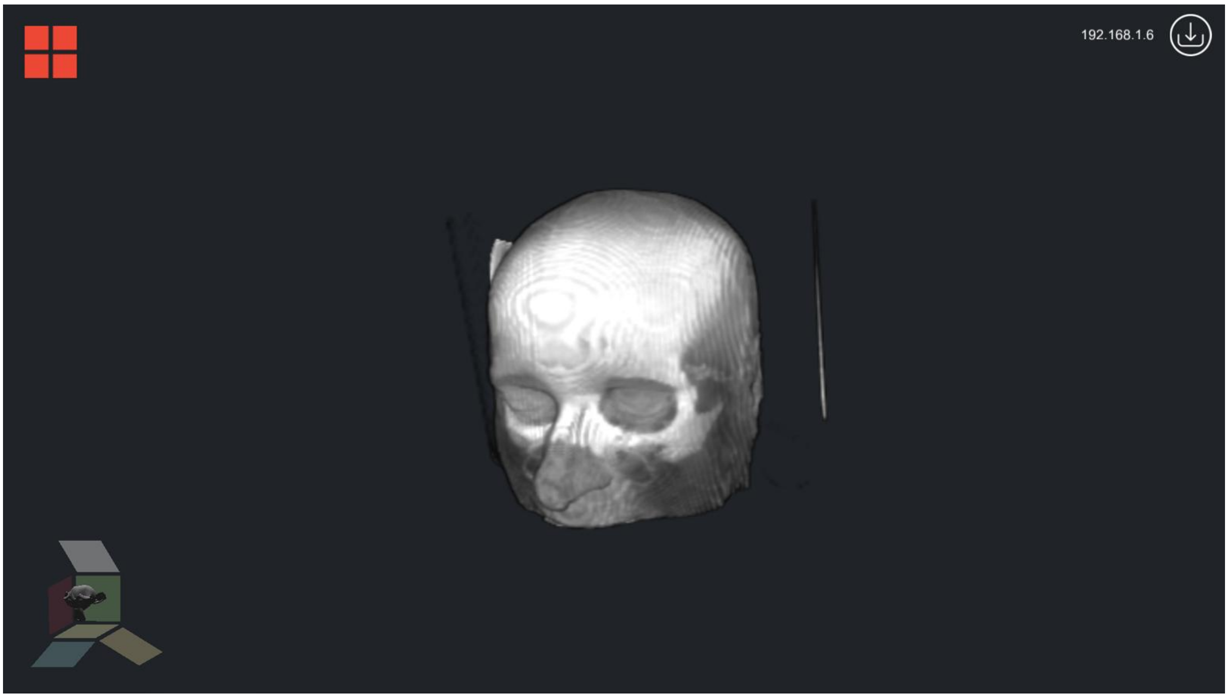


Appendix G – Voxel TIPS Functionalities









Appendix H – Authorization forms

DECLARAÇÃO DE CEDÊNCIA DE IMAGEM

PROJECTO IT-MEDEX

Eu, ____,

Portador(a) do Bilhete de Identidade/Cartão de Identificação n.º__________ do arquivo de identificação de __________, emitido a __/__/___, com o NIF n.º ________________, aceito participar voluntariamente em gravações (fotográficas e/ou vídeo) do projecto IT-MEDEX, gerido por Vasco Pires, e declaro ter tomado conhecimento e estar de acordo com as seguintes condições de participação:

1. No quadro da legislação em vigor e sem prejuízo do meu direito à honra, intimidade e imagem própria, autorizo expressamente a cedência integral e a título gratuito dos direitos referentes à minha imagem, relativos à participação no projecto IT-MEDEX, para os fins a que a mesma se destina;
2. Mais autorizo que seja esta cedência outorgada à equipa do projecto IT-MEDEX, bem como ao grupo VIMMI e demais entidades parceiras;
3. Estou ciente de que o projecto IT-MEDEX poderá produzir conteúdos de referência bibliográfica (artigos, posters, etc.) a serem enviados para conferências nacionais e/ou internacionais, para o que a cedência dos direitos à minha imagem são extensíveis às ações de divulgação e promoção que venham a revelar-se necessárias, nos suportes escolhidos para o efeito.
4. Mais declaro não me ser devida, a nenhum título, qualquer remuneração ou compensação por esta cedência.

Data: ___ de ______________ de 2016

Projecto financiado por:

Declaração de consentimento informado para recolha de dados

Designação do Estudo: IT-MEDEX – projecto FCT (PTDC/EEI-SII/6038/2014)

Eu, abaixo-assinado:

- Fui informado de que o Estudo de Investigação acima mencionado se destina a investigar as actuais práticas e lacunas em medicina e ilustração científica, no que diz respeito à visualização e exploração de imagens 3D;

- Aceito participar de livre vontade no estudo acima mencionado. Concordo que sejam recolhidos dados para o sistema a testar e autorizo o seu tratamento estatístico. Para tal, autorizo a recolha dos meus dados pessoais (nome, email);

- Foi-me garantido que todos os dados relativos à identificação dos Participantes neste estudo são confidenciais e que será mantido o anonimato;

- Sei que posso recusar-me a participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto;

- Também autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato;

- Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Nome do participante:____.

Email do participante:____.

Nome do Investigador: [ou do seu representante legal, se for o caso].

Data ___/___/_____

Assinatura ______________________________________