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DM

A multimodal Tablet-Based Interface for Designing and
Reviewing 3D Engineering Models

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MASTER DISSERTATION

Duarte Paulo Ferreira Gouveia

MASTER IN INFORMATICS ENGINEERING


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ABSTRACT

The ability to view and interact with 3D models has been happening for a long time. However, vision-based 3D modeling has only seen limited success in applications, as it faces many technical challenges.

Hand-held mobile devices have changed the way we interact with virtual reality environments. Their high mobility and technical features, such as inertial sensors, cameras and fast processors, are especially attractive for advancing the state of the art in virtual reality systems. Also, their ubiquity and fast Internet connection open a path to distributed and collaborative development. However, such path has not been fully explored in many domains. VR systems for real world engineering contexts are still difficult to use, especially when geographically dispersed engineering teams need to collaboratively visualize and review 3D CAD models. Another challenge is the ability to rendering these environments at the required interactive rates and with high fidelity.

In this document it is presented a virtual reality system mobile for visualization, navigation and reviewing large scale 3D CAD models, held under the CEDAR (Collaborative Engineering Design and Review) project. It's focused on interaction using different navigation modes. The system uses the mobile device's inertial sensors and camera to allow users to navigate through large scale models.

IT professionals, architects, civil engineers and oil industry experts were involved in a qualitative assessment of the CEDAR system, in the form of direct user interaction with the prototypes and audio-recorded interviews about the prototypes. The lessons learned are valuable and are presented on this document.

Subsequently it was prepared a quantitative study on the different navigation modes to analyze the best mode to use it in a given situation.

KEYWORDS

Multimodal interfaces, motion-based input, multitouch user interfaces, hand-held devices, CAD, collaborative interfaces, navigation modes.

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1. INTRODUCTION

1.1 Context

In the oil & gas industry everything is done in large scale and using advanced technology. The project of a new production unit, for example, is a very lengthy and expensive process and depends sometimes on the availability of an adequate technology. Due to their large complexity, this kind of projects involves not only geographically distributed teams but also teams of specialists in different areas using different software tools [17].

Virtual reality and multimodal user interfaces have revolutionized the way we work by combining different input modalities [3]. On the other hand, multitouch technology has become mainstream and tablet-based multitouch has emerged as a mobile interaction style standard, especially due to the success of products such as the iPad. Despite these significant advances, most of the interactive technologies deployed in real world design and engineering contexts are still regarded as being difficult to use, especially when engineering teams need to collaboratively visualize and review large scale 3D CAD (Three Dimensional Computer-Aided Design) models. This is the scenario of the oil industry, which necessarily involves large teams that review, manipulate and discuss around large CAD models, which are sometimes difficult to visualize and navigate through.

In this document, it is analyzed how the manipulation of CAD models can significantly benefit from the so-called natural interaction techniques [10]. More specifically we hypothesize that multitouch and inertial sensors-enabled tablets can be very useful for engineering teams that are interested in design and review tasks. We present a novel VR (Virtual Reality) system interface designed to support those tasks in a context using mobile devices (e.g. one engineer uses different navigation modes to analyse a 3D model oil & gas platform).

1.2 Goals

Despite many significant advances, most of the VR tools deployed in real world design and engineering contexts are still regarded as being difficult to use, especially when engineering teams need to collaboratively visualize and review large scale 3D CAD (Computer-Aided Design) models. This is precisely what happens with the oil platform industry, which necessarily involves large teams that review, manipulate and discuss around large CAD models, which are sometimes difficult to visualize and navigate through. This document presents some arguments that show that the manipulation of CAD models can benefit significantly from the so-called natural interaction techniques [2].

The goal of this thesis is to study and to make tests with navigation through complex 3D CAD models using accelerometer based approaches versus touch gestures based approaches.

More specifically, we present a new mobile-based system that employs multitouch and accelerometer inputs. This tablet-based solution can be useful for engineering teams that are interested in design and review tasks. This new VR multimodal interface was designed to support those tasks in a mobile context of usage (e.g. one engineer at the offshore oil platform, another engineer at the central office in the mainland). The system allows the navigation, reviewing and annotation of 3D CAD models in a mobile, collaborative context, coupling a fast OpenGL-based framework with an efficient communication protocol.

There are two variants of the CEDAR mobile user interface: multitouch-only and multitouch coupled with accelerometer-based input. The multitouch-only user interface uses two “joysticks”, which are used to navigate through the 3D platform. The left button is used to control the displacement along the Z-axis (i.e., moving forward or backwards), the right button is used to simultaneously control the X and Y position of the camera (i.e. where the user is looking at). In the second version, were added accelerometer-based input capabilities, so that users can make navigation by simply tilt the tablet device left/right or up/down in order to control where they are looking at.

1.3 Contribution

This dissertation presents a study about navigation in virtual reality, utilizing 3D CAD models to effectuate design review. We adopted a technology used in the industry of games to perform this navigation in complex 3D models.

Recent progresses in mobile devices (tablets), specifically iPads and their multimodal capacities were taken advantage of, because the advantage of multiple input modalities contributes for increased usability: the weakness of one modality is offset by the strengths of another.

Multimodal input user interfaces have implications for accessibility. A well-designed multimodal application can be used by people with a wide variety of impairments. A prototype for support of navigation in complex 3D CAD environment was implemented. Three modes of navigation were implemented, although the focus of this study and the tests that were executed were directed only for two modes of navigation (multitouch-only and multitouch coupled with accelerometer-based input), due to the fact that the first mode, based only in multitouch technology is already utilized in other systems for a longer time. In the qualitative tests that were done with the users, the conclusion was that there wasn't a better mode than the other, and what mattered was the goals of navigation and the location of the user as sometimes the utilization of the navigation mode with multitouch coupled with accelerometer-based input, cannot be done if the user is in a limited space.

These modes of navigation that were studied create a base for future jobs that involve tasks of 3D CAD design review utilizing multimodal systems.

1.4 Summary

This document describes an experience with the creation of a prototype for navigating and reviewing 3D engineering models, applied to the Oil & Gas industry. Task analysis and storyboards were produced, designed and evaluated to a prototype that combines the power of mobility brought by tablets with a new navigation mode that employs every sensor present in the tablet to deliver a better experience.

This experiment was conducted with, architects, civil engineers and professional of the Oil & Gas industry, targeting a qualitative assessment made by the experts and later a qualitative evaluation to demonstrate which mode is the most appropriate at a given moment for a given situation. Lessons learned are valuable, both in terms of performance and experience design, issues that necessarily arise when creating new collaborative virtual reality systems.

This document is organized in the following way: First, the review of state of the art in four different aspects: (i) CAD tools and environments for visualization, (ii) 3D navigation design and review, (iii) different aspects of collaboration tools and (iv) the usage of small screens and inertial sensors on virtual reality environments. Secondly, we present a mobile user interface specifically conceived through close collaboration with researchers and practitioners at a large oil company. In the fourth chapter we describe the results from a user study where was performed a qualitative and quantitative study using several interaction models, all of them based on touchscreen and/or inertial devices. And finally, the results and conclusions describe some of the lessons learned and outline novel research avenues for the near future.

2. RELATED WORK

2.1 3D CAD Tools and environments for visualization

These days, modern information technology tends to increase the complexity of artifacts, whether they are small or huge systems like industrial plants or traffic control systems. The new digital technology is better prepared to deal with this complexity than the older technologies. And one of the major factors is the increase of connectivity. Small and isolated artifacts are getting aggregated and integrated into larger artifacts with the contribution of modern communication and sensor technology [18]. But these technological advances that allow us to increasingly resolve the problems that we face, are contributing also to an increase of complexity [19].

The total experience of interacting with a digital artifact depends on a complex combination of conditions, having to do with functionality, performance, appearance and more [20].

They [20] propose a notion of benign complexity, where a distinguish number of higher-level strategies for dealing specifically with complexity is made. They propose and identify five strategies for dealing with complex interaction: (1) eliminate unnecessary complexity; (2) make it simple by sacrificing (quality of) function; (3) hide complexity; (4) confine complexity; (5) dilute complexity.

Modern information technology tends to increase the complexity of artifacts, whether they are small, portable devices or big systems like factories plants or Oil&Gas industry plats. Reduce complexity is something that the new digital technology can deliver that older technologies could not. A contributing factor is the increased connectivity. Tools for the creation and modification of complex models have become incredibly sophisticated and powerful.

With the growing number of users who need to use solutions for 3D navigation to perform certain functions associated to 3D design plans, for example, design and review. Many users reject 3D tools because their initial interaction with the tool, resulting in non-productive or enjoyable experience. Making 3D navigation can be very difficult to learn, resulting in many rejecting 3D tools [21]. These studies describe the major properties needed for safe navigation and propose solutions to improve the learning experience for users that are new to 3D. According with [21], these properties are divided in seven categories: (1) cluster and cache tools; (2) create task and skill-based tool sets; (3) provide orientation awareness; (4) enhance tool feedback; (5) offer pre-canned navigation; (6) prevent errors; and (7) recover from errors. Many existing navigation tools offer some of these properties, and it is important to realize the need to provide all of these properties to achieve a productive rewarding navigation experience.

Recent studies focused on the impact that CAD tools may have on creative problem solving for engineering such as in [12]. From a wide variety of available tools in the market, the Autodesk Revit Architecture [22] - designed under the concept of building information model (BIM - Building Information Modeling). This tool allows the user design in both 2D and 3D modes. The database includes all project information along the various stages of the construction cycle. It's considered a 4D CAD tool, because it uses time as the 4th dimension. Another tool is Autodesk 360 Mobile [22]. This lets the user view and record what is being made by the team over time and subsequently share these changes that are being made by the team, increasing the collaboration. CadFaster [23] is a tool developed to increase collaboration, productivity and effectiveness for Architectures, Engineering and construction (AEC), mechanical and plant design. In addition firms are seeking fast reading and smooth handling of complex and large CAD data files. This tool has the ability to allow distribution, annotation, and real-time co-viewing of diverse 3D designs. CATIA Version 6 – V5 [24] is another tool with options to take maximum advantage of the collaborative potential between mixed teams. These two solutions (Autodesk Design Review, CadFaster) were designed to operate in multimodal user interfaces, under IOS (iPad) on professional work environments.

In the world of 3D CAD data, the interoperability issues are universal: every respondent dealt with different file types; most used some type of collaboration tools. And a world-class organization needs people to be able to collaborate and communicate effectively across the globe. They certainly can't do that if they can't share project data.

There are some solutions in the market like, CADdoctor [25] that includes expanded capabilities for data translation end-to-end throughout product development to promote process automation, reduce design and manufacturing times and improve product data quality. As computer-aided design (CAD), engineering (CAE), and manufacturing tools (CAM) have become more complex, the drive to seamlessly share data between them has grown stronger.

There are a lot of challenges to sharing this 3D data because these tools have differing data input requirements. Some, like CAD, need extraordinary detail. Others, like CAE analysis tools, need very specific levels of simplicity. CAM systems have exacting surfacing and manufacturability constraints. One example of how such technology is becoming limited involves the use of a software "translator" to meet complex interoperability needs. There are some solutions like the Anark Core [26], adds product restructuring capabilities, expanded PDM server integration, and support for another property tools in the market. In conclusion, applications transform native 3D CAD data for use throughout manufacturing design, engineering and support departments.

Several tools and research prototypes have been developed with the goal of improving the visualization, manipulation of 3D CAD models. It's the case of Giga-Walk [1, 15], academic solutions. This system was implemented to deal with large data sets generated representing power plants, ships, Oil&Gas industry plants. The biggest challenge here is rendering these

environments at the required interactive rates and with high fidelity. This is because there are many complex issues with respect to the design and performance of systems for interactive display of complex environments.

More recently augmented reality applications for industrial building acceptance have begun to develop [14]. Because in these last years, industrial applications at large-maintenance assembly, construction, service, repair, training, factory planning have received a lot of attention by researchers and technology enterprises. On the other hand, they [27] propose the use of a lightweight flexible display to manipulate the shape of a desired volume. This work uses a video projector and a movable projection screen to create a system to allow a user to view virtual objects, closely and naturally without any special knowledge about the equipment.

Virtual reality and multimodal user interfaces have revolutionized the way we work by combining different input modalities [3]. Surveys have shown good support for enhanced visualization and communication, circumscribed thinking - when the designer's ideas are circumscribed by the CAD tool's abilities - and for premature design fixation (premature commitment to a given design solution). These new capabilities (virtual reality and multimodal) allow conjugation with the use of computer gaming elements to interact with the designs and products by the users [16]. This kind of navigation and action allow players to move through the environment and interact with the virtual world. The users are evaluating while having an engaging experience.

2.2 3D navigation, manipulation, design and review

The use of 3D models is prolific, ranging from industrial design to scientific visualization. Navigation is one of the elementary tasks of 3D virtual environment. However, such a camera movement is not trivial and standard tools do not provide an efficient and unique tool for such task. Several studies have been developed, such, [28] in which these start using motion instead of static images as the basis of composing a conducting review, where the static views were replaced with moving "shots". Other study [29], where it was studied that controlling the virtual viewpoint and understanding the position of the viewpoint relative to the object is a significant task for users new to 3D. To help facilitate this paradigm transition, in particular, the orientation issues, they developed a 3D orientation indicator controller. Another solution proposed is through simple mouse-based controls, a user cannot only navigate through complex environments, but also flay around objects to inspect them, regardless of size, shape or scale. In [30], it is proposed a system for multiscale navigation of 3-dimensional scenes that incorporates an image based environment representation.

Inspecting a 3D object is a common task in 3D applications. Hover Cam [29] is a technique for interactive object inspection, where the main purpose is to move the camera, under a small set of constraints including collision detection in the hover direction and the motion direction followed by a small number of corrections, to maintain the hover distance from the object. Thereby the user simplifies interaction that only requires a 2D input, which can be engaged with one control. This means that the user can move around an object moving to unknown positions or orientations.

Both the Boom chameleon [16] and ARPlanar [14] systems proposed a new device solution using a desktop multitouch display on a tracked mount. While Boom Chameleon allows rotating the screen around a fixed point to observe and annotate 3D models such as using a physical moving canvas, this approach is the minimally intrusive capture of information, and one method of minimizing intrusion is to simultaneously capture the different modes of input. The display acts as a physical window into 3D virtual environments, through which a one-to-one mapping between real and virtual space is preserved. Then a 3D annotation application that exploits this configuration in order to simultaneously capture viewpoint, voice and gesture information is used allowing an untrained user to move around a 3D model and inspect it from different viewpoints. AR-Planar proposes a more mobile setup to be used in indoor scenarios and compared it with first handled PCs. Navidget [8] presents a 2D navigation widget for 3D navigation for pen-based mobile devices using a lasso to define the point of interest and rotate around it. It allows easy and fast camera positioning in 3D environments from 2D inputs, through an adapted widget. This work derives from the Point-of-Interest (POI) technique introduced by Mackinlay [13], where the user selects the endpoint of a trajectory in order to automatically fly to a corresponding location. This technique is also known as the "go to" function for a wide range of 3D viewers.

Selecting the endpoint of a trajectory has several advantages: - In this case only a pointing device and a start signal are requested by POI techniques. No additional devices, such as keyboards or joysticks, are needed. Consequently, a POI approach can be used with a wide variety of alternative equipments, including mobile devices and large touch screens for collective work. POI techniques are particularly well suited for optimizing 3D navigation in alternative visualization situations. POI approaches are very simple and direct. Users simply have to select the point to which they want to fly and wait for the camera movement, so the time-lag is much less objectionable as an immediate feedback is not required. All visible parts of the scene can be reached directly. The camera movement in the 3D environment operates within controlled completion times, consequently users can quickly travel long distance. Another advantage is that sometimes it's difficult for the user to construct a cognitive map when navigating in large and complex 3D environments. Using the POI technique the whole environment is traveled over from the current position to the desired location, and the speed of camera movement gives an indication of the distance traveled.

On the other hand, POI techniques have two significant disadvantages: they are Surface-dependent. The target is always a point on a surface. Consequently, the only possible camera movements are translations towards a surface of the 3D scene. This is restrictive as users may want to move to other locations. It is not possible to move to a location where two objects can be seen within a closer view, because the system does not distinguish between the two objects; the other drawback is that users can only give the point to which they want to fly. They do not control how they go there. In particular, it's not possible to control parameters regarding the distance between the endpoint of the camera trajectory and the target, or the angle from which they want to view the target.

Nowadays there has been made a big effort on intuitive 3D interaction techniques. Multitouch based navigation interfaces such as Dabr[6], ScrutiCam[5] and Drag'n Go[11] try to propose easier navigation methods. However, they do not fully explore the mobility offered by existing mobile devices.

The Dabr[6], proposes the use of the benefits of a multi-touch approach coupled with a low latency user interface. The intuitive navigation gestures are a desirable combination for a truly intuitive and authentic experience. These concepts of multi-touch interaction provide natural interfaces in many fields. These techniques allow a direct manipulation and have shown to be very appealing to users.

In ScrutiCam[5], a 3D camera manipulation technique is proposed to easily control camera motions around an object by moving the areas of interest to the center of the screen. It is based on the "click-and-drag" mouse move, where the user "drags" the point of interest on the screen to perform different camera movements such as zooming, panning and rotating around a model. Another technique is based on the Point-Of-Interest (POI) approach, where the final camera position is specified by clicking on the screen. Contrary to other POI techniques, in this project the user can control the animation of the camera along the trajectory, which is an advantage over the other proposes.

This study Drag'n Go[11], combines the advantages of point of interest [10] with features of direct manipulation [14]: reversibility of movement, no delay between interaction and result. It's based on a traveling path between the avatar position and the target position. They provide a direct way to control the camera in multi-scale virtual environments using a simple method to implement that can be used on a large range of devices. The major advantage is that the user controls the progression of the navigation by the position of his cursor using the line between its initial position and the bottom border of the screen as a slider.

Other examples of multimodal user interfaces in professional work environments include real-time simulation of 3D complex phenomena, training and edutainment, tele-presence and tele-robotics and even simple business meetings [13]. However, the objective is to maintain the focus

on the oil and gas industry. This industry is well positioned to drive the directions of future research in VR since it's one of the biggest users of high-end hardware and software [13][7]. The cognitive processes involved in the three-dimensional engineering tasks at stake are also the perfect playgrounds for evaluating novel multimodal user interfaces like the one we present in the following section.

2.3 Collaboration

In the last two decades technological advances make it easier for people to travel, communicate and do business internationally. The economies become more connected to other economies, they increase opportunity but also increase competition. Globalization becomes a more and more common feature of world economics [31]. The strategies are followed by industries in de-constructing and concentrating on the core competencies leading to the implementation of the concept of distributed virtual enterprises where employees with different cultures, different languages and concepts, using different tools and processes, need to collaborate product development. The use of collaboration during the design stage can help in reducing design time typically by 25-40% [2].

Product design review is a typical scenario of collaborative product development. A typical design team is constituted by members from multiple disciplines and also geographically. The design review and the engineering change approval can take place in a collaborative environment during the detailed design stage of the product development.

Collaboration problem solving environments focus on the development and integration of scientific tools and technologies coupled with collaborative environments to support the modeling and simulation of complex scientific and engineering problems. These capabilities enable engineers to setup solutions in an integrated environment [13].

A collaborative CAD system cannot be simply set-up through equipping a standalone CAD system with IT and communication facilities. It needs some innovations or even fundamental changes in many aspects of CAD systems, such as infrastructure design, communication algorithms and geometric computing algorithms, due to the complexity of collaborative design activities and the specific requirements of CAD systems.

This kind of collaborative system needs two types of capabilities and facilities: distribution and collaboration [32]. These two terms emphasize the different aspects of a system: physically, the former separates CAD systems as geographically dispersed and expands them to support

remote design activities, and, functionally, the latter associates and co-ordinates individual systems to fulfill a global design target and objective. However, although having different focuses, they are closely inter-related and complementary. A collaboration mechanism needs the specific design of the distributed architecture of a system to meet the functional and performance requirement.

It's intended to control the execution of large and complex engineering projects involving many geographically distributed teams involved. This kind of technologies also allows an integration of different applications providing the team workers with means of information exchange. According to the functions and roles of users participating in a design activity, a collaboration CAD can be organized as either a horizontal or a hierarchical manner. The horizontal collaboration emphasizes on collocating a design team from the same discipline to carry out a complex design task in a synchronous or asynchronous way. The hierarchical collaboration can establish an effective communication channel between upstream design and downstream manufacturing and it can enrich principles and methodologies of concurrent engineering to link diversified engineering tools dynamically.

Collaborative Virtual Environments (CVEs) are a special case of Virtual Reality environment systems, with the purpose of providing distributed teams with a common virtual space where they can meet as if face-to-face, co-exist and collaborate while sharing and manipulating, in real-time, the virtual artifacts of interest.

They can be seen as the result of a convergence of research interests within the Virtual Reality (VR). These environments are becoming increasingly used due to a significant increase in cost-effective computer power, advances in networking technology and protocols, as well as database, computer graphics and display technologies. Studies of a cooperative work in real-world environments have highlighted the important role of physical space as a resource for negotiating social interaction, promoting peripheral awareness and sharing artifacts [1]. This is important because virtual reality may enable participants to discuss and manipulate shared 3D models and visualizations in such a way that each user can adopt their own viewpoint and can naturally indicate where the others look and point.

2.4 Use of small screens and inertial sensors

Our approach combines existing sensor based mobile devices with multitouch navigation to propose a reliable navigation technique for on-site collaborative engineering design review tasks.

Recently, computer technologies have multiplied, and there are large interactive displays that overcome some of the physical constraints of the relatively small display of a traditional desktop or laptop PC. Hand-held devices are ubiquitous and have become part of our lives these days. These devices are also increasingly being equipped with special sensors and nontraditional displays. These technologies can promote simultaneous collaboration, and permit everyone to see a shared display that co-ordinates the group's view of the media being worked with. However, this does not give each person an individual view.

When considering how the iPad or other portable equipment flexibility could apply to our day-person today life, it's not difficult to imagine how it could also be used in your work life. The equipments entered into the business world in a process of bottom-up integration, into the workplace, by consumers and employees versus a traditional top down corporate-leadership push. This kind of equipments was being brought inside the companies by employees and subsequently began to show the potential of these devices to the leadership. Then corporations started picking up on the value the iPad could provide their businesses with the developing and adapting services. The opportunities for using a lightweight, portable, connected device are vast. These equipments are a platform for accomplishing ambiguous goals. Its purpose is not well defined because each individual has different expectations of them.

Some studies related to collaborative interfaces where done with iPad [32], where they proposed a collaborative annotation system that uses a set of individual iPads. The size and shape of the hardware gives all the advantages of these equipments.

On the other hand, there has been some research into building virtual reality for hand-held devices [9]. They take advantage of its mobility and ubiquity as well as a growing number and quality of sensors. Currently, interaction in these equipments is still mostly finger-based. These studies have revealed that when a motion based interaction was used, the Field of View perceived was significantly greater and the level of user felt presence was higher.

3. CEDAR SYSTEM

3.1 CEDAR Project

CEDAR - **Collaborative Engineering Design And Review** is an international project team investigation with focus on collaboration. It's primarily concerned with collaborative work: designing an effective human-to-human interaction and communication for solving conflicts and enhancing group productivity.

Designing and reviewing large scale engineering models is a particularly complex activity, especially when it involves collaborative teams dispersed throughout the globe. This is precisely the case of the oil and gas industry, the main application domain targeted by the Collaborative Engineering Design and Review (CEDAR) project. The research goal of CEDAR is to create, evaluate and refine a novel system for supporting these activities in a real life environment, advancing the state of the art in multitouch surfaces, large scale interactive displays and mobile collaborative systems.

In order to achieve this goal, CEDAR's unique research approach combines the power of novel interaction paradigms with the results from ethnographic studies of real world engineers and their successive evaluations, thus achieving an effectively functional engineering design and review system.

The team consortium is composed by:

- Joaquim Armando Pires Jorge as main researcher;
- João António Madeiras Pereira as researcher;
- Pedro Filipe Pereira Campos as researcher;
- Luciano Pereira Soares as researcher;
- Hildegardo José Quintal Noronha as researcher with scholarship;
- Duarte Paulo Ferreira Gouveia as masters student;

3.2 Task Analysis

3.2.1 Introduction

One of the main objectives of the engineering department's at large industries is the construction of integrated information systems to control their projects. These systems should offer resources for the 3D visualization of models with enough realism to be used for virtual prototyping, design review, change management systems, and training, among other activities. Modern information technology tends to increase the complexity of artefacts, whether they are small, personal devices or huge systems. Consequently the engineering, design and review of CAD models is a complex, collaborative activity, in particular when large-scale models are involved, as in the oil industry. Inspection is commonly used in Computer-Aided-Design (CAD) applications, where users have to look at specific parts, zoom in and out or turn around some details of a 3D model. Such a task requires the use of several different tools. Switching between each of them is time consuming and users may feel lost if too many tools are available.

The development of many fields such as human augmentation, volumetric and holographic displays, automatic content recognition, natural-language question answering, speech-to-speech translation, big data, gamification, augmented reality, cloud computing, NFC, gesture control, virtual worlds, biometric authentication methods and speech recognition [33] as well as the increasing connectivity contributed for the increasing interaction between humans and technology making it more natural.

The available resources at Tecgraf-PUC Rio were used to conduct user observations and informal interviews with the engineers involved in collaborative engineering design and review activities and of course the several meetings with CEDAR team researchers complemented this analysis with research literature results.

This section presents the methods and all the information handling necessary for the development of the prototype to generate high-quality visual feedback from the virtual environment in order to increase the degree of immersion on navigation of 3D models using tablets (iPads).

3.2.2 Hypothesis

The use of hand-held devices (tablets) is each time more frequent whether in the daily life of people or for professional purposes. This equipment has become more equipped with sensors and special screens that give us the possibility of new ways of interaction. The implementation of a prototype to create and test new modes of navigation in complex 3D models is proposed, such as 3D plants of structures of the oil and gas industry.

Our hypothesis is:

Accelerometer-based approaches are more efficient than touch gestures-based approaches in navigation through complex 3D CAD models.

Beyond the applications previously referred, there is already a large diversity of tools from different manufacturers for hand-held devices (iPad). At this moment, if we go to a shop of applications of Apple (App Store), we find a big diversity of applications that allow the visualization of 3D models as well as to take annotations. The principal applications are previously referred amongst with: TurboViewer Mobile [IMSI/Design], IPUB (Inventor Publisher Mobile Viewer)[Autodesk]; eDrawings for iPad [solidworks]; e iRhino 3D. Most of these applications that were referred use the storage in the cloud to save the 3D models.

3.2.3 Scenarios

One of the main objectives of the engineering department's at large industries is the construction of integrated information systems to control their projects. These systems should offer resources for the 3D visualization of models with enough realism to be used for virtual prototyping, design review, change management systems, and training, among other activities. Because interfacing some of the user's articulations in the real world back into the virtual environment, the user can interact with the environment in a more effective way.

However, the engineering, design and review of CAD models is a complex, collaborative activity, in particular when large-scale models are involved, as in the oil industry. Inspection on these models is commonly used in Computer-Aided-Design (CAD) applications, where users have to look at specific parts, use zoom or turn around some details of a 3D model. Typically this kind of task requires the use of several different tools and switching between each of them is time consuming and contributes to increased complexity.

The use of advanced computer graphics and virtual environments has sparked a digital revolution in many activities, thanks to the novel visualization and manipulation possibilities they provide. Ironically, engineering teams still regard the usage of some of these systems as laborious and complex, and it hasn't been until recently that collaborative virtual environments have finally started to move out from research labs into the industry. The main intend is mainly the review of large-scale CAD models of oil platforms, manifolds, risers and other sophisticated structures, more precisely in offshore engineering projects in the Oil&Gas industry. This kind of projects (offshore engineering projects) involve not only geographically distributes teams but also specialists teams in different areas using different software tools [19].

By studying the users' needs, the related existing work and the possibilities that recent advances in multimodal technologies now offer, we expect to shed new light into how an integrated environment should be conceived and designed in order to positively influence the collaboration levels between dispersed teams of engineers that need to review oil platform problems as well as to design solutions for those problems.

In the offshore engineering field, the project of deep-water production systems, including oil platforms, ships and all the subsea equipment that plays a part in the production process, is currently designed by means of complex computer modeling systems. The design of a new production unit is a lengthy and expensive process, which can last many years and consume hundreds of millions of dollars, depending on the complexity of the unit and the maturity of the technology required to make the project technically and economically feasible. Due to their large complexity, projects in this field are segmented, divided into smaller interrelated. During the conceptual design phase of the project, the work is carried out basically, but not only, by the following teams [19]:

- Naval Engineers;
- Structural Engineers;
- Production and equipment Engineers;
- Chemical and process Engineers;
- Geotechnical Engineers.

This CEDAR work package is primarily concerned with collaborative work: designing an effective human-to-human interaction and communication for solving conflicts and enhancing group productivity. Based on resources available at Tecgraf-PUC Rio to conduct user observations and informal interviews with the engineers involved in collaborative engineering design and review activities by the CEDAR team two main scenarios were identified:

- the design review 3D CAD Models;
- riser analysis.

The focus of this work was the first scenario (the design review 3D CAD Models). Both scenarios have commonalities, such as:

- Engineers are focused on making comparisons, simulations, visualizations;
- Engineers collaborate in three different session types: informal (ad-hoc), lecture (only the coordinator has control over the camera) and classroom (one coordinator and everyone can ask to control the camera).

However, it was identified some significant differences between the two scenarios, both of which can provide opportunities for design innovation. In this case (this document), the whole analysis is going to be presented taking into account the first scenario (design review 3D CAD Models).

Scenario 1 – Design and Review workflow

Design review is the process of checking the correctness and consistency of an engineering project while making the necessary adjustments. In the session, users manipulate engineering objects, create annotations and do measurements. The ability to **move**, **rotate** and **scale** objects is important for various purposes, such as **joining models**, **viewing hidden areas**, **planning the placement of new devices**, and **simulating a maintenance or intervention operation in a process plant**. Moreover, integration with an engineering database from the CAD system is useful to **create annotations emphasizing critical parts** (Figure 3.1). Comments attached to objects can also be used as recommendations for project management. Figure 3.2 shows a measurement taken for planning the movement of a large tank in a production unit. Users create annotations to guide the maintenance procedure and animate the entire operation.

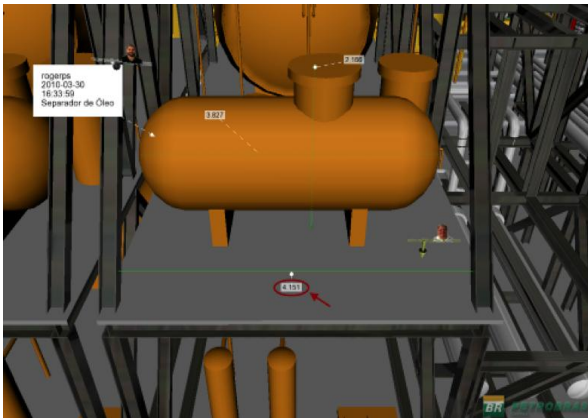


Figure 3.1: a screenshot of the desktop-based software currently being used by the engineering team to review and annotate the platform's 3D model.



Figure 3.2: a screenshot of collaborative session using large screen used by the engineering team to review the platform's 3D model.



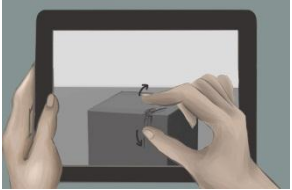
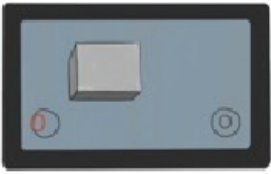
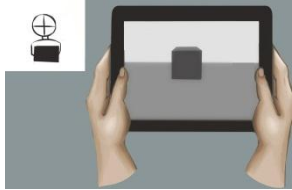
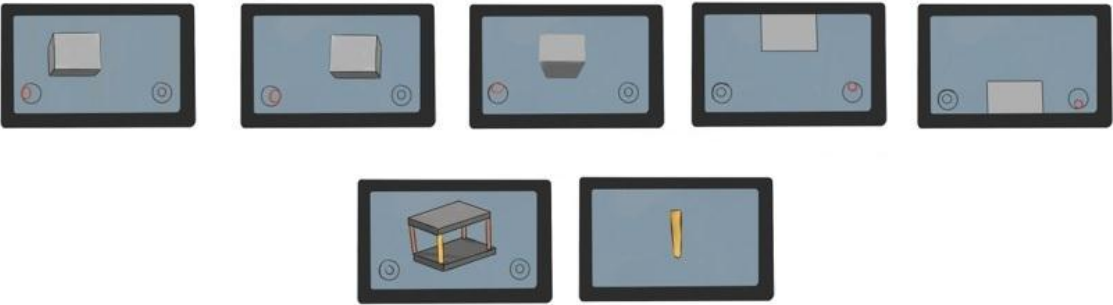


Figure 3.3: a screenshot of collaborative session using large screen used by the engineering team to review the platform's 3D model.

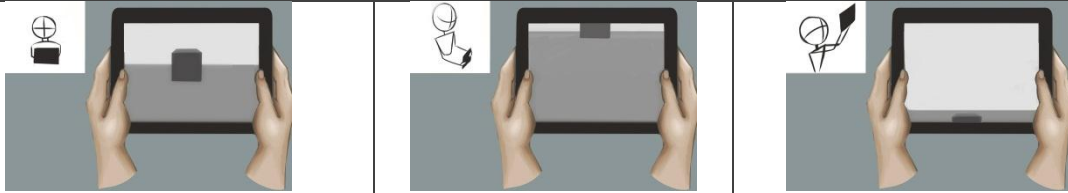
In this scenario, the importance of supporting both synchronous *and* asynchronous (through the annotations) communication is observed among the necessity of implementing a solution that permits the user to establish design review sessions with the possibility of navigating through 3D CAD models in a virtual environment.

3.2.3 Storyboards

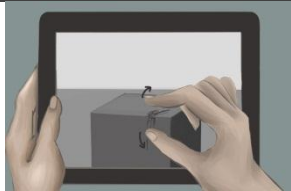
Storyboards were employed to facilitate the ideation process as well as to better explore the possible design concepts. Figure 1 illustrates a particular one. During the specification phase, screens that the software will display were designed to illustrate some of the important steps of the user experience. Helping the user understand exactly how the software will work, much better than an abstract description. A particular part of the storyboard created, illustrating the different navigations modes, is presented below.

		
<p>John and Mary are two collaborators in a petrolific company. Mary explains to John that the company needs to install new equipment in one of the Oil&Gas platforms of the company. She provides John the dimensions of this new equipment and asks him to search the most adequate local in the platform to install it.</p>	<p>John connects his iPad and starts to inspect the plant of the platform in a 3d form.</p>	
		
<p>Gestures based</p>	<p>Multitouch</p>	<p>Multitouch coupled with accelerometer-based input</p>
<p>In order to inspect the model John has 3 different modes of navigation.</p>		
		

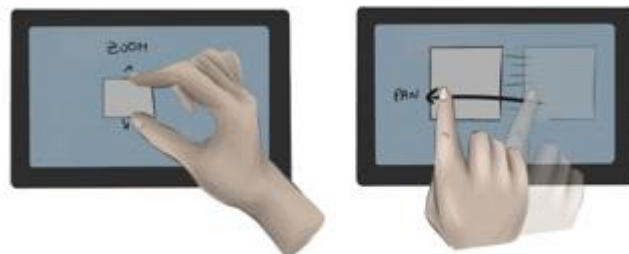
In a first phase to travel in the corridors of the platform and observe the different sections and artifacts that exist, he chooses to use a system with two "joysticks" (the circular images underneath the user's fingers), which are used to navigate through the 3D model, as if he was in an environment of a game executing a determined route.



To facilitate his navigation in the model, John activates another mode of navigation that he has at its disposal. This mode utilizes the accelerometer to take advantage of John's movement or of the movements he gives to the tablet. This way, John, while turning along with the tablet in real life, also turns in the model. This mode behaves as if the user is holding a camera, which allows a natural visualization and navigation.



After finding the local that he considers the most adequate for the installation of the equipment, he starts to observe closer the artifacts existent in this area.



This way, he takes advantage of the third model of navigation that the prototype supports. This model permits John to manipulate the artifacts with the fingers and to be able to zoom, pan and pinch in the artifacts.

Figure 3.4: A particular part of the storyboards created, illustrating the navigation mode.

This storyboard indicates that, high-end visualization systems are commonplace in Oil&Gas industry, especially in Exploration and production segment. Oil companies were among the first to make industrial use of the Virtual Reality centers. But these kind of projects (offshore engineering projects) involve not only geographically distributed teams but also teams of specialists in different areas using different software tools. Moreover, the engineering, design and review of

CAD models are complex, in particular when large-scale models are involved, as in this case. A system that possibilities navigation to be intuitive and easy to use as well as efficient, allowing the user to achieve his task in short time is what is pretended.

3.2.4 Requirements

A lot of useful data was produced, and most relevant issues were filtered out to design a novel user interface aimed at supporting the engineering design and review activities. As mentioned before in other sections of this document, in a review session, engineers manipulate 3D engineering objects (artifacts), creating annotations and performing measurements. The ability to move, rotate and scale objects is important for various purposes, such as joining models, viewing hidden areas, planning the placement of new parts, and simulating maintenance or intervention operations in a process plant turning navigation in one of the elementary tasks of 3D virtual environment. It's composed of two parts: locomotion where there is a physical control of the camera and the way finding where a path is found through the environment. Despite being widely studied, there is still need for more efficient and simple techniques.

Taking into account the scenarios previously identified, storyboards, uses cases and all of the analysis, the conclusion was that the prototype has to permit a set of factors and characteristics that are correlated between themselves. They are presented below:

- **Increase efficiency** - Use of intuitive tools to inspect, measure, mark up, and review 3D CAD models;
- **Enhance communication** – Must enable the sharing of the navigation views sessions as well as the changes with the extended team and stakeholders;
- **Reduce time** – By increasing the level of collaboration between the engineers, it permits to reduce the time in planning and execution of tasks.
- **Improved performance** – permits to take advantage of enhanced features of the portable equipment (iPad) and frameworks;
- **View** – permits to view high-resolution 3D models and navigate through them allowing a generation of high-quality visual feedback from the virtual environment generating a high degree of immersion;
- **Measure** - Measure parts, areas, surfaces, and dimensions for more accurate communication and perception;
- **Mark up and annotations** – Possibility of adding comments, information, and suggestions on 3D files;
- **Track and import changes**—Manage, track, and round-trip changes into the original design software to complete the review cycle;
- **Intuitive** – The interface of the user should be intuitive and have a good usability to avoid a bad use of the tool. The tool must be more approachable and less brittle to ease 2D users into the 3d world;
- **Orientation awareness** - another common problem observed with new-to-3D users is the loss of orientation. Users seem to forget where they are in 3D. Users

navigate to a view without understanding how they got there. It's important to improve orientation awareness.

The uses of advanced computer graphics and virtual environments per se have sparked a digital revolution in many activities, thanks to the novel visualization and manipulation possibilities they provide. But the implementation and use of these systems continue to be complex and hard-working nowadays. To take advantage of this prototype it is necessary to take into account some relevant factors:

- Communication support – The system must provide different communication support possibilities: synchronous or asynchronous, enabled in various media types. This support should be provided in a seamless way, so that our users can start a communication of one or of another type while they are interacting with the system, or they should be able to plan certain time for a specific communication interaction.
- Cooperation and flexibility support – there should be process model flexibility support, like dynamic change of process instances during run-time to support dynamically evolving processes.
- Awareness – there are types of awareness that can be foreseen in our scenario, the most important ones are: workspace awareness in the virtual environment – to provide control of collaborative interaction and changing of the user location; mutual awareness – to allow users see each other's identity and observe each other's actions.

This prototype with the implementation of virtual reality (VR) techniques such as three-dimensional geometric modelling, scientific visualization, immersive virtual environments, has a great potential in applications in different areas and tasks of the daily work day of the petrolific industry [17]. Some of the applications are identified below:

- Training and security simulations;
- Design;
- Planning and optimization of marine installations;
- Sub-sea layout enagement of production equipments;
- Remote teleportation on interventions on submarine equipments;
- Preparing maintenance and inspection plans in production units;
- Planning oil pipeline installation and monitoring;
- Emergency scenario applications.

Hardware considerations

While projecting and implementing the prototype, it was taken into account some of the characteristics at the level of hardware, knowing that the pretention is to visualize 3D CAD documents that normally are very big and demand capacity of storage and processing. Next, factors that were taken into account in the development of the prototype are presented:

Limitations of the platform:

- Storage – At this moment the maximum capacity of the iPad is 64 gigabytes. This way, frameworks of precompiled routines were used so that the prototype would occupy the minimum possible space.
- Duration of the battery – The battery is a limitative factor of these equipments, although the capacity of storage of the batteries are each time bigger and the systems consume each time less energy whereas it is necessary to take into account the control of access to CPU and graphic units, principally when referred to multimedia systems.
- Limitation to the access of data – Each application is installed in “sandbox”, turning the access restricted from other applications and certain doors. However, data available through internet can be accessed.
- Limitation of memory – It doesn't support swap to execute virtual memory, so it's necessary to take a lot of care in the utilization of this resource, as we have the risk of occupying the whole memory of the system.
- Limit of application – It isn't possible to execute applications in 2 level due to Apple's policy. For an application to be utilized it is necessary that the one utilized before is shut down and unoccupied from control.

3.3 System Design

3.3.1 Introduction

In this section, the creation process for a system aimed at supporting the Oil&Gas industry engineers' activities is described. This includes mainly the review of large-scale CAD models of oil platforms, manifolds, risers and other sophisticated structures, and this was carried out collaboratively with Oil&Gas industry engineers and researchers, throughout many meetings and subsequently qualitative user evaluation and posteriorly a quantitative evaluation was effectuated as already referred.

This prototype was developed to function on the operative system device of Apple, better known as IOS (iPhone Operating System). Apple doesn't permit that its system is installed in other hardware, do it implied that this prototype was developed to function in the equipment of the iPad. The interaction with this equipment is done utilizing the concept of direct manipulation, utilizing multi-touch gestures. It also has many sensors like the accelerometer, magnetometer, gyroscope, possibilitating the development of new interaction methods.

In this prototype was used some of these sensors, in particular, the multitouch ability, accelerometer and gyroscope for developing a multimodal user interface with navigation capability for complex 3D CAD model.

3.3.2 Implementation

As it was already referred, this prototype was developed to function on the IOS (iPhone Operating System) architecture. To accomplish, it was necessary to execute some steps. First, it implied that the development was done in the environment of Apple, utilizing a computer with the operative system of Apple being registered as an Apple developer, utilizing software of development: IOS SDK (XCode).

Developing for IOS implies knowledge about the utilization of the paradigm Model–View–Controller (MVC). It is a type of computer user interface that separates the representation of information from the user's interaction with it. The model consists of application data and business rules, and the controller mediates input, converting it to commands for the model or view. The central idea behind MVC is code reusability and separation of concerns.

In addition to dividing the application into three kinds of components, the MVC design defines the interactions between them:

- A controller can send commands to its associated view to change the view's presentation of the model (for example, by scrolling through a document).
- A model notifies its associated views and controllers when there has been a change in its state. This notification allows the views to produce updated output, and the controllers to change the available set of commands.
- A view requests from the model the information that it needs to generate an output representation.

Allowing that different views and controllers to be developed for the same model. It also allows the creation of general-purpose software frameworks to manage the interactions.

System Architecture

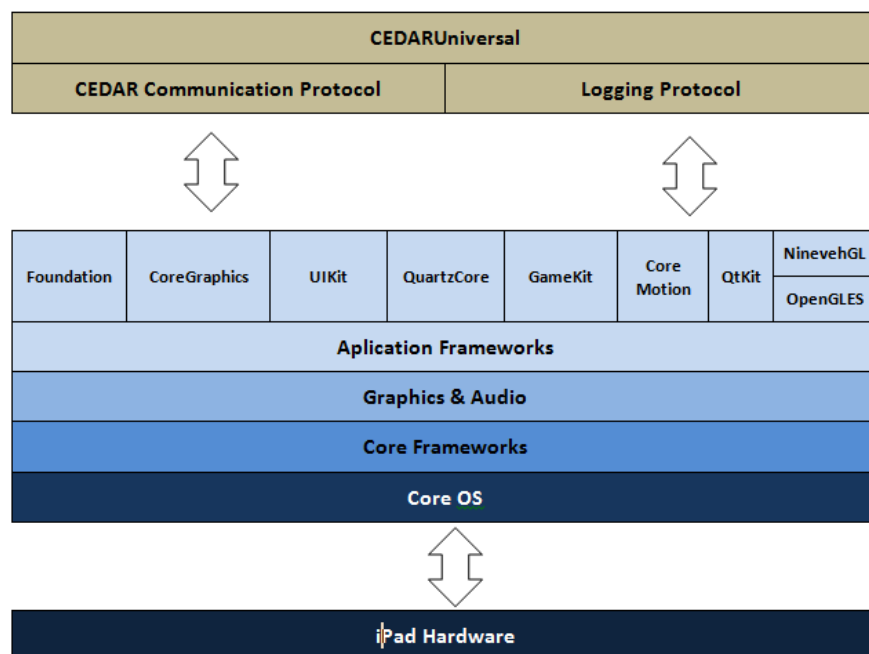


Figure 3.5: System Architecture – Architecture of the implemented system.

This is the architecture of the system that was developed as referred in the previous section (Task Analysis). This prototype was developed to function in IOS platform. This is the reason that most of the components that constitute the architecture belong to Apple.

Only components that are above the layer of “Application Framework” will be referred due to the fact that these components were used in the implementation of the characteristics of the prototype. A 3D engine (NinevehGL) was utilized to generate and implement the 3D models.

The iPhone (same as iPad) OS's frameworks are divided into four major layers. Each of these layers contains a variety of frameworks that we have access when the applications of IOS are developed.

- GameKit framework – This framework was used to provide the connectivity service. Only one of the three functionalities of the framework was used, Peer-to-peer connectivity, to create an ad hoc Bluetooth network between multiple iPads in the same local area for data exchange among the CEDARUniversal application to send zoom values, rotations and translations coordinates. This framework provides a simple way for applications to connect to each other using ad-hoc peer-to-peer communication without having to be connected to a common network. Despite its name, GameKit has been used for many non-gaming purposes as well as for games.

- Core Motion framework – This framework lets the application receive motion data from device hardware and process that data. The iPad 2 hardware includes an accelerometer, a magnetometer and a gyroscope. Through the CMMotionManager class the application starts receiving accelerometer, gyroscope, magnetometer, and combined device-motion events at regular intervals, to track the iPad's orientation (for zooming, guiding and collaboration activities). The user can simply tilt left/right or up/down the tablet device in order to control where they are looking;

- UIKit framework – most of programming work was done using the UIKit (UI) or Foundation (NS) frameworks. These libraries are collectively called Cocoa Touch; they're built on Apple's modern Cocoa framework, which is almost entirely object-oriented. It provides the classes needed to construct and manage an application's user interface for iOS. Summing, it provides an application object, event handling, drawing model, windows, views, and controls specifically designed for a touch screen interface to track the different users' pinch, pan, swipe (for rotations, translations and other manipulation operations);

- QTKit framework – is a framework with a robust API for manipulating time-based media and provides a set of Objective-C classes and methods designed for the basic manipulation of media. The QuickTime Framework was used for multimedia-annotations for the 3D models and for collaborative activities in order to record navigation and notes made on audio format that the user has done on navigation tasks.

- NinevehGL framework - is a free 3D engine to iOS, made with Objective-C and working with OpenGL programmable pipeline, allowing less cod lines and complexity by using 3D models. The main features in NinevehGL are:

- OpenGL ES 2.0 (Programmable Pipeline): It uses the newest OpenGL ES version. More power, faster, lighter, better and shaders.
- NinevehGL doesn't need plugins or special 3D formats to import. In this moment it's possible to import OBJ files or COLLADA files (all 3D software's export one of them).
- NinevehGL is made with the native iOS language. Classes and routines follow all the Apple/Cocoa Touch guidelines.

The main disadvantage is that this engine is still in development, it is still a beta version. But for now it can cope up with the objectives proposed in this project. The fact that the engine only supports two 3d formats is also a limitation. Another limitation is the fact that it isn't possible to utilize plugins to load these models in the engine. This impossibilitates the usage of compression in models because in this case the models that are utilized are of big dimension and are constituted by a large number of objects (polygons) and textures. This requires an enormous use of the Disk I/O, as well as the processor and a large memory requirement.

- **CEDAR Communication Protocol**, custom developed an application on top of NinevehGL and GameKit, used to synchronize gesture-based changes to the 3D model between the iPads involved in the navigation section. Therefore, the information about the navigation of a model is distributed to the rest of the iPads involved in the session of design and review. Information about: positions x,y and z of the camera as well as velocity of rotation and translation are transmitted between the equipment (iPads that are involved). To begin a session of navigation with another use or group of users, the Bluetooth technology has to be activated in the equipments and one of the iPads has to be defined as a server and the remaining ones as clients. From this moment forward, the login process is executed and furtherly the acceptance of the connections is established between the iPads.

- **Logging Protocol** is custom-developed, for reviewing sessions and for research studies' data gathering; its function is to record the design and review sessions that are established by users. The navigation and comments by the users are recorded in the form of audio.

- **CEDARUniversal** – It's the user interface where all of the design and review tasks about 3d models are effectuated. It utilizes the systems that are implemented in the lower layers, whose functions were already explained. The software is designed in order to allow multiple tablets (iPads) to communicate synchronously according to changes performed in the 3D CAD models and therefore was based on Apple GameKit framework in order to take advantage of Bluetooth communication technology. These two view modes behave as if the user is holding a camera, which allows a natural visualization and navigation.

3.3.3 Prototype

The software was designed in order to allow multiple tablets (iPads) to communicate synchronously according to changes performed in the 3D CAD model. These equipments are one of the most rapidly adopted consumer technologies in history and are poised to fundamentally disrupt the way people engage with the digital world both on-the-go and perhaps most notably[33]. This kind of devices are become part of our lives these days. Hand-held devices are also increasingly being equipped with special sensors and non-traditional displays. Some studies have shown the possibility of the use of this kind of devices (and-held devices) as an effective virtual reality (VR) platform and provide sufficient immersion and presence, through multimodal interaction [9].

The system is built upon the concepts of intuitive visualization and cooperation. But the main effort, in this Thesis, was the navigation in 3d models, because navigation and action allow players to move through the environment and interact with virtual world. To achieve these objectives while using those concepts several test view modes were built, two of which ended up selected for further improvement.

Two variants of the CEDAR mobile user interface were developed: multitouch-only and multitouch coupled with accelerometer-based input. These two view modes behave as if the user is holding a camera, which allows a natural visualization and navigation. Despite an apparent similarity on interactions, the two view modes are quite different in both the technical and user interaction components.

Figure 3.6, 3.7 illustrates the multitouch-only user interface. It uses two “joysticks” (the circular images underneath the user’s fingers), which are used to navigate through the 3D model (Oil&Gas platform). The left button is used to control the displacement along the Z-axis (i.e., moving forward or backwards) and the right button is used to simultaneously control the X and Y position of the camera (i.e. where the user is looking at).

Game concepts were used in the process implementation of the application; it’s the case of the integration of the joysticks to permit the navigation through the 3d model and also the case of the Apple GameKit framework to permit the communication between mobile devices (iPads) and consequently the share of navigation view.

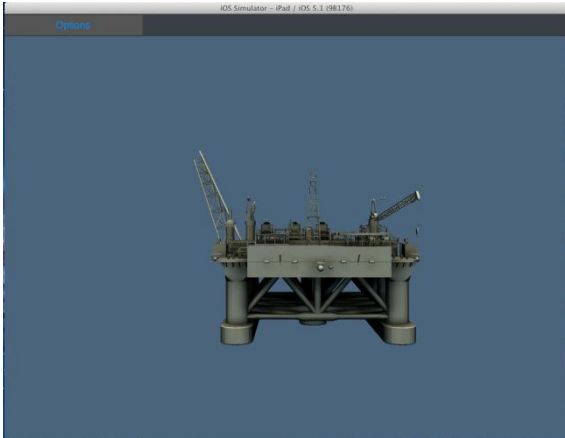


Figure 3.6: User Interface prototype

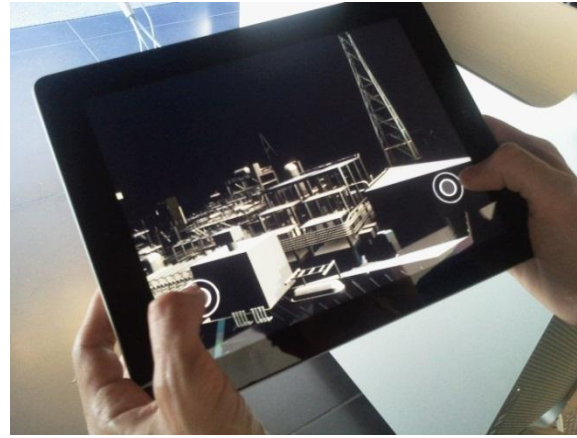


Figure 3.7: One of the navigations view

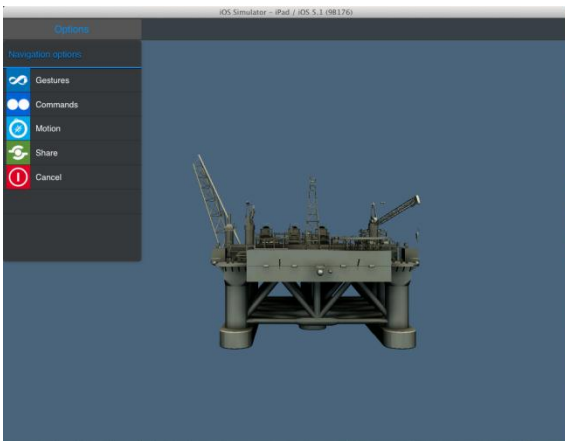


Figure 3.8: Menu options

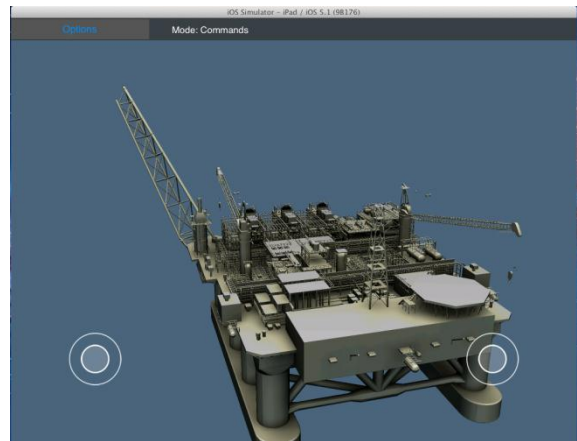


Figure 3.9: Navigating using Joystick (multi-touch)

In the second version, beyond the “joysticks” an accelerometer-based input was added, so that users can make the same movements using the left button and right, as in first variant of CEDAR mobile user interface. In addition they can simply tilt left/right or up/down the tablet device in order to control where they are looking at. Figure 3.8 illustrates this. This view mode uses built-in inertial sensors to aim the camera in a first person view mode, just as if the user was holding a real camera and filming around. To allow the user to move around, it uses in-screen joysticks, illustrated in Figure 3.9.

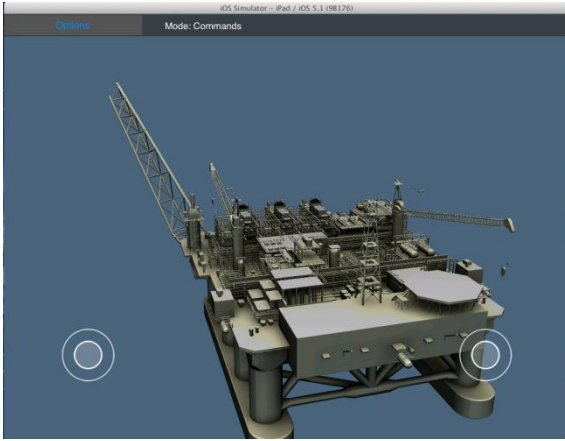


Figure 3.10: Navigating using Joystick (multi-touch) + accelerometer



Figure 3.11: Navigating using Joystick (multi-touch) + accelerometer



Figure 3.12: Navigating using Joystick (multi-touch) + accelerometer in another 3D Model

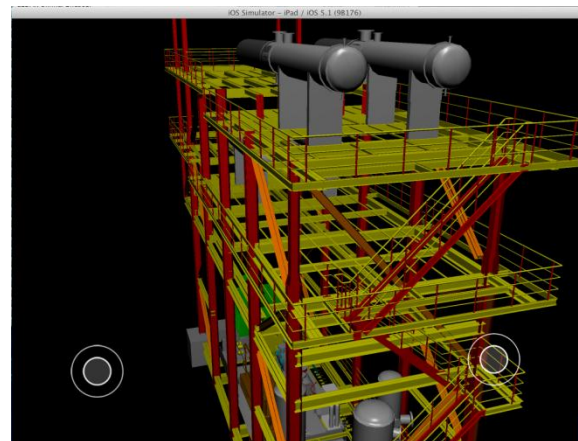


Figure 3.13: Navigating using Joystick (multi-touch) + accelerometer in another 3D Model

These two users' interfaces can be shared between multiple iPads allowing one user to guide or show some features on the model to the other users. The navigation is shared between iPads creating an improvement in the cooperativeness between the users in the same geographical space.



Figure 3.14: Establishing a collaborative session

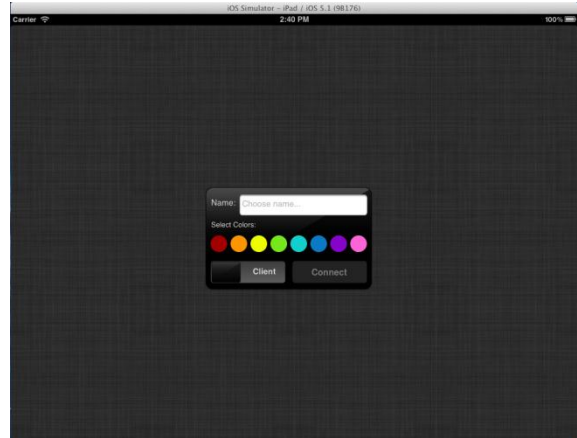


Figure 3.15: Populate fields

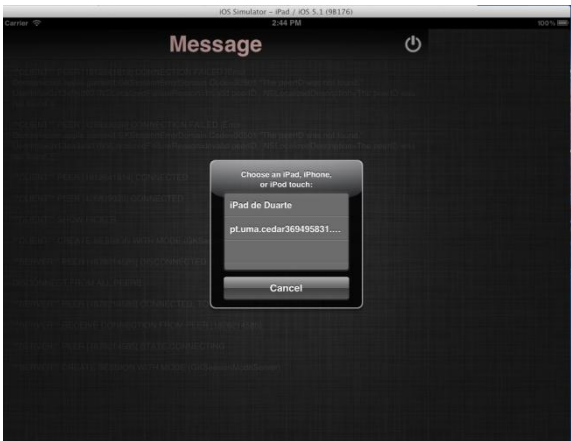


Figure 3.16: Selecting the clients to the session

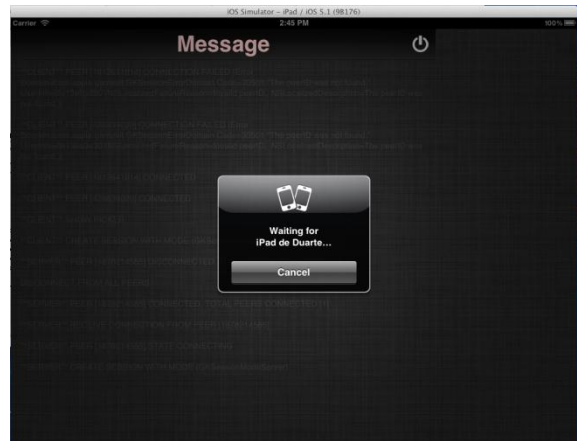


Figure 3.17: Accepting connection

3.4 User Evaluation

3.4.1 Experimental Setup

Two experiments were effectuated. The first experiment was executed in the phase of the development of the application that was used to test the usability of the prototype in order to figure out if there was a better or more effective navigation between the prototypes. In addition the experiment was executed to assess the feasibility of virtual reality with iPad.

The qualitative user evaluation was composed by a quick presentation of the system and its goals while trying not to give away to the user any information that would change his interaction in any way. Following that, users were given some time (about 30 min. each) to play around with the prototypes while talking freely about the system. This experience was voice recorded and the most important re-marks about the system were written down. The users experimented several prototypes so they could get a feeling of the different interactions types.

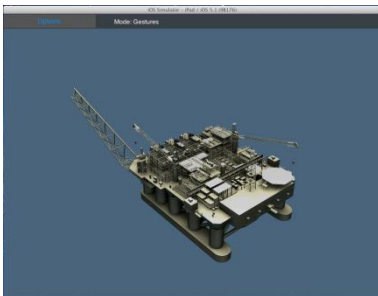


Figure 3.18: Multi-touch using gestures

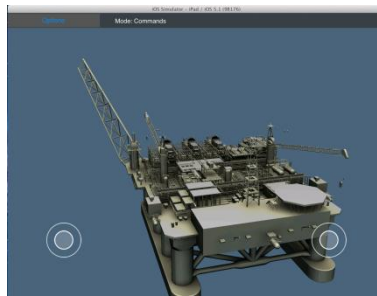


Figure 3.19: Multi-touch using joysticks



Figure 3.20: Multi-touch using joysticks plus accelerometer

At the end of the evaluation, the users were given some time to talk about the system and then they were asked some key questions in order to assess:

- The perception of the preferred navigation mode;
- The perception of the easiest navigation mode;
- Differences in the navigation modes related to the level of complexity in certain tasks;
- General feedback about the collaborative system as a whole.

Not surprisingly, the users felt that each navigation mode had pros and cons on different situations and tasks. It was interesting to note that, for simple tasks the users were more inclined towards joystick and gesture based interaction styles while for more complex tasks they chose the

first-person navigation mode. They all agreed that this kind of system would effectively help them on modeling and cooperatively reviewing constructions and construction sites.

Regarding the support for collaborative work, the feedback was particularly positive. There are very few solutions for navigating and reviewing 3D CAD models and those that exist are not mobile and/or are very difficult to use. Users even gave some examples as how they sometimes need to perform some cooperative work. In particular, the importance of several shared views, since current industrial solutions force all engineers to look at the same screen.

After finalizing the implementation of the prototype, some considerations that were obtained from the qualitative evaluation that was used as a guiding base was utilized for the implementation of the different methods of navigation in 3D CAD models were utilized. The second phase was initiated, where a quantitative evaluation was prepared to see if there were really benefits from the use of the accelerometer in navigation for the 3D CAD design review.

In order to compare the two different conditions (multitouch-only and multitouch coupled with accelerometer-based input) the basic approach was to leave the users to navigate through an immersive, highly visual, 3D environment. The experiment was conducted with ten participants (four female users and six males), architects and IT professionals, but most of them with no experience in using tablets. Participants were 25-45 years old.

The testing began after an initial briefing to explain the main propose of the experiment and the application operation, in particular the different types of navigation implemented and how to use these types of navigation.

It was used as within-subjects experimental design where the participants performed two tasks (T1 and T2, described below), under two different conditions: multitouch-only and multitouch coupled with the accelerometer-based input. For the sake of brevity it will be referred to these two conditions (our independent variables) as MT and MT+A. In a random order, half of the participants performed the tasks under multitouch-only and then under multitouch plus accelerometer input, the other half performed the tasks under multitouch plus accelerometer input and afterwards under multitouch-only. Every participant started out with task 1 (simpler than task 2) and then moved on to perform task 2. Both tasks were specifically designed in close cooperation with engineers and researchers at a very large oil industry company, with the specific goal of attaining task cases that would be a representative sample of the type of activities faced in the real world quotidian endeavours of oil platform engineers. In other words, our project's demonstrator sub-team validated them.

For each trial session, we measured the task completion about the two different user interfaces. Therefore, the experiment was a 2 x 2 repeated measures design with 2 user interfaces and 2 tasks.

The 3D model utilized for the execution of these tasks was a model of an oil platform of deep sea. The model is presented in the following figure. The users had to pass through some floors and corridors of this model, which represents a platform belonging to a high sea oil exploration.



Figure 3.21: 3D platform model

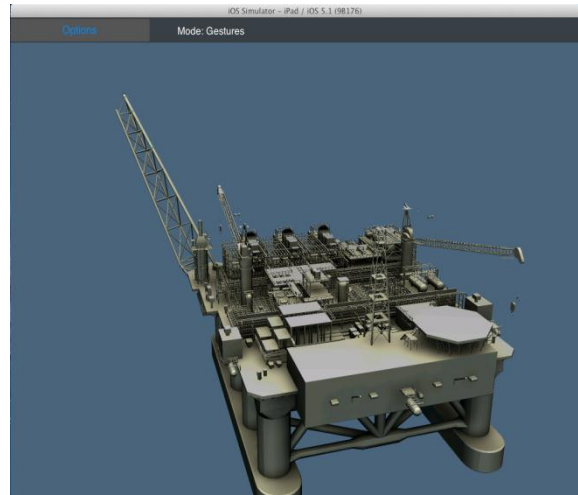


Figure 3.22: 3D platform model been used in prototype

3.4.2 Task 1 – Navigation Through a Path

Participants started out by performing this task, which is simpler than task 2. In this task, all the participants need to do is simply to navigate through a path highlighted on the virtual floor of the platform, until they reach a certain spot, Fig.3.23, 3.24. The task is obviously considered complete when they reach that spot.

This task was effectuated utilizing the two modes that were referred. In the MT case the user only uses the joysticks to navigate in the model. In the MT+A case, the user has the help of the accelerometer to navigate in the model.

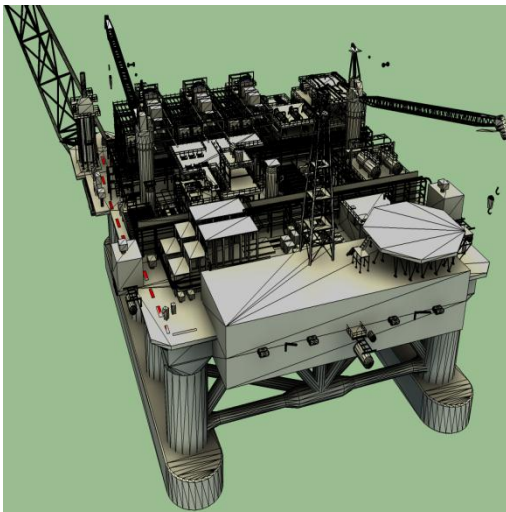


Figure 3.23: Path highlighted on the virtual floor

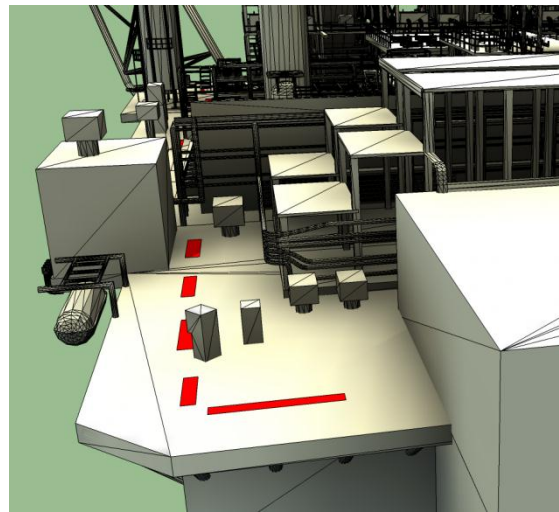


Figure 3.24: Path highlighted on the virtual floor

3.4.3 Task 2 – Look for an equipment in a section

In this task 2, the user had to navigate freely without a specific path, until he found a determined section that was identified as section C and seek the tank number two. The five sections were identified in the platform with the following terms: Section A, Section B, Section C, Section D, Section E. The user initiates his task always from the same starting point in one of the sides of the platform. The only thing provided to the user is a map where the platform divided by sections is presented in a general way. He has to navigate through the platform until he finds the section that is pretended. The task obviously ends when the engineer finds this the element (Tank number 2).

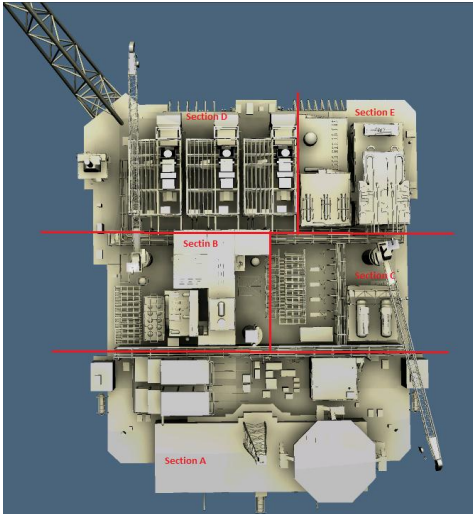


Figure 3.25: Platform mapped



Figure 3.26: Navigating in Platform 3D Model

3.4.4 Task Completion Times

As mentioned before, task completion times were measured and Figure 3.27 shows the obtained results for the average completion times in the different conditions and tasks. The effective time to complete is defined as the time it takes to the user to complete the tasks.

	Task1	Task 2	Interfaces
user 1	143,5	140,1	MT
	153,9	143,2	MT+A
user 2	160,3	180,7	MT
	137,9	134,6	MT+A
user 3	128,6	120,5	MT
	117,5	93,8	MT+A
user 4	157,1	173,4	MT
	180,2	161,3	MT+A
user 5	135,4	167,2	MT
	132,3	147,9	MT+A
user 6	143,9	136,5	MT
	130,6	132,5	MT+A
user 7	152,2	180,3	MT
	120,1	155,1	MT+A
user 8	152,7	157,8	MT
	160,2	164,2	MT+A
user 9	184,3	203,9	MT
	190,5	184,4	MT+A
user 10	123,4	115,4	MT
	107,7	82,6	MT+A

Legend:

Task 1 - Navigation Trough a Path
 Task2 . Look for na equipment

Interfaces:

MT - Multitouch-only
 MT+A - Multitouch + Accelerometer

Figure 3.27: Average completion time graphics

In order to determine the statistical significance of these differences, it was performed a two-way ANOVA with $\alpha=95\%$ and $p < .05$. The main effect for the user interface (MT versus MT+A) concludes that varying users has effect on the navigation with support of accelerometer, because P-Value is less than the level of significance. Also concludes that varying the tasks does not affect the navigation, i.e., the users felt the same level of exigency for the two navigation modes. The last factor, the P-Value for interaction variation is more than the level of significance, so the interaction between users and tasks has no effect on navigation.

This experimental study has revealed that when a motion based interaction was used, the user performs the tasks sometimes more quickly. But not all users are familiar with motion interaction yet. It was concluded that the only factor that influenced the navigation was the ability to take advantage of accelerometer potentials.

4. CONCLUSIONS

4.1 Conclusions

Supporting the needs of offshore engineering teams is an important industrial problem that should be addressed taking into account the rapid evolution in user available interaction styles. The potential for innovative solutions that is brought by tablet-based computing is enormous. In this document, the industrial creation and evaluation experience of a new mobile system for collaboratively navigating and reviewing 3D engineering models, applied to the oil industry, is described.

Storyboards and scenarios were used to elicit requirements together with oil industry experts, instead of high-level task analysis.

It's observed that none of the navigation modes studied is perceived as being better than the other. They are each adequate to different tasks. Let's consider the following example:

- The camera tracking navigation mode can be used to present the model to a fellow engineer, allowing him to perceive where the problem is. Afterwards, the user can touch the position he wishes to go to and navigate around to better position your camera (or navigate indoors or even under tight spaces).
- The virtual camera navigation mode is the only mode that requires minimal training (about a few minutes). The main issue is the novel interaction style, since the users expected a physical joystick or any other kind of physical input; on the case of the tablet and in the absence of any physical input devices, users went for touch-screen interaction plus motion. This is due to training and pre-made assumptions.

All the navigation modes studied (multitouch-only and multitouch coupled with accelerometer-based input) have their application and, qualitatively, seem to be easier, faster and more intuitive than mouse/keyboard or joystick interactions styles.

This experimental study has revealed that when a motion based interaction was used, the user performs the tasks sometimes more quickly. But not all users are familiar with motion interaction yet. It was concluded that the only factor that influenced the navigation was the ability to take advantage of accelerometer potentials.

4.2 Future Work

The system is not yet mature. There is room for future work, such as improved interaction type and orientation awareness because a common problem in 3D navigation is loss of orientation, because users seem to forget where they are in 3D and many times users navigates to a view without understanding how they got there. Another feature is the error recovery option for when the user accidentally gets to an empty view. Another important feature that can be implemented: the user touches a position on the model and is "teleported" there using POI technique. This way the user can be looking at the model from a "bird's-eye" perspective and touch the model in an area of interest to switch to a first-person perspective. And where there is probably more room for future work is on the collaborative features, because it's one of the most important issues in CEDAR project.

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APPENDICES

Appendix A – Users (Testers) demographics

Age	Sex
25	F
33	F
34	F
38	M
38	M
45	M
35	M
30	M
33	M
29	F

Mean	34
Male	6
Female	4

Appendix B - Effective Completion Times

	Task1	Task 2	Interfaces
user 1	143,5	140,1	MT
	153,9	143,2	MT+A
user 2	160,3	180,7	MT
	137,9	134,6	MT+A
user 3	128,6	120,5	MT
	117,5	93,8	MT+A
user 4	157,1	173,4	MT
	180,2	161,3	MT+A
user 5	135,4	167,2	MT
	132,3	147,9	MT+A
user 6	143,9	136,5	MT
	130,6	132,5	MT+A
user 7	152,2	180,3	MT
	120,1	155,1	MT+A
user 8	152,7	157,8	MT
	160,2	164,2	MT+A
user 9	184,3	203,9	MT
	190,5	184,4	MT+A
user 10	123,4	115,4	MT
	107,7	82,6	MT+A

Legend:

Task 1 - Navigation Trough a Path

Task2 . Look for na equipment

Interfaces:

MT - Multitouch-only

MT+A - Multitouch + Accelerometer

Appendix C - Analysis of Variance Effective Time Completion

Anova: Two Factor With Replication

Summary	Total		
<i>user 1</i>			
Count	2	2	4
Sum	297,4	283,3	580,7
Average	148,7	141,65	145,175
Variance	54,08	4,805	36,19583
<i>user 2</i>			
Count	2	2	4
Sum	298,2	315,3	613,5
Average	149,1	157,65	153,375
Variance	250,88	1062,605	462,1958
<i>user 3</i>			
Count	2	2	4
Sum	246,1	214,3	460,4
Average	123,05	107,15	115,1
Variance	61,605	356,445	223,62
<i>user 4</i>			
Count	2	2	4
Sum	337,3	334,7	672
Average	168,65	167,35	168
Variance	266,805	73,205	113,9
<i>user 5</i>			
Count	2	2	4
Sum	267,7	315,1	582,8
Average	133,85	157,55	145,7
Variance	4,805	186,245	250,9133
<i>user 6</i>			
Count	2	2	4
Sum	274,5	269	543,5
Average	137,25	134,5	135,875
Variance	88,445	8	34,66917

<i>user 7</i>			
Count	2	2	4
Sum	272,3	335,4	607,7
Average	136,15	167,7	151,925
Variance	515,205	317,52	609,3758

<i>user 8</i>			
Count	2	2	4
Sum	312,9	322	634,9
Average	156,45	161	158,725
Variance	28,125	20,48	23,1025

<i>user 9</i>			
Count	2	2	4
Sum	374,8	388,3	763,1
Average	187,4	194,15	190,775
Variance	19,22	190,125	84,96917

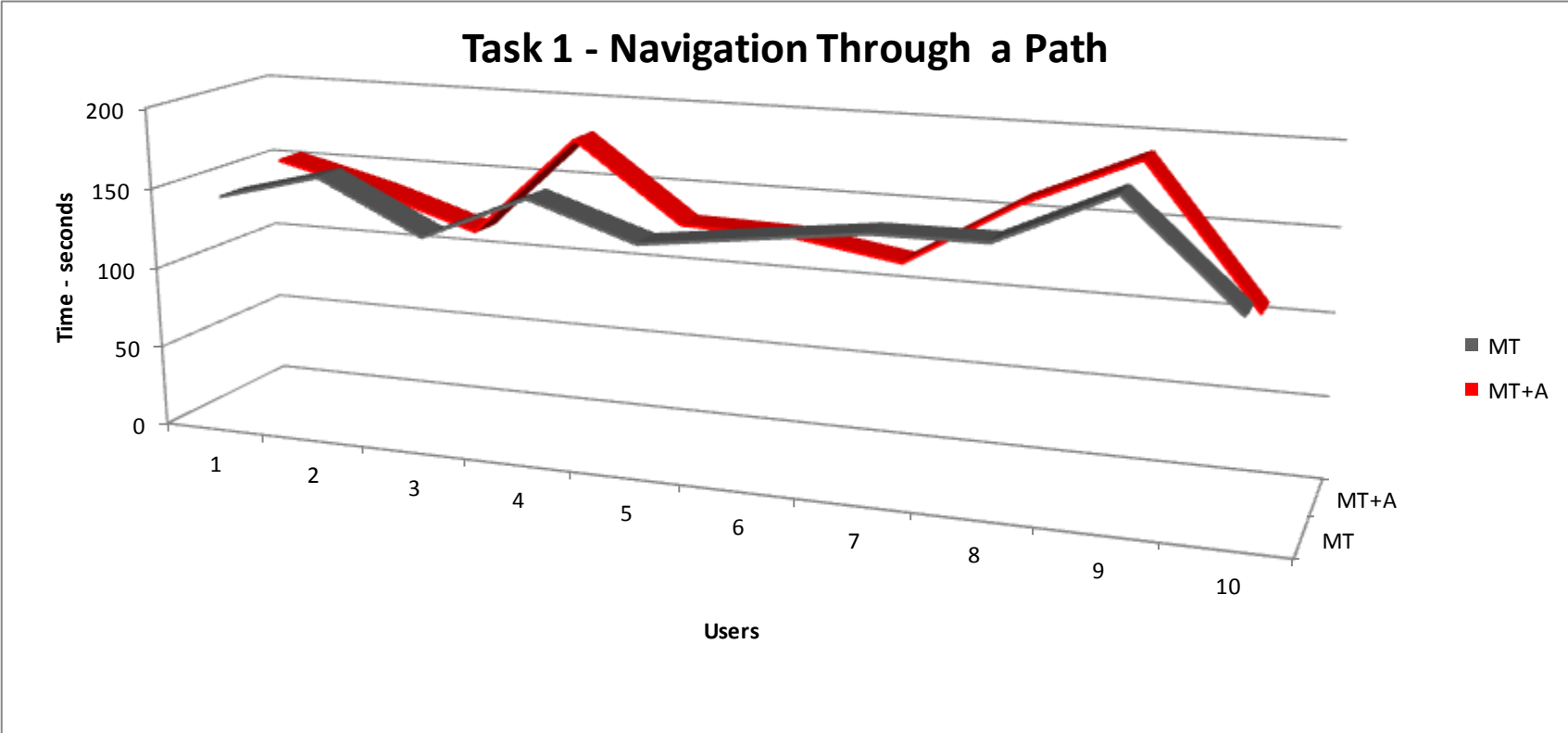
<i>user 10</i>			
Count	2	2	4
Sum	231,1	198	429,1
Average	115,55	99	107,275
Variance	123,245	537,92	311,6892

<i>Total</i>			
Count	20	20	
Sum	2912,3	2975,4	
Average	145,615	148,77	
Variance	508,7287	937,9685	

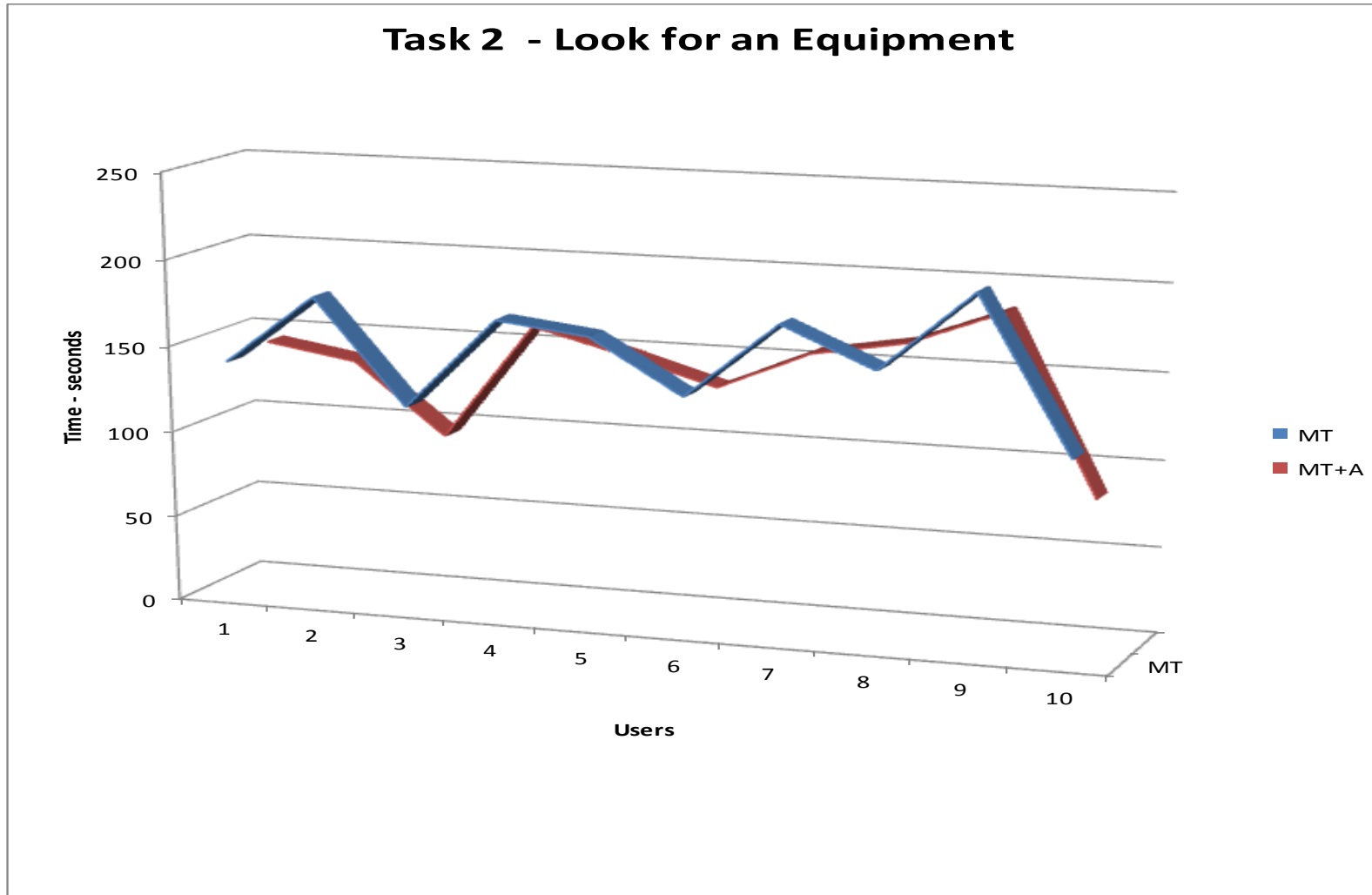
ANOVA

<i>Source of Variation</i>	<i>SQ</i>	<i>gl</i>	<i>MQ</i>	<i>F</i>	<i>P-Value</i>	<i>F crit</i>
Sample	21134,9	9	2348,322	11,26357	4,58E-06	2,392814
Columns	99,54025	1	99,54025	0,477438	0,497527	4,351244
Interaction	2182,587	9	242,5097	1,163182	0,368314	2,392814
Within	4169,765	20	208,4883			
Total	27586,79	39				

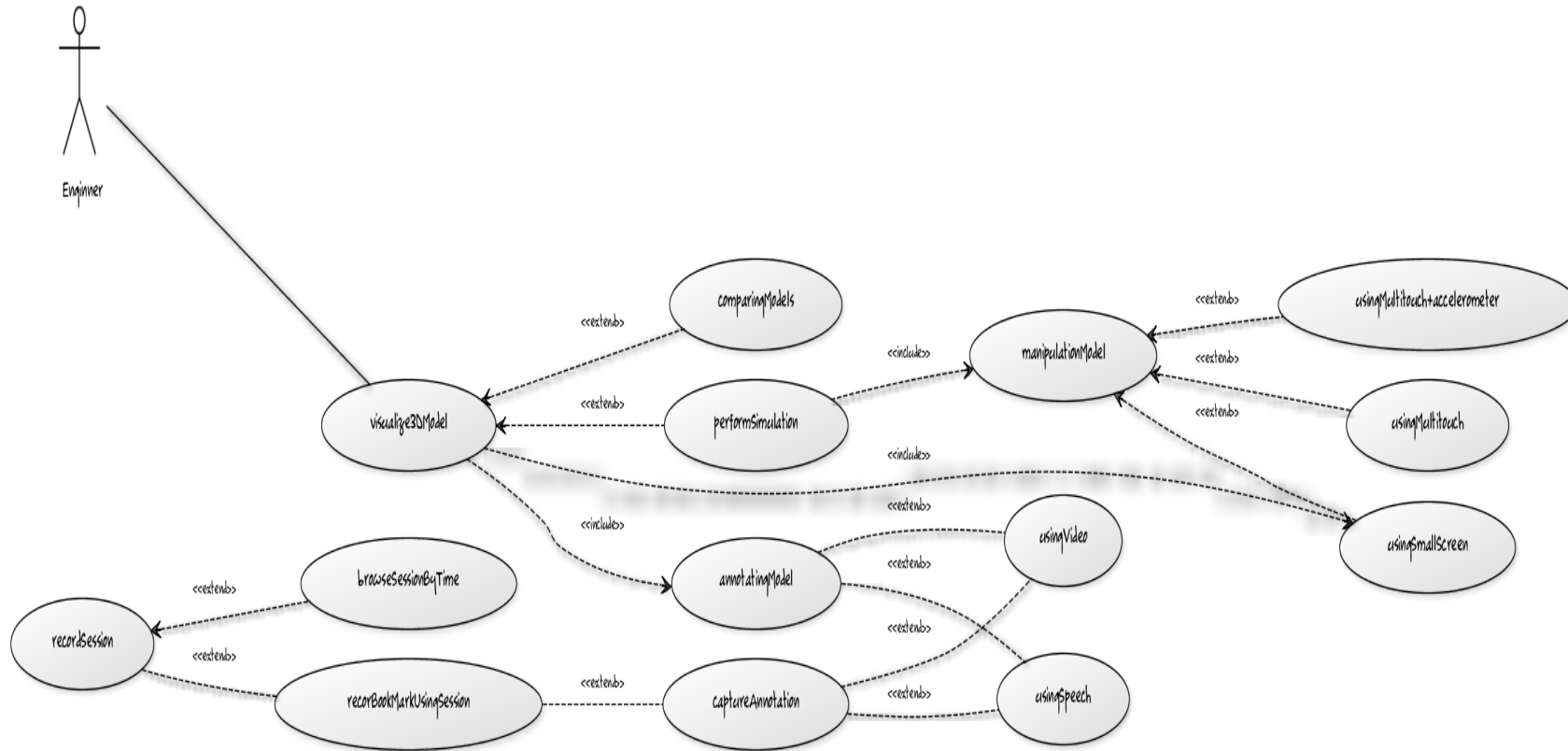
Appendix D – Graphics – Task 1 Navigation through a Path



Appendix E – Graphics – Task 2 Look for Equipment



Appendix F – Uses Cases Diagram



Appendix G – Task 2 Map

