FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

The Augmented Reality Systems in a Maintenance of Equipment tutorial context

Sofia Alexandra Gonçalves Rodrigues

Master in Informatics and Computing Engineering

Supervisor: António Augusto de Sousa (Professor Associado)

Co-Supervisor: Maria Teresa Restivo (Investigadora Principal)

1st February, 2015

The Augmented Reality Systems in a Maintenance of Equipment tutorial context

Sofia Alexandra Gonçalves Rodrigues

Master in Informatics and Computing Engineering

Approved in oral examination by the committee:

Chair: Jorge Barbosa (Professor Auxiliar)

External Examiner: Paulo Dias (Professor Auxiliar)

Supervisor: António Augusto de Sousa (Professor Associado)

Co-Supervisor: Maria Teresa Restivo (Investigadora Principal)

1 st February, 2015

Abstract

Augmented Reality's development as a concept and available related techniques have been stabilizing throughout the years, allowing numerous AR applications to appear in several areas such as medical, design, maintenance and repair, annotation and visualization, robot path planning, military aircraft and entertainment which has received the most attention.

While many of those areas have shown the advantages AR can bring, there are still some loopholes that need to be filled. Assembly and maintenance of equipment, for instance, has been a thoroughly investigated subject of study in AR.

Many applications have been developed which demonstrate the benefits of AR in assembly tasks, but this dissertation's main innovative point is to allow the creation of AR assembly tutorials using the same AR system that allows its tutorial execution. The creation of tutorials would be carried out through the use of a manual 3D scanner, in order to carefully pinpoint each location of the assembly components.

Several virtual Objects were included in the application to aid in pointing out and guiding the user, to focus his attention in the right area. This application also aimed at a high level of customization in the interface, specifically the positioning and content of Menus.

Ten users participated in an evaluation which required the creation of a simple tutorial. Through this evaluation, it was possible to see how quickly the user adjusted to the interface's logic and easily customized the virtual objects. The calibration between the Augmented Reality System and the 3D Digitizer was also a positive point due to its simplicity, which allowed to see how intuitive and effective the 3D Digitizer was in positioning virtual Objects and interacting with the interface. Overall, the results demonstrated that this authoring tool was effective and intuitive whether when using the 3D Digitizer or the keyboard shortcuts as an interaction tool.

Keywords: augmented reality, maintenance and assembly, tutorial creation, procedural instructions

Resumo

O desenvolvimento da Realidade Aumentada como um conceito e as técnicas disponíveis relacionadas têm vindo a estabilizar ao longo dos anos, permitindo o aparecimento de uma numerosa quantidade de aplicações de Realidade Aumentada em áreas como a medicina, design, manutenção e reparação, anotação e visualização, planeamento de trajectória de robôs, aviação militar e entretimento que tem recebido mais atenção.

Embora muitas dessas áreas tenham demonstrado as vantagens da Realidade Aumentada, ainda existem algumas aberturas por preencher. A montagem e manutenção de equipmento, por exemplo, tem sido um tema de estudo investigado minuciosamente.

Várias aplicações têm sido desenvolvidas que demonstram os benefícios da Realidade Aumentada em tarefas de montagem, mas o ponto principal de inovação desta dissertação foca-se em permitir a criação de Tutoriais de montagem utilizando Realidade Aumentada através do mesmo sistema de Realidade Aumentada que permite a execução do tutorial. A criação de tutoriais seria efectuada através da utilização de um digitalizador 3D, de modo a identificar cuidadosamente a localização da próxima peça a ser montada.

Vários objectos virtuais foram incluídos na aplicação como apontadores e guias para o utilizador, de forma a focar a sua atenção no local correcto. Esta aplicação também teve como objectivo um alto nível de customização na interface, mais especificamente no posicionamento e contéudo dos menus.

Dez utilizadores participaram numa avaliação que exigiu a criação de um tutorial simples. Através desta avaliação, foi possível analisar a rapidez de ajuste do utilizador à lógica da interface e a facilidade de customização dos Objectos virtuais. A calibração entre o Sistema de Realidade Aumentada também foi um ponto positivo devido à sua simplicidade, o que permitiu analisar a eficácia e intuitividade do digitalizador 3D no posicionamento de Objectos virtuais e na interacção com a interface. No geral, os resultados demonstraram que esta aplicação foi eficaz e intuitiva independentemente da escolha de ferramenta de interacção do utilizador (digitalizador 3D ou atalhos de teclado).

Palavras-chave: realidade aumentada, manutenção e assemblagem, criação de tutoriais, instruções processuais

Acknowledgments

While words can hardly suffice to express my gratitude, I'd still like to thank my advisors, Prof. A. Augusto de Sousa and Prof. M. Teresa Restivo, for their everlasting patience and knowledge that they bestowed upon me, as many times as it was necessary at times to repeat the information. I'd like to thank Prof. J. Miguel Leitão also for his assistance with OpenSceneGraph that allowed me to speed up the development to a pace that hardly seemed possible before.

To my family, I can only say that I couldn't ask for a better one. Thank you for letting me work at my pace, even when it didn't seem the most fitting choice. Your support even when patience was lacking in me or the small gestures in the early mornings mean the world to me. It's the little things that truly matter the most.

Cathy, I couldn't call you any other way. For always sticking with me, no matter what or how long it goes between any interactions, you are a most precious best friend to me and always will be. Your artsy self was of course, highly appreciated for this dissertation and saved me for sure. To Liliana, a dear friend who is always willing to listen and help, I doubt my gratitude will be enough for your proofreading and advice, but I couldn't let it go unspoken. I hope to never lose contact with you. To João and Carlota, you two most likely have no idea how the time spent with you saved my sanity. When my brain was mostly nonexistent, the nights we spent playing, talking and relaxing brought it back so easily it still amazes me. For supporting me and bringing me up when I most needed it.

Conny, how you stood by my side all these years still amazes me. You inspire me to strive harder and to not give up. I am truly happy to be considered a best friend to you. Adi, while life brought us through many painful hurdles, I'm glad in the end contact was never truly broken. I hope to one day see you and Conny somewhere in Europe! You two made me grow in a way that I truly believe helped me during my dissertation.

Lastly, I'd like to thank the researchers, technicians and students involved with the lab for their always present help and for those moments past 19h30 when one's sanity was reaching the limit, but it was still possible to laugh before finally going home.

Sofia Rodrigues

Contents

List of Figures

List of Tables

Abbreviations

6DoF	Six Degrees of Freedom
AA	Augmented Assembly
AM	Augmented Maintenance
AR	Augmented Reality
CAD	Computer-Aided Design
CAVE	Cave Automatic Virtual Environment
GUI	Graphical User Interface
HUD	Head-up Display
HMD	Head-mounted Display
OS	Operative System
RV	Reality-Virtuality Continuum
SDK	Software Development Kit
VR	Virtual Reality

1 Introduction

Augmented Reality's development as a concept and available related techniques have been stabilizing throughout the years, allowing numerous AR applications to appear in several areas such as medical, design, maintenance and repair, annotation and visualization, robot path planning, military aircraft and entertainment which has received the most attention.

While many of those areas have shown the advantages AR can bring, there are still some gaps that can be filled. Assembly and maintenance of equipment, for instance, has been a thoroughly investigated subject of study in AR.

An assembly task typically has two phases, depending on the degree of familiarity with the object to be assembled. The first phase consists in the reading and comprehension of the assembly instructions, and the second phase, the task execution. There are a few known problems such as the time spent in the task and the learning curve for new tasks (Tang et al. 2003) which can be reduced through the use of AR, therefore improving the worker's performance (Neumann and Majoros 1998). Through immersing the user, AR can also potentiate a better interpretation of the instructions, therefore reducing the number of errors and can optimize the project through the comprehension of the difficulty of the assembly phase.

Authors such as Henderson and Feiner (2009) proved the benefits of AR to task performance and several projects were developed that tested AR's effectiveness compared to other visualization and annotation methods (Baird and Barfield 1999, Reinhart and Patron 2003, Wiedenmaier et al. 2003, Sausman et al. 2012, Hou and Wang 2013, Hou et al. 2013). Their results showed, for example, that using AR decreased the learning curve and accelerated the assembly of the objects, reducing unnecessary body movements as well.

1.1 Motivation and Objectives

From the projects evaluated, all of them focused on the utilization of AR and evaluating its benefits and effectiveness through a tutorial that varied in its complexity. None of the projects researched focused on the creation of an AR assembly or maintenance tutorial using the AR

system itself, which is what this dissertation plans to approach, along with testing its utilization to prove it brings an added bonus to the user.

Therefore, the objectives for this dissertation will be (1) to research and analyze applications in the same context – applications related to assembly and maintenance of equipment – that are based in AR, (2) to develop a tridimensional structure of medium complexity that will serve as a base to support the AR studies that will be performed in a tutorial context, (3) to specify, implement and evaluate a tutorial system, based in AR, which will, through its usage, facilitate the learning of the previously referred structure. And finally, (4) the main activities and sequence of processes will also be determined, in the context of a tutorial elaboration, to therefore allow the creation of a perspective towards the implementation of a tutorial creation system for the developed system.

1.2 Dissertation Structure

Besides the introduction, this report also contains five more chapters. In chapter 2, it is described Augmented Reality, by briefly introducing the Reality-Virtuality Continuum, followed by the Augmented Reality systems where it is explained its typical components. This subsection also details the types of devices, user interfaces and software that were researched during the development of the state of the art. Chapter 2 also contains general Augmented Reality applications and the related work to this dissertation. The latter expands mainly towards the applications related to assembly and maintenance and related works that prove the benefits found when AR is used in assembly and maintenance tasks.

In chapter 3, the solutions evaluated for the Augmented Reality Software and the Graphical User Interface are discussed. Chapter 4 explains how the application's conception occurred and the conclusions reached in terms of structures required and components for the system. Chapter 5 builds on the conception detailed in the previous chapter and describes the possible solutions and final solution found for the application. In comparison with Chapter 4, section 5.2 uses a similar architecture Figure with the components now filled in. The calibration research is detailed in this chapter as well, along with the user interface interaction and the features of the application. This chapter also details how the creation of tutorials was tested and preliminarily evaluated. Finally, in chapter 6, the dissertation is concluded with the goals met and possible future work.

2 State of the Art

Augmented reality in maintenance and assembly is a widely investigated field, in which a thorough research was required in order to find the best approach to this problem.

As such, in this chapter, in the first section it is explained what the Reality-Virtuality Continuum is as an introduction to Augmented Reality and its History, which is explained in the second section. It is then followed by the third section, which details the components of an Augmented Reality system and explains the types of tracking, display devices, user interfaces and software that were found and analyzed. Several software possibilities were researched and the most seemingly fitting will be later compared in Chapter 3. Their advantages and disadvantages found will be explained along with the reason for choosing the software system the dissertation's application utilized.

Finally, Augmented Reality applications in general and the related work to this dissertation – applications related to assembly and maintenance of equipment – are also analyzed in a section of its own, with a few applications not quite related to maintenance or assembly of equipment also detailed in the second subsection due to the relevance of some technological aspect or development strategy. The problems found in this area are described per application and the gaps that allow this dissertation to exist are also fully explained.

2.1 Reality-Virtuality Continuum

The Reality-Virtuality Continuum was defined by Milgram and Kishino (1994) in order to classify the various aspects of what they defined as Mixed Reality (MR). Their goal was to separate a variety of environments that were being associated with Virtual Reality, despite not providing total immersion and complete synthesis. They explained that these environments fall in a virtuality continuum, where real and virtual worlds are merged in different ways ranging from Real Environments to Virtual Environments.

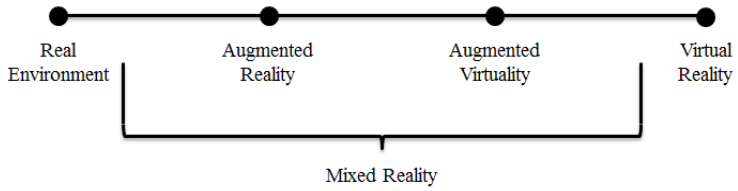


Figure 2.1: Reality-Virtuality Continuum

The Figure above details the taxonomy described, with Real Environment being the world as we know it on one extreme of the scale and Virtual Reality on the other extreme. The Real Environment in this taxonomy consists of only real objects and can include, for example, what can be observed through a video display of a real-world scene. Another example would be to visualize the same scene directly, instead of through any electronic display system. Virtual Reality, as the opposite of Real Environment, consists of only virtual objects and an example of it would be a computer graphic simulation within a CAVE (Cave Automatic Virtual Environment). Accordingly to Milgram and Kishino, between Real Environments and Virtual Reality is the Mixed Reality which is composed of environments where real world and virtual world objects are presented together within a single display. In Augmented Virtuality, the primary world is the virtual world being augmented by real objects. Finally, in Augmented Reality, the primary world is the real world being augmented by virtual objects. Augmented Reality will be defined in more detail in the next section along with its history and examples.

2.2 History of Augmented Reality

Augmented Reality (AR) had its start in 1968 when Prof. Ivan Sutherland invented the first Head-mounted Display (HMD) (Sutherland 1968). It later became referred to as the “Sword of Damocles” (Van Krevelen and Poelman 2010), since it had to be hanged from the ceiling by an adjustable pole, for it was uncomfortable to use and far too heavy for the user to support it with his own strength. The system was primitive and the graphics that comprised the virtual environment surrounding the user were merely wireframe rooms shown through miniature CRTs, such as the third picture below. It had two types of head sensors, a mechanical sensor as shown in the center picture below and an ultrasonic sensor.

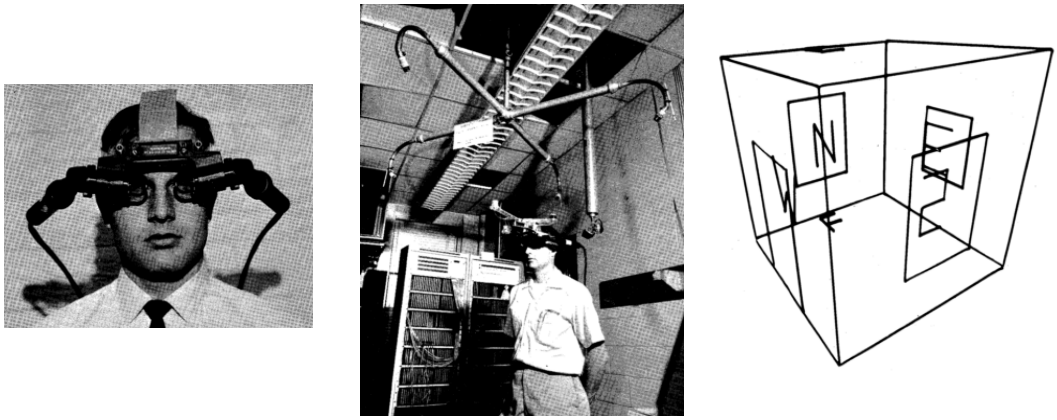


Figure 2.2: Sutherland's Head-mounted three dimensional display

It was only in 1992 however that the Augmented Reality term was coined by Caudell and Mizell in their work performed at Boeing that conveyed wiring instructions for aircraft assembly (1992). They described Augmented Reality as an overlaying of computer-presented material on top of the real world through the use of an HMD. They also discussed the advantages of Augmented Reality versus Virtual Reality where the former requires less processing power due to needing less rendering. The need for stronger research in the registration requirements that are needed to align real and virtual worlds was also acknowledged by them.

Two major contributions to Augmented Reality happened in 1993, with Rosenberg's Virtual Fixtures and the KARMA[1] from Feiner et al. At the U.S Air Force Armstrong Labs, Rosenberg developed one of the first known Augmented Reality Systems, Virtual Fixtures, where he studied the benefits of Augmented Reality on a workspace in direct and remotely manipulated tasks by using an overlay of augmented sensory information. He confirmed that, despite the normal decrease in performance when comparing in-person manipulation tasks to remote tasks, through the use of overlays in remote tasks, the performance was restored to a value closer to in-person tasks. It was also discovered that using the overlays in person could double the human performance of the task (Rosenberg 1995).

KARMA (Knowledge-based Augmented Reality for Maintenance Assistance) was developed by Feiner et al. in the Computer Graphics and Interfaces Lab of the University of Columbia and allowed the user to perform a simple maintenance task on a laser printer (1993). By attaching Logitech 3D Trackers to key components of the printer, they were able to monitor the trackers' position and orientation as the user visualized the instructions through a see-through head-mounted display as shown in the Figure below. It was one of the first assembly and maintenance applications that used augmented reality and demonstrated its benefits.

1 http://monet.cs.columbia.edu/projects/karma/karma.html

Figure 2.3: KARMA – Steven Feiner, Blair MacIntyre, Dorée Seligmann

The first of the two widely accepted Augmented Reality definitions was by Milgram and Kishino, where they defined Augmented Reality as a part of the Reality-Virtuality Continuum (RV), which ranges from a completely real environment to a completely virtual one as defined in the previous section in further detail (1994).

The second widely accepted definition of Augmented Reality appeared in 1997. According to Azuma's commonly accepted definition, augmented reality (AR) can be defined as "a system or visualization technique that fulfills three main features: (1) a combination of real and virtual worlds, (2) real time interaction and (3) accurate 3D registration of virtual and real objects" (Azuma 1997).

One of the first marker systems was presented by Rekimoto which allowed camera tracking with six degrees of freedom (6DoF) (1998). The 2D matrix markers were square-shaped barcodes (see Figure 2.4) and acted as the reference point for registering information in real world images.

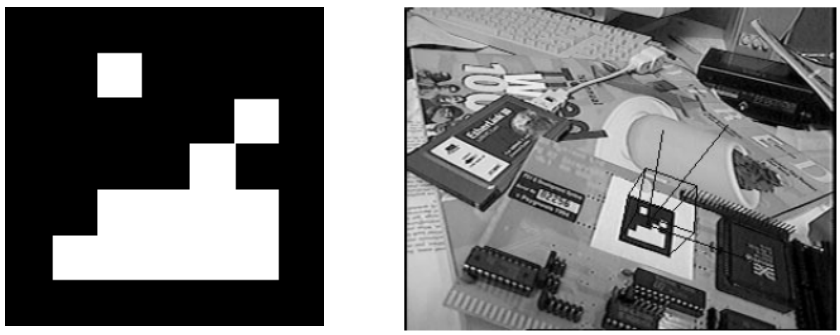


Figure 2.4: Rekimoto's 2D Matrix Markers

His method allowed the identification of 2^{16} (65536) different objects through the barcode markers, making it a cheap Augmented Reality system since the markers could be printed and allowed attachment of virtual objects to real world objects at virtually no cost. Despite the combination of visual markers and a video camera, the placement of objects by the developer was not a simple process. Since it required accurate 3D position measurements, Rekimoto also developed an authoring tool that determined the position of a 3D point in the real world based

on two 2D images where the 2D matrix code is visible. Through a stereo vision method, the 3D position was determined based on the pair of 2D points given and the virtual object was placed.

The first mobile Augmented Reality system (MARS) began in 1997 with the Touring Machine (Feiner et al.). The MARS unit provided campus information through a see-through head-worn display with an integral orientation tracker, assisted the user in finding places and allowed him to query the system about items of interest, such as buildings and statues surrounding him. The unit also possessed a hand-held computer with a stylus and a touchpad interface, a backpack holding the computer, differential GPS and a digital radio for wireless web access. The other projects associated to MARS were the Mobile Journalist's Workstation (Hollerer, Feiner, and Pavlik 1999), UIs for Indoor/Outdoor Collaboration (Höllerer et al. 1999) and the MARS Authoring Tool (Sinem and Feiner 2003).

Figure 2.5: MARS - Touring Machine

It was only in 1999 that an Augmented Reality system would reach the open-source status and become available to the general public. Kato and Billinghurst developed ARToolkit (1999), a marker-based tracking system that became one of the most well-known tools for Augmented Reality and gave rise to many other systems.

Thomas et al. developed AR-Quake, an augmented reality extension to the desktop game Quake (2000). The initial setup was based on a six degrees of freedom (6DoF) tracking system that used GPS, a digital compass and a vision-based tracking system that used fiducial markers. Over the years, the backpack that the users equipped on their backs became smaller and lighter, but it is still a system impossible to mass produce due to its heavy cost of equipment. The game is playable indoors or outdoors, allowing users that are playing inside in the desktop computer to cooperate or play against users that are outdoors. Actions of the outdoor users are performed by movements in the real environment and through the simple input interface.

The first see-through Augmented Reality system for tracking 3D markers on a phone was developed by Mathias Möhring et al. and supported the detection and differentiation of different 3D markers (Mohring, Lessig, and Bimber 2004). The integration of rendered 3D graphics into

the live video stream was performed through a weak perspective projection camera model and an OpenGL rendering pipeline.

In 2008, Mobilizy launched Wikitude[2] on the first android smartphone, an application that combines GPS and compass data with entries from the Wikipedia. With the launch of Google's mobile operating system it was possible to create the augmented reality application, Wikitude World Browser, that overlays information in the real-time camera view of the smartphone.

Also in 2008, Metaio presented a commercial mobile AR museum guide that combined technologies such as markerless tracking, hybrid tracking an Ultra-Mobile-PC (Miyashita et al. 2008). The markerless tracking was performed through the tracking of natural features. The AR-guide was possible to use by any museum visitor and was available during a six-month exhibition on Islamic Art. They proved that their usage of full 6-DOF Augmented reality as a support for appreciating artwork was possible without restrictions such as markers or other environmental instrumentations. Through their work, the usage of Augmented Reality in route guidance was proved as another possible area for the field.

In 2009, ARToolkit was ported to Adobe Flash (FLARToolkit[3]) bringing the open-source SDK to the web browser.

With the technological advancements, gradually Augmented Reality is migrating from marker-based systems to markerless and mobile context-aware methods (Barandiaran, Paloc, and Graña 2010, Álvarez, Aguinaga, and Borro 2011, Dedual, Oda, and Feiner 2011, Klein and Assis 2013). And while head-mounted displays are mostly only a novelty for the general public, their growth and the way Augmented Reality changes the human-Computer interaction is gradually turning wearable display devices into a part of our daily lives.

2.3 Augmented Reality Systems

An AR system is typically composed of the components detailed in the Figure 2.6, requiring a camera, the display device (monitor, projector or HMD – Head-mounted display) where the video image captured by the camera is merged with the graphics image, a graphics system and a tracking system. The camera can be immobilized or be controlled by the user, in which case the display device would most commonly be an HMD. The area tracked depends on the type of tracking being used, where for example, a fiducial marker vision-based tracking system is most commonly used to track and display 3D spatially registered content for a small working area and a natural features vision-based tracking system is able of tracking much larger areas.

2 http://www.wikitude.com/

3 http://www.libspark.org/wiki/saqoosha/FLARToolKit/en

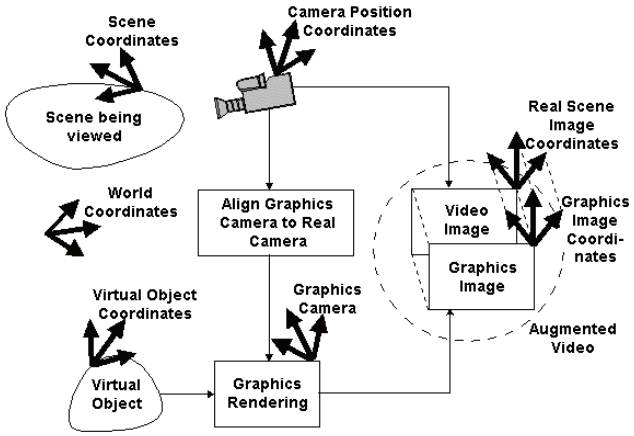


Figure 2.6: AR System Components

The following subsections will explain in further detail which types of display devices, interfaces and types of tracking are associated to Augmented Reality Systems. The types of markers existent will also be detailed along with the types of tracking. Finally, the last subsection will specify the software systems researched and evaluated.

2.3.1 Display Devices & Tracking

Augmented Reality can be used indoor or outdoor and according to Zendjebil, I., et al (2008), AR can be classified as marker-based or markerless. Marker-based techniques utilize 2D fiducial markers artificially planted in the real environment and that are easy to detect and distinguish along with being less demanding in processing power.

Existing techniques for detecting and identifying markers in the context of computer vision include correlation, digital or topological methods. Comparisons have been made between the marker processing algorithms and the digital code approach was concluded to be the most robust and reliable (Köhler, Pagani, and Stricker 2011).

Correlation techniques require additional files to store the known patterns to be able to measure the degree of correlation of a pattern found inside an image and match it successfully. An example of a system using such a technique would be ARToolkit. Digital methods however, do not require additional files to match the binary code from the marker with a non redundant ID for identification. Lastly, topological methods extract markers from the image topology and, along with correlation methods, tend to be the least robust (Costanza and Robinson 2003, Fiala 2005).

Marker trackers mostly use square or circular tags such as the ones in the Figure 2.7. These geometry primitives are well-detectable in images, serving as an initial hint for the presence of a marker. While square tags allow the marker's content to be accessed using only homography and the camera pose computed from the vertices tends to be unique, circular markers are not bound by vertices, allowing the camera pose for accessing the marker content to be computed from the whole contour surrounding the marker. The later tag tends to possess a

more robust detection towards occlusions. However, circular tags require the intrinsic data of the camera to always be known and there is always a pose ambiguity when only a single marker is used (Chen, Wu, and Wada 2004, Koehler, Pagani, and Stricker 2010). Possible examples of square and circular markers can be seen in the Figure below. The first marker is used in ARToolkit (correlation method) and it demonstrates that it is an object easy to identify by its black and white regions, also allowing the pose estimation of the objects to be calculated through the asymmetry of the content inside the black region of the marker. The middle image is a marker used in ALVAR, identifiable by a binary code. The image on the right is a circular marker used by PrizaTech[4].

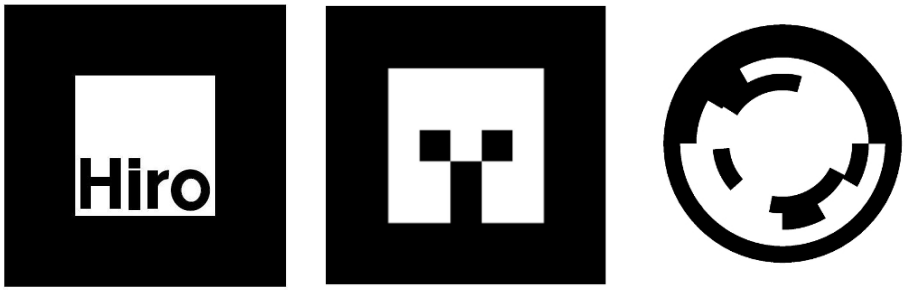


Figure 2.7: Square and Circular Markers

Markerless techniques, on the other hand, rely on natural features existing in the real environment, such as corners, edges or line segments. A widely growing markerless technique is the Edge-based, which uses 3D CAD Models provided to compare with the 2D information extracted from the scene and is used in applications outlined in the assembly and maintenance applications section.

Currently, marker-based technique is the most used in the research performed. However it should be noted that this pose estimation method requires the placement of artificial markers a priori in the scene, which isn't always possible.

Both techniques will be described further in the Software section in the augmented reality systems found and evaluated.

As for the display devices used in Augmented Reality, desktop-based applications typically use a monitor and a stationary camera. However, for a higher degree of immersion and interaction by the user, HMD displays can be used instead which would also possibly increase the mobility of the application if the camera was the only hindrance. An HMD is a Head-mounted display device, meaning a wearable device, that the user can utilize to see the real world and the virtual content. The HMD can be either an optical see-through or a video see-through.

An optical see-through HMD doesn't capture the real world unlike a video see-through. It displays the virtual objects through the optical combiners on an image plane in front of the user's eyes, merging them with the real world. The optical combiners tend to be partially reflective and partially transmissive, so that the user can visualize both the virtual objects that

4 http://www.prizatech.com

are bounced off the combiners and the real world. An example of a optical see-through system can be seen in the Figure 2.8.

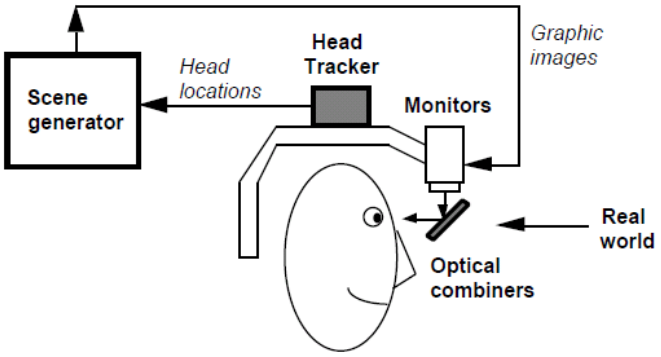


Figure 2.8: Optical see-through HMD (Azuma 1997)

A video see-through HMD utilizes one or two cameras mounted on the head gear to capture images of the real world that are then later combined with the virtual objects to create the augmented view. An example of a video see-through HMD can be seen in the Figure 2.9.

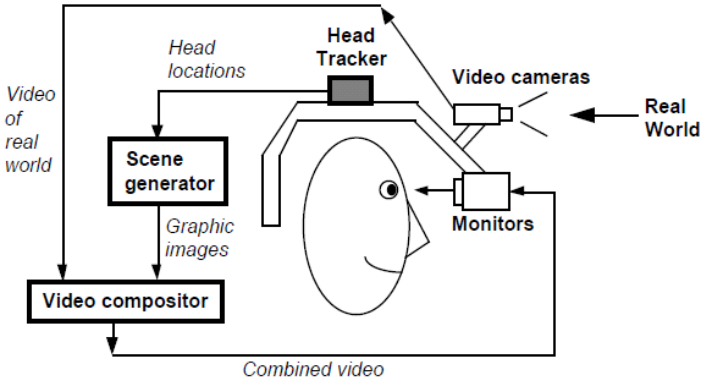


Figure 2.9: Video see-through HMD (Azuma 1997)

While video see-through systems face challenges such as resolution, due to having to capture the real world as well, and safety since they are essentially closed-view HMDs that when turned off make the user effectively blind. They also offer a higher degree of flexibility in merging both virtual and real worlds which can produce environments that are more compelling than those produced by optical systems (Rolland and Fuchs 2000, Juan and Calatrava 2011). Both have their advantages and disadvantages and face similar problems in registration and calibration which have been a point of interest over the years in research related to Augmented Reality.

For this dissertation's application, an HMD would be the most appropriate choice to allow the user to move around the workplace and visualize the objects integrated in each step of each instruction of the tutorial he is working with. A markerless approach would also seem the most appealing for the user in terms of setup difficulty since it would not require markers. However a

marker-based currently provides more stability when considering the components required for this application, as it will be discussed further in Chapter 3.

2.3.2 User Interfaces

Carmigniani et al. divided the Augmented Reality interfaces into four possible groups: Tangible interfaces, Hybrid interfaces, Collaborative interfaces and Multimodal interfaces (2011).

Tangible interfaces, as the name suggests, allow direct interaction with the real world through the use of real, physical objects and tools. For Augmented Reality, there are several examples demonstrating the use of this interface, such as the VOMAR application developed by Kato et al. which allows an user to move around virtual objects in the AR interface by using a real paddle (2000). Since virtual objects are always drawn on top of the real world images, the authors opted for minimizing the hand occlusion with transparency cues.

Another example of a tangible AR user interface is the metaDESK which explores the physical instantiation of interface elements from the graphical user interface paradigm by giving physical form to windows, icons, handles, menus and controls (Ullmer and Ishii 1997).

Tangible user interfaces in Augmented Reality can also include the use of gloves (Cooper et al. 2004) or wristbands (Feldman et al. 2005).

Hybrid Augmented Reality interfaces are composed of a mixture of different yet complementary interfaces which allow the possibility of interaction through a wide range of interaction devices. Through a flexible infrastructure, the input and output devices as well as the interaction techniques that use them are easily accommodated in a hybrid user interface. This causes an increase in the number of operations the system can support beyond the conventional ones, even possibly allowing users to specify new operations at run time (Feng, Duh, and Billinghurst 2008).

Sandor et al. developed a hybrid user interface that allowed the user to manipulate objects through various interaction techniques, such as whole-body interaction by using a dance pad, manual input devices (knobs, sliders and bend sensors), and game controllers (2005). As defined above for hybrid user interfaces, they support interactive end-user reconfiguration of the mapping between devices, objects and operations. Their system used a head-tracked, see-through display and provided overlaid visual and auditory feedback when the system was being reconfigured.

Another example of a Hybrid Augmented Reality user interface would be the balloon selection project developed by Benko and Feiner (2007). They developed a 3D selection technique that utilized a hybrid touch-sensitive interface and demonstrated the possibilities of multi-finger and multi-touch techniques for improving interactions on and above those surfaces. Their technique decomposed a 3DOF precise positioning task into a set of 2DOF and 1DOF positioning tasks on the tabletop and reduced hand fatigue while allowing the users to gain accuracy.

Collaborative Augmented Reality interfaces utilize multiple displays to support remote and co-located activities. The former type of activity coordinates efficiently with Augmented

Reality through the integration of multiple devices with multiple locations that allow the enhancement of teleconferences (Barakonyi, Fahmy, and Schmalstieg 2004). These interfaces can also be applied to medical applications to perform diagnostics, surgery or routine maintenance. The latter type of activity requires 3D interfaces to improve the collaboration of the physical workspace and has as an example the Studierstube project and related framework (Schmalstieg, Fuhrmann, and Hesina 2000, Schmalstieg et al. 2002). This project aims at bridging multiple user interface dimensions through Augmented Reality and features multiple users, contexts, locales, applications, 3D-windows, hosts, display platforms and operating systems.

Multimodal Augmented Reality user interfaces combine two or more user input modes, such as speech, touch, natural hand gestures or gaze with real objects in a coordinated manner. These types of interfaces aim to offer an expressive, transparent, efficient, robust and highly mobile human-computer interaction (Carmigniani et al. 2011) and allow the user to switch the input mode to one better suited to a particular task or setting.

An example of this type of user interface is the MIT's sixth sense wearable gestural interface WUW (Mistry, Maes, and Chang 2009). This interface seeks to bring information away from paper and computer screens through the use of a tiny projector and a camera mounted on a hat or worn as a pendant. It sees what the user sees and augments surfaces, walls and physical objects through natural hand gestures, arms movement or through interaction with the object itself. Lee et al. also developed a multimodal interaction system that utilized the user's gaze information to interact with the Augmented Reality environment (Lee et al. 2010). The wearable Augmented Reality annotation system was composed of an optical see-through HMD, a camera and an eye tracker.

The user interface for this dissertation's application will be a tangible interface since, despite the keyboard shortcuts that will be available for the menu interface, the user will most commonly not begin using the application through the shortcuts, but rather using a 3D Digitizer. This interaction between the user and the application will be explained in Chapter 4.

2.3.3 Software

Several well-known AR software platforms were developed by research groups such as the Human interface Technology Laboratory (HIT) from Washington University, the Computer Graphics and Interfaces Lab from Columbia University and the VTT Technical Research Centre of Finland, which allowed the development of specific-purpose AR applications.

These platforms, which provide basic algorithms and implementation knowledge in various specialized problems, have examples such as ALVAR, ARTag, ARToolkit and Studierstube that provide the user with an easy-to-use tool, therefore allowing anyone who has AR or no AR background to quickly develop AR applications from scratch.

This section will be mostly focused on detailing the development systems investigated that were available for Windows, although some will also have mobile options available. There were

many more such as Catchoom[5], Cortexica[6], D'Fusion[7] and Layar[8] that were only available for mobile platforms and were therefore not the main target of this research due to the use of the manual 3D Digitizer making the application indoor based and stationary.

ARToolkit[9] (Kato and Billinghurst 1999), is one of the examples of marker-based platforms that this investigation will discuss in larger detail and is the most well-known tool that has been widely used for AR applications. It has an open-source and free platform version that allows the tracking of pre-designed markers to recognize different targets on which the virtual objects can be superimposed. While the ARToolkit free version is no longer updated, it gave rise to many other platforms based on its source-code, such as ARToolkitPro, NyARToolkit (a multi-platform and OS) and ARToolkitPlus. ARToolkitPro[10] is the commercial version of ARToolkit by (ARToolworks) which provides natural features tracking that the open-source version does not, along with a more robust tracking algorithm. It is also available as a mobile version for iOS and Android. ARToolKitPlus was one of the successors of ARToolkit and was created by (Wagner and Schmalstieg 2007) based on ARToolkit's and ARTag's source-code. It brought many performance improvements over the original ARToolkit and was succeeded by Studierstube tracker[11].

ALVAR[12], which was developed by the VTT Technical Research Centre of Finland, also allows marker-based applications as the ones described above and markerless through features in the environment or templates given to the application. It was based on ARToolkit as well, and its last update was in 2012. It was designed with flexibility in mind and is independent of any graphical libraries, allowing its easy integration in existing applications. It provides high-level tools and methods for the creation of augmented reality applications with a few lines of code. It also includes interfaces for all of its low-level tools and methods, which allows the creation of alternative solutions and entirely new algorithms by the user.

ARTag (Fiala 2005), on the other hand, is no longer available due to licensing. It was originally created by Mark Fiala from the Computational Video Group of the Institute for Information Technology, and was also based on ARToolkit. Goblin XNA[13], from the Columbia University, initially allowed the use of ARTag to create augmented reality games for windows and xbox, but switched to ALVAR due to licensing issues detailed above.

On a commercial level, companies like Metaio have released an SDK[14] with several licensing options available, ranging from free to full-rights, and which provide similar options to the ones above, but on a wider scale of tracking possibilities. Unlike the previously mentioned libraries, Metaio SDK allows both marker-based and markerless AR applications to

5 http://catchoom.com/product/craftar/augmented-reality-and-image-recognition-sdk/

6 http://www.cortexica.com/

7 http://www.t-immersion.com/products/dfusion-suite/dfusion-pro

8 https://www.layar.com/products/creator/

9 http://www.hitl.washington.edu/artoolkit/

10 http://www.artoolworks.com/

11 http://studierstube.icg.tugraz.at/handheld_ar/stbtracker.php

12 http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/index.html

13 http://goblinxna.codeplex.com/

14 http://www.metaio.com/sdk/

be developed for free with a watermark. It was also the only SDK found that allowed 3D-model based tracking.

Robocortex[15] offers two SDKs, Rox Tracking SDK and Rox Odometry SDK, but only the later is for Augmented Reality Applications. It only allows the use of natural features of the referenced images to track and position the objects.

ARPA[16], Qualcomm Vuforia[17] and Xloudia[18] are examples of SDKs that can only be utilized in Windows through their Unity plugins, however the later is a commercial SDK only with no free version and it merely allows image and movie tracking through natural features. All three can be utilized in iOS and android. ARPA offers, through its unity plugin only available for the pro version, the automatic detection of images which represent natural markers and the display of any kind of multimedia content over them in real time. And Qualcomm Vuforia offers the following features through its unity plugin: image targets, cylinder targets to track objects such as a can of Coca-Cola, multi targets, user defined targets to allow the user to choose his own marker, smart terrain, cloud recognition to recognize targets located in a cloud database, text recognition, frame markers and virtual buttons.

The libraries that will be discussed and evaluated in Chapter 3 are ALVAR, ARToolkit and Metaio SDK. They were tested as a possible incorporation to the application and the results of the evaluation will be further discussed in the Augmented Reality Libraries subsection of Chapter three.

2.4 Augmented Reality Applications

Augmented Reality applications first appeared in the military, industrial and medical areas and were mostly confined to researches that never reached the general public. As the years passed, open-source and commercial Augmented Reality systems began to appear and spread the use of augmented reality to other areas such as entertainment, edutainment, design, navigation, touring, personal assistance, among many others.

The first subsection of this section will discuss some general areas of applications and the second subsection will give a stronger focus to the assembly and maintenance area due to being the focus of this dissertation. It will analyze the applications in detail to compare with this dissertation's focus.

2.4.1 General Applications

Augmented Reality's benefits and advantages were applied in several areas besides the targeted area for this dissertation, maintenance and assembly. In the educational field, Augmented Reality can be used as a complement in various ways. Markers can be embedded in the students' textbooks or other educational reading material to provide them with additional

15 http://www.robocortex.com/index.php/sdk

16 http://arpa-solutions.net/en/ARPA_SDK

17 https://developer.vuforia.com/resources/sdk/

18 http://www.xloudia.com/tech/

information in the form of text, graphics, video and audio (Medicherla, Chang, and Morreale 2010, Chen and Tsai 2012, Di Serio, Ibáñez, and Kloos 2013). It can also serve as an alternative way to visualize parts or systems of the human body (Blum et al. 2012) and mathematical and geometric concepts in a collaborative manner (Kaufmann and Schmalstieg 2003). Augmented Reality also benefits remote education by allowing students and instructors to share an Augmented Reality environment and providing the students the opportunity to interact and collaborate actively (Ying 2010).

Besides the educational field, Augmented Reality is also used in the medical field where it can be used to provide surgeons with additional information that can be directly overlaid on the patient's body during surgeries and other interventional procedures (Marescaux et al. 2004, Nicolau et al. 2005, Nicolau et al. 2011). It can also aid in rehabilitation by, for example, providing the patient with a virtual three-dimensional limb visualization that demonstrates the movement that must be performed (Klein and Assis 2013).

In areas such as tourism and sightseeing for example, Augmented Reality can enhance the user's experience by providing location-based information such as simulations of historical events or a look into the past of the location and how it evolved (Hollerer, Feiner, and Pavlik 1999). It can also provide additional information and guidance in urban environments or museums (Feiner et al. 1997, Miyashita et al. 2008) and can be used to reconstruct cultural heritages, allowing visitors to visualize and learn about the ancient architecture and customs (Vlahakis et al. 2002).

Augmented Reality is widely used in commerce as well for advertising and promoting brands or products in an interactive manner. Above all, it is a technology that is gradually being acknowledged for its benefits in a wide variety of areas, which is aiding in the development of its effectiveness and overall growth.

2.4.2 Assembly and Maintenance Applications

Assembly instructions, drawings or schematics are often detached from the equipment, creating an attention split in the worker’s focus between the instructions and the parts being assembled which consumes valuable time, especially when the instructions are not conveniently placed relative to the operators’ workspace. Some of the detriments of switching focus between the paper instructions and the workplace can be reduced productivity, increased assembly times and errors, repetitive motions and strain injuries (Ong, Yuan, and Nee 2008).

AR allows the display of information in the user’s field of view, therefore reducing possible motion injuries, decreasing the time spent and improving the task performance. It allows the worker to fully concentrate on the assembly task, not needing to switch his attention and body position as he is working.

It was proven that AR can be used effectively in assembly sequence planning and evaluation. Reiners et al. (1999) delineate a demonstrator for the task of door lock assembly (see Figure 2.10) in a car door to teach users how the door lock is assembled into the car door. Raghavan et al. (1999) developed an AR-based mixed prototyping method for assembly

evaluation that allowed a human to be guided by a multimedia augmentation to assemble an industrial object.

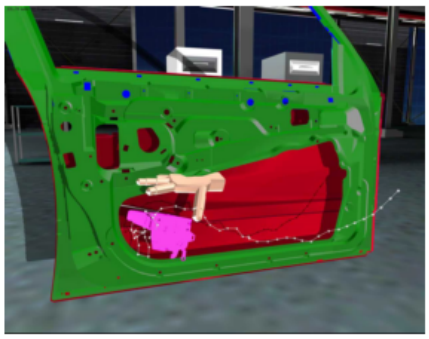


Figure 2.10: Doorlock Assembly

Baird and Barfield (1999) developed a system to evaluate the effectiveness of wearable augmented reality displays in assembly tasks. Their proposed task consisted in the assembly of a computer motherboard by fifteen subjects and the instructions were seen in a paper manual, a computer screen, an opaque augmented reality display or a see-through augmented reality display. Their variables for evaluation were the time of assembly and number of assembly errors, plus a usability questionnaire. The preferred device was the see-through display; however there were many dependent variables that the authors chose to not isolate and may have influenced their results, such as the differences in comfortableness provided by the HMDs used, how strong the contrast was and how easy it was to read with. There was also no registration of text instructions associated to the actual object when using AR; instead, the text instructions were seen unattached to anything in specific and near the motherboard. Nevertheless, the augmented reality display devices were still chosen in favor of the paper manual and the computer screen.

Stork and Schubö (2010) also investigated the benefits of AR and spatial cueing in assembly tasks. Their results showed that tasks using contact analog highlighting extracted the most benefits and improvements over all in task performance, reduction of performance times, eye fixations as well as increased velocity and acceleration of reaching and grasping movements. Tang et al. (2003) developed a simple lego assembly to test the relative effectiveness of AR instructions in an assembly task. Their results indicated that overlaying 3D instructions on the assembly task reduced the error rate by 82%, particularly helping in diminishing cumulative errors. They also demonstrated that the mental effort required for the task was reduced through the use of AR.

Pathomaree and Charoenseang (2005) developed an AR assembly training system to intensify the skill transfer in assembly tasks. Their experimental results showed that the AR training assembly system increased the speed of assembly of the user when transferring from AR to non-AR. It could also reduce assembly completion times as well as the number of assembly steps.

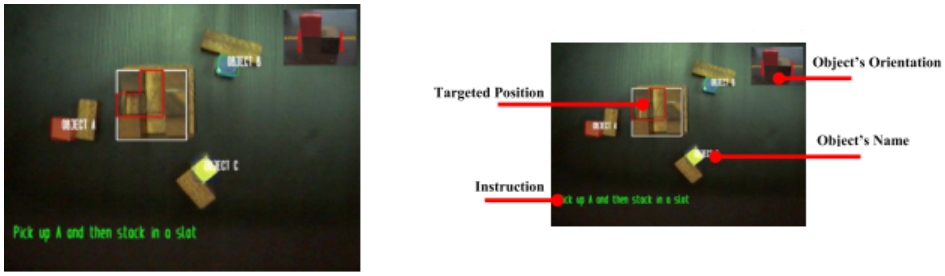


Figure 2.11: Pathomaree and Charoenseang

Recently, Hou et al. (2013) developed an AR System animated prototype for assembly tasks, using a lego model as the assembly and experimental tester task. Their results demonstrated that the AR system yielded shorter task completion times, less assembly errors, and lower total task load. The learning curve of novice assemblers was also reduced and the task performance which was relevant to working memory was increased when using AR training.

In the marker-based applications, Liverani et al. (2004) demonstrated that AR can be integrated with a CAD assembly software and a wearable computer system for checking and evaluating assembly sequence and interactive validation. A sample of their work can be found in Figure 2.12.

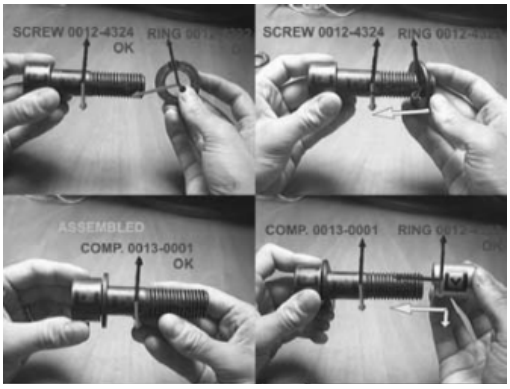


Figure 2.12: Liverani et al.

Salonen et al. (2007) proposed a system for a 3D wooden puzzle assembly using ARToolkit (see Figure 2.13). The system was fixed, simple and it functioned in an intuitive manner. It mainly had the goal of serving as a demonstration to the industry of the capabilities of AR and receive feedback on its advantages and disadvantages. Zauner et al. (2003) developed an AR-assisted step-by-step furniture assembly system, where ARToolkit was used for tracking and recognition of assembly components.

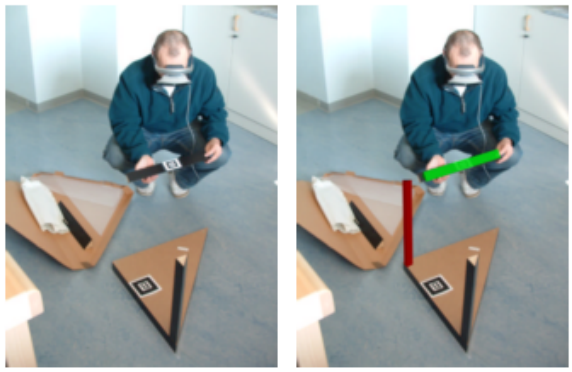


Figure 2.13: Zauner et al.

Platonov et al. (2007) described a solution for AR based repair guidance through the use of a markerless CAD based tracking system which was able to handle different illumination conditions during the tracking stage, partial occlusions and rapid motion (see Figure 2.14). Starting in 2007, Feiner and Henderson, from the Computer Graphics and User Interface Laboratory at Columbia University, began developing a series of prototypes to evaluate the benefits of AR in maintenance and repair tasks and whether it improved task performance. Their latest publication associated to ARMAR was in 2011 where they focused on the psychomotor phase of a procedural task (Henderson and Feiner 2011).

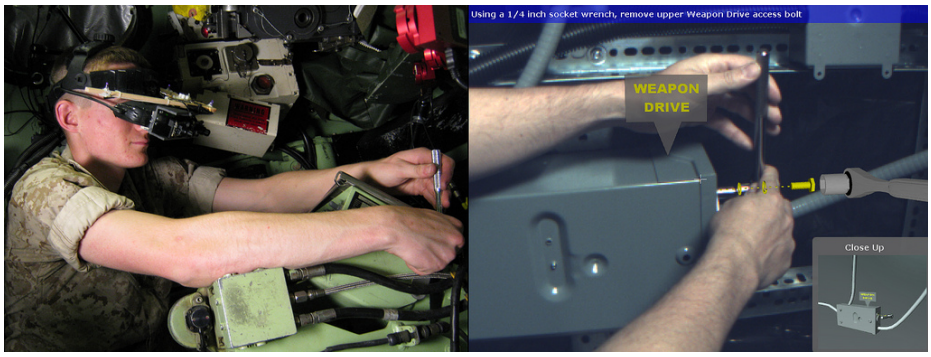


Figure 2.14: ARMAR

On a more interactive level, Yuan et al. (2008) developed an AR-based assembly guidance system using a virtual interactive panel and an interaction pen that allows the user to easily proceed through a pre-defined assembly sequence without needing any markers attached on the assembly components (see Figure 2.15).

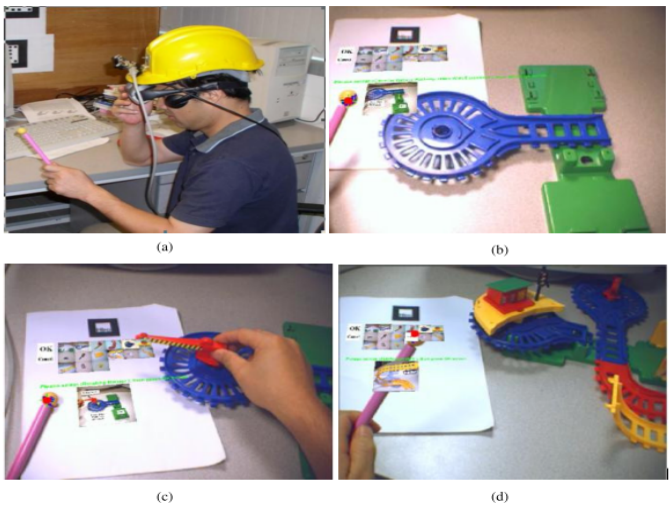


Figure 2.15: Yuan et al.

A considerable amount of applications have been currently developed, however its totality was not discussed here. Most AR assembly systems are currently based on pre-defined markers, with different patterns for each assembly component in order to properly track them (Raghavan, Molineros, and Sharma 1999, Liverani, Amati, and Caligiana 2004, Hou and Wang 2013). One of AR's challenges is to be able to determine when, where, and what virtual information to display in the augmented world during the assembly process. There is also an issue with requiring at least a partial understanding of the surrounding assembly scene, which currently is only available through feature tracking methods.

2.5 Summary

In this chapter, the Reality-Virtuality Continuum and Augmented Reality were defined, along with Augmented Reality system components, including display devices, possible tracking types and user interfaces. They were explained in as much detail as possible to allow the related applications' value to this dissertation to be clearly understood.

It was also demonstrated that over the years, the areas where Augmented Reality could enhance performance or contribute to a fuller experience have been increasing and allowing the amount of research and investment to grow in a considerable manner.

As for the related applications to this dissertation, it was shown in this chapter that the applications found mainly focused on the utilization of tutorials and the benefits that AR can provide to maintenance and assembly tasks, in terms of reducing eye and head movement and increasing focus on the task. To the best of our knowledge, there are no approaches that allow creation and use of tutorials.

As such, the focus of this dissertation is to implement an innovative approach that allows the creation of tutorials through the use of the AR system, and also allows their use.

Further detailing in regards of the technological research that was required for this dissertation and implementation will be discussed in the following chapters.

3 Technological Discussion

Before and during the development of the application, several possibilities were evaluated for the required components. As such, this chapter will detail the choices found for each component, their characteristics and explain how they were evaluated and discarded.

The possibilities evaluated were for the Augmented Reality Library and the Graphical Interfaces. The former occurred before any sort of application development started, while the later occurred during development also.

3.1 Evaluated Solutions

The components that required an analysis and investigation were the Augmented Reality Library and the Graphical Interfaces.

The requirements for the Augmented Reality Library differed based on the tracking type. Libraries, such as ALVAR and Metaio, that allow markerless tracking, had different features to be evaluated that could weigh in its advantages or disadvantages when compared to ARToolkit that only contained marker-based tracking.

For the marker-based tracking, the existence of a multimarker implementation was necessary to increase robustness to occlusion so that even if one marker is obscured, another may be visible, and to improve pose-estimation accuracy since in a multimarker set, all the marker corners are used to calculate the pose which means that the markers effectively cover a larger optical angle and reduce the numerical error. The multimarker tracking principle bases itself on a set of markers that are defined based on their relative positions. By having at least one of those markers visible, it is possible to compute the position of the marker set in the camera's coordinate system.

Both types of tracking, marker-based and markerless, were tested in a variety of lighting conditions and marker positions (object position for the markerless tracking that Metaio possesses), and also in their pose-estimation stability, tracking speed, how many markers it is possible to track at the same time and in how complete marker occlusion is handled.

For the Graphical interfaces, the possibility of using it in a multi-threaded application where the main thread did not need to be directly associated with running the interface was a requirement. The main thread would have to run the video capture and marker tracking at all times, making it impossible to do so if it is waiting for user input.

3.1.1 Augmented Reality Libraries

The software systems that were evaluated were ALVAR, ARToolkit and Metaio SDK. As previously described, the open-source version of ARToolkit allows marker-based AR applications and is no longer being updated, but the author of this document had access to it in a subject she attended and is therefore more familiarized with it. There is also a commercial version of ARToolkit, but that was not evaluated nor considered in table 3.1.

Metaio SDK was included in this evaluation due to its 3D CAD Tracking and the evaluated ALVAR version here is the one available for Windows and Linux (there is another mobile SDK version, but it is not available to the public). All other libraries found either required Unity Pro, were commercial versions or did not meet the required parameters in marker-based tracking. The table in page 25 compares the three Augmented Reality Libraries.

ARToolkit is a multi platform library that offers marker-based tracking in an user accessible manner. It also offers camera calibration, the ability to use any square marker patterns as long as they follow the black square design and doesn't have a steep learning curve. It has a simple graphic library based on GLUT[19] and a fast rendering based on OpenGL[20]. Overall it is a good starting approach to small Augmented Reality projects. However, the lack of support such as 3D Model Loaders and user interface components make this library less approachable for bigger Augmented Reality projects.

Metaio SDK allows the creation of marker-based or markerless AR applications. The types of tracking available are fiducial tracking, sensor-based tracking, markerless tracking, instant tracking, QR/barcodes or a dummy. Fiducial tracking has three types of markers available: ID markers, Picture markers or LLA (Latitude, Longitude and Altitude) markers. Sensor-based tracking can be done through GPS coordinates or orientation of the device. Markerless tracking has three types of markers available: a 2D Image, a 3D Map and a CAD Model. Instant tracking allows the user to take a snapshot of the camera stream and use it as a markerless image tracking reference in 2D space. Instant 3D tracking stands for creation of the point cloud (3D map) of the scene and immediately use it as a tracking reference. The dummy tracking can be used to easily attach an overlay to the rendering source in a fixed pose.

The first comparison occurred between ARToolkit and Metaio SDK and several tests were performed to evaluate their performance. The tests performed aimed at testing how the marker-based algorithms on both SDKs behaved with multiple fiducial markers in terms of illumination variability and tracking speed and stability. For Metaio SDK it was also tested multiple picture markers and 3D model based tracking.

19 https://www.opengl.org/resources/libraries/glut/

20 https://www.opengl.org/

The results demonstrated that Metaio provided more stability in illumination variance and partial occlusion of markers. It was also faster in recognizing the fiducial markers, which were the only ones that could be compared with ARToolkit. Further tests were done in 3D model based tracking which proved to be difficult to work with, as it was still in its beta phase. The multimarker system that Metaio offers is also not truly a multimarker implementation when compared to ALVAR and ARToolkit. It is merely the tracking of multiple single markers in parallel. This does not serve the purpose of reducing marker occlusions by the user while the application is running and a tutorial is being created.

ALVAR was found in a posterior date and was the chosen Augmented Reality Library for this application. It allows both marker-based and markerless tracking. Its marker-based tracking provides an accurate marker pose estimation, two types of square matrix markers (*MarkerData* and *MarkerARToolkit - fiducial*), allows future marker types to be easily added and can recover from occlusions. When using multiple markers for pose detection, the marker setup coordinates can be set manually or they can be automatically deduced through autocalibration. Its markerless tracking includes feature-based by tracking features from the environment and template-based which consists on the process of matching images or objects against predefined images or objects. Besides its tracking features, it also allows the hiding of markers, has tools for camera calibration, a few methods for tracking optical flow, includes the Kalman library and several other filters, allows distorting or undistorting of points and can project points, and finally, it can also find the exterior orientation by using point-sets.

Since ALVAR only depends on OpenCV[21], a Computer Vision library, it is not bound to any graphical libraries and provides samples of integration with GLUT and OpenSceneGraph[22]. After a few initial hurdles with OpenSceneGraph, the author found ALVAR to be the most efficient in tracking speed and stability despite changes in the illumination. The OpenSceneGraph was also considered in choosing ALVAR since it eliminated the search of a Graphical Library with its various features, such as most importantly the scene graph implementation, but also its support for OpenGL and a wide range of 2D Image and 3D database formats. It has loaders available for formats such as 3DS, OBJ, PNG, JPEG among others, and also has support for anti-aliased Truetype text. OpenSceneGraph, through the scene graph approach, represents 3D worlds as a graph of nodes that can be logically and spatially grouped for behavior and high performance. Overall, since it is an OpenGL-based high performance 3D graphics toolkit and one of the three most used in Virtual Reality, it allowed the author to use her OpenGL knowledge from previous subjects in a more effective way than using OpenGL directly through GLUT and ARToolkit.

21 http://opencv.org/

22 http://www.openscenegraph.org/

SDK	Marker-based Tracking	Marker Identification Type	Markerless Tracking	OS	License Type	Advantages	Disadvantages	Score
ALVAR	Fiducial Single and Multi-marker	Digital Codes (ID) and Correlation	Image Tracking (Natural Feature)	Windows, Linux	LGPL	Can be used with OpenSceneGraph. Offers tracking heuristics that identify markers that are "too far" and that help recover from occlusions in the multimarker.	Steep learning curve for users not experienced with ALVAR and OpenSceneGraph.	8
ARTool-kit	Fiducial Single and Multi-marker	Correlation	N/A	Windows, Linux, Mac OS X, SGI	GPL	Appropriate for learning Augmented Reality.	Windowing systems support integration is difficult and outdated.	5
Metaio	Fiducial Single and Multi-marker	Digital Codes (ID)	Image Tracking (Natural Feature) and 3D CAD Tracking (Edge Tracking)	IOS, Android, Windows, Linux, Mac, Unity 3D	Free with watermark + commercial SDK version available	Appropriate for Commercial use in small advertising applications.	3D CAD Tracking is too unstable and has no multimarker (only parallel single marker tracking - low usability with having to separate objects per coordinate system)	4

Table 3.1: Augmented Reality Libraries

In conclusion, when comparing the three systems similarly to Table 3.1, ALVAR scored the highest, despite the steep learning curve caused mostly by OpenSceneGraph since the author was not familiar with it. ARToolkit was quite simple to use for starting projects and Metaio had its highest simplicity in quick, single-marker projects. However, for this dissertation, since the application required a good structure to be built on, ALVAR proved to be the most favorable, along with its more efficient tracking techniques that use ID methods.

3.1.2 Graphical User Interfaces

Despite choosing ALVAR that enabled the use of OpenSceneGraph, the windowing system of the later wasn't sufficient for the editing feature of the application. An extra GUI was required to create secondary windows for editing parameters such as text color, text size or to manually reposition an object. The evaluated GUIs were Qt[23] (versions 4.86. and 5.3), GTK3[24] and the Win32 API.

The goal here was to find a GUI that would function properly in a thread different from the main one, since the main thread would always need to be running the video capture and computer vision algorithms.

Unfortunately, while Qt seemed like a promising choice, it was not possible to include it in the middle of the development after realizing that another GUI was needed. Both versions 4.86 and 5.3 did not compile in the environment used, Visual Studio 2010 (VS2010), as it is mentioned in the website that Qt applications will run more smoothly on its Creator program (despite providing a Visual Studio plugin). Since the application development had already started in VS2010, Qt was discarded in order to not need to restart the application from zero.

The next GUI found was GTK3 which, despite its seemingly steep learning curve, was easy to use after a few initial hurdles adjusting to it and provided components such as combo boxes and spin buttons in alternate threads as it was required.

This GUI was chosen and used for editing object options that will be explained in the following chapter.

3.2 Summary

This chapter aimed at explaining the discussions undertaken during the research of components for the application developed along with paths that were discarded due to the impossibility of their development. As appealing as the Metaio SDK appeared to be, it was not viable for implementation through either its marker-based tracking or markerless. Also despite the familiarization of the author with ARToolkit, ALVAR was still a stronger choice for the final solution due to providing Openscenegraph and a steadier tracking than ARToolkit.

The fact that the object edition required an additional interface was due to the fact that the 3D Digitizer and the menu interaction, which will be discussed in further detail in the following

23 http://qt-project.org/

24 https://developer.gnome.org/gtk3/stable/

chapter, reached their limit when it came to editing data belonging to the objects. It would have required virtual keyboards, which were out of the scope and time for this dissertation.

4 Conception of a Tutorial System based on Augmented Reality

The Assembly and Maintenance applications investigated all followed a particular structure, by using procedural instructions to demonstrate how to assemble or maintain the object in focus for their projects. This type of instructions follows the procedure form and describes how to complete tasks in a stepwise manner (Eiriksdottir and Catrambone 2011).

As mentioned in Chapter 2, Augmented Reality is a good addition to the assembly and maintenance area since it allows the worker to focus on a task more effectively (Neumann and Majoros 1998). While a regular task would require the worker to switch his attention between the object, the manual and the pieces yet to be assembled, Augmented Reality can reduce that attention switch to only the transition between the object and the pieces by simply displaying the instructions directly associated to the object in its work area (Hou et al. 2013).

Therefore, while the benefits of using Augmented Reality in Assembly and Maintenance applications have been proven, as previously explained in Chapter 2, the applications reviewed did not consider the authoring of assembly and maintenance tutorials. This gap proved to be an interesting starting point for researching what would be required to allow the user to create his own tutorials.

4.1 Tutorial Structure

The authoring application would have to allow the user to create, edit and visualize Augmented Reality tutorials related to the assembly and maintenance of objects. Due to being a tutorial to replace physical manuals of maintenance or assembly, it requires a pre-defined structure that would allow the user and the application to easily communicate. The initial structure was a Tutorial that was composed of a list of steps where each step had a list of objects. However, this structure didn't allow the use in an effective manner of procedural instructions. Since Eiriksdottir and Catrambone discovered that the performance of procedural

instructions is increased when examples are provided along with specific goals and step descriptions, the structure in the Figure 4.1 that splits Instructions into Steps seemed the most fitting. This hierarchy was chosen in order to allow, for example, a tutorial instruction to have two Steps: the first where the user is shown what to place where, and the second Step as a confirmation of what should now be the final result. This type of structure also allows for a final Step where the user is notified that tutorial was completed.

This structure also highlights one of the current challenges of Augmented Reality, which is to be able to determine when, where and what virtual information to display in the augmented world during the assembly or maintenance process. For this application, since the main focus is the creation of Tutorials, the helping objects (virtual) chosen were given the following functions: arrows can point to bring to focus a certain area of the object, Text can be used to detail the steps descriptions associated to each Instruction and 3D Models can serve as a virtual representation of the real object piece.

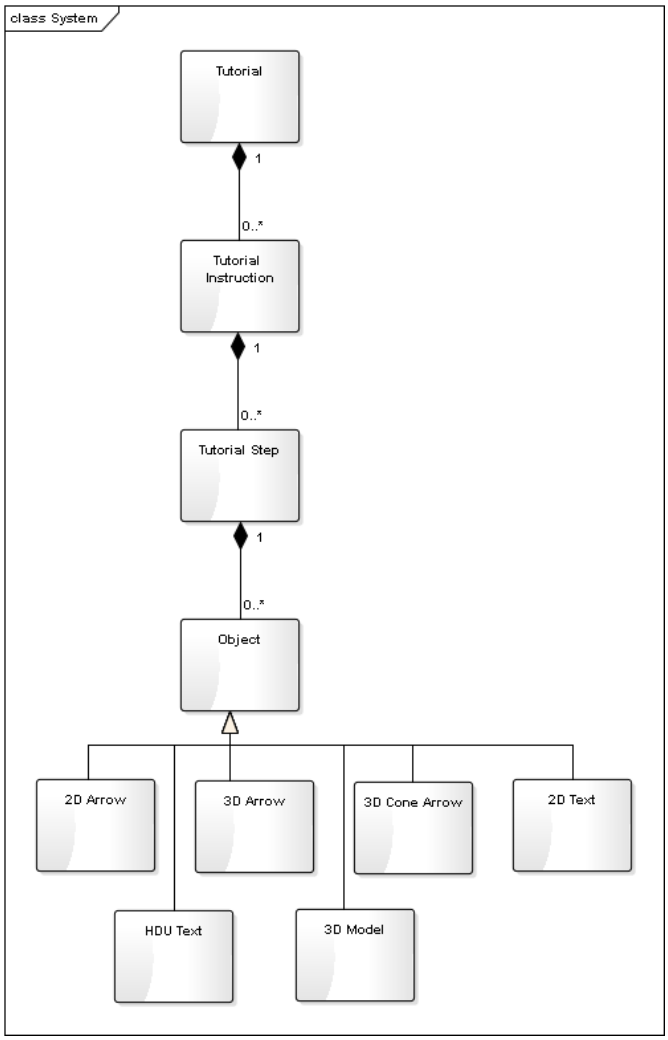


Figure 4.1: Tutorial Structure

In this structure, a tutorial is composed of an ordered sequence of instructions where each instruction contains an ordered sequence of steps and each step contains the objects that the user

can visualize. Each object is of one of six different types: a 2D arrow, a 3D arrow, a 3D cone arrow, an HUD text, a 2D Text or a 3D Model.

4.2 Architecture

Considering the evaluated related work, the authoring application would provide a higher degree of tracking stability if it incorporated an Augmented Reality software that allowed marker-based tracking and multimarkers. Recovery from occlusion would also be an added bonus to avoid breaking the concentration of the user.

Feature-based tracking or 3D CAD Tracking on their own can make a system more mobile than marker-based, but considering the fact that a 3D Digitizer is needed to capture 3D coordinates, the system would already be restricted to a small workplace area. The 3D Digitizer available for this application was the Phantom Omni Device[25] that actually is a Haptic device. The Phantom Omni Device will not be used as a Haptic device, but rather as a means to acquire 3D coordinates, that would allow the user to position the stylus where they would like. Those 3D Coordinates would then be transformed into the 3D World coordinates of the Augmented Reality Library system. For the purpose of reinforcing the idea that this device has not been used as a Haptic device and rather as a digitizer, it will be referred to as a 3D Digitizer.

As such, the following image – Figure 4.2 – details a possible high-level architecture for the system components of the authoring application.

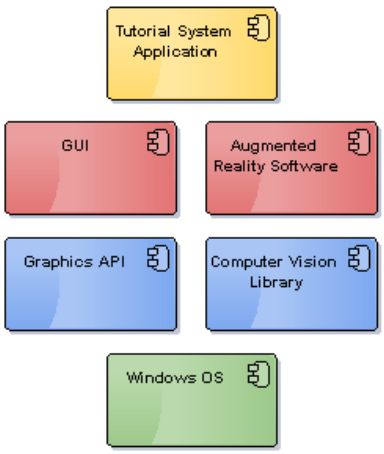


Figure 4.2: High-level Architecture

At the bottom, the Operating System (OS) chosen is Windows due to the author's familiarity with the Augmented Reality systems available for this OS. Most software libraries researched were either available for Windows and mobile (iOS and android) or mobile only.

Above the Operating System would lie the Computer Vision library, which would be responsible for processing the images captured from the camera and finding the markers that the Augmented Reality Software would then analyze. The Graphics API would be responsible for

25 http://www.dentsable.com/haptic-phantom-omni.htm

responding to the Augmented Reality Software in terms of drawing Objects, managing illumination and handling the rendering of the interface and the current Tutorial being visualized if any is being shown.

The Graphical User Interface (GUI) will serve for the user to create, edit and visualize Tutorials. The Tutorial System Application component detailed above would then be responsible for handling the files associated to Tutorials and connecting the GUI, the Augmented Reality Software and the Graphics API.

4.3 Augmented Reality System Components

As previously mentioned in Chapter 2, an Augmented Reality System is typically composed of a camera, a display device, a graphics system and a tracking system. The application would require the previously referred Augmented Reality software, a display device to visualize the virtual objects that would preferably be an HMD to allow the user to visualize the virtual content freely, a device to acquire 3D Coordinates, a graphical user interface, a graphics API to represent the virtual objects and if possible, to create a structure similar to the Tutorial structure mentioned above to organize them. The user interface envisioned for this application would be tangible since a 3D Digitizer would be used to interact with the application to place virtual Objects.

4.4 Possible Solutions

The solutions described here were created before development started. They were divided into two possibilities, the first for a marker-based approach and the second for a markerless approach.

Both solutions would require the use of a graphical interface such as Qt[26] for example and a 3D Digitizer to acquire the 3D coordinates of the position of each assembly component in its sequence in the task. Two solutions were still demonstrated at this time instead of a final one, mainly due to difficulties in the choosing of a SDK that would be fitting for what it is wanted, which was a markerless solution. Since the markerless solution might not be possible due to Metaio's 3D CAD tracking still being in a beta phase, a marker-based solution was also shown. While they may appear similar in most aspects, it is the interaction with the SDK that would vary and matter the most in terms of tracking.

The differences between both solutions can also be found in the physical space required for each, as a marker-based approach similar to the project that Liverani et al. (2004) developed would require a bigger working space than the markerless approach which would not require any markers for the assembly components to be detected.

The Execution environment is the same in both solutions, requiring a multimedia edition tool for the tutorial creation that would provide the user with a graphical interface to create assembly instructions.

26 http://qt-project.org/

The data management component would be directly connected to the data storage where the tutorial instructions will be stored in format to be discussed still.

The Execution environment would then have the AR tutorial creation and tutorial execution in separated components, along with the 3D coordinates acquisition that would communicate directly with the 3D digitizer during the creation of the tutorial.

The main differences as explained above would be in the SDK, which for the marker-based solution – in Figure 4.3 – would be for example ARToolkit and consequently Assimp to load the 3D Models since ARToolkit does not provide that feature, or Metaio SDK's marker-based algorithms.

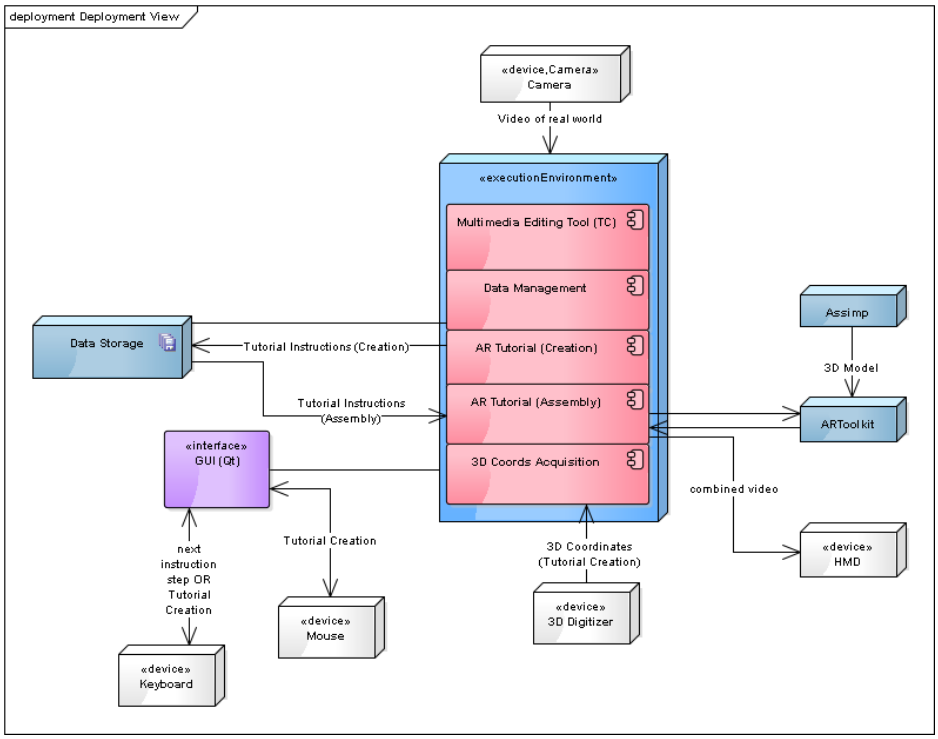


Figure 4.3: Marker-based System using ARToolkit

A markerless approach – in Figure 4.4 – which was considered to be more intuitive and innovative would then rely on the Metaio SDK's new feature, 3D CAD tracking through the detection of prominent edges of the given model. It was the preferred approach, but it was not showing as many signs of productivity as the marker-based approach, due to difficulties in lack of documentation for the windows platform. The android and iOS platforms were better documented, but would not fit the requirements of this dissertation, as the user needs both hands free to be able to properly assemble the equipment.

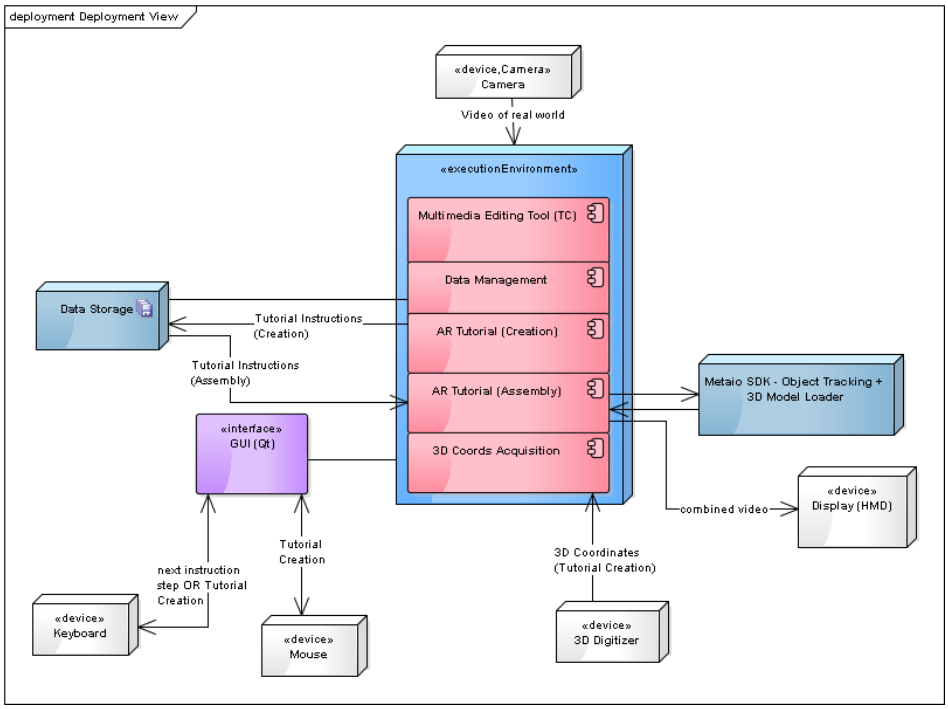


Figure 4.4: Markerless System

4.5 Summary

This chapter envisioned the Tutorial structure for the authoring application based on the research performed. The use of procedural instructions will be a good performance enhancer along with organizing the structure for easier comprehension. The types of Objects required for the application were also discussed here, along with their functions.

A high-level architecture with the required components for the application was demonstrated as well, along with the components the Augmented Reality system will require. This architecture's format will be used in Chapter 5 as a comparison between the necessities each component required and what was found to fill them.

The possible solutions found before development started were also explained here, along with the reasoning behind why they were not the solution explained in Chapter 5.

5 Implementation of a Tutorial System based on Augmented Reality

Before the implementation began, there were two solutions that were discussed in Chapter 4. This chapter will detail the solution found for the authoring application in a more technical manner. It will explain the solution developed, its architecture and how the required features were implemented. The user interface interaction through the 3D Digitizer along with the calibration of the device with the Augmented Reality software will also be explained here.

The following section details how the the application was evaluated, its results and user database.

Finally, a summary of this chapter is given, concluding the work explained in it.

5.1 Solution

In the Conception section, a high-level architecture was shown to explain what would be the components required for the Tutorial System based on Augmented Reality (Figure 4.2). In this section, the Figure 5.3 shows a similar diagram as before but with the components now filled in with the architecture chosen for the developed solution.

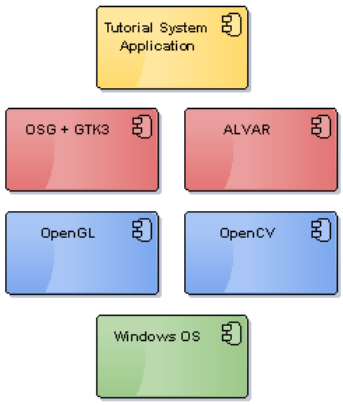


Figure 5.1: Solution Architecture

The Augmented Reality software chosen was ALVAR[27] which is built on top of OpenCV, a Computer Vision library. ALVAR also provides integration examples with OpenSceneGraph, a 3D Graphics Toolkit built on top of OpenGL. The Graphical User Interface built through OpenSceneGraph[28], which incorporates the menus that will be detailed in section 5.3, also required GTK3 for the editing of Object Properties through secondary popup windows. Each secondary window was associated to a thread and a GTK3[29] application with objects varying from combo boxes to spin buttons and text editors. The thread was necessary to keep the main thread with the video running and the 3D Digitizer thread for position acquisition, both always running at all times.

In the previously suggested solutions, the 3D Digitizer was only used in the placement of virtual Objects during the creation of Tutorials. This solution also uses the 3D Digitizer for the virtual menu interface. This interface's only constant feature is the physical surface with printed buttons that have numbers on them. This allows for the menus to have a constant position for the user's focus to easily adjust.

27 http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/

28 http://www.openscenegraph.org/

29 http://www.gtk.org/

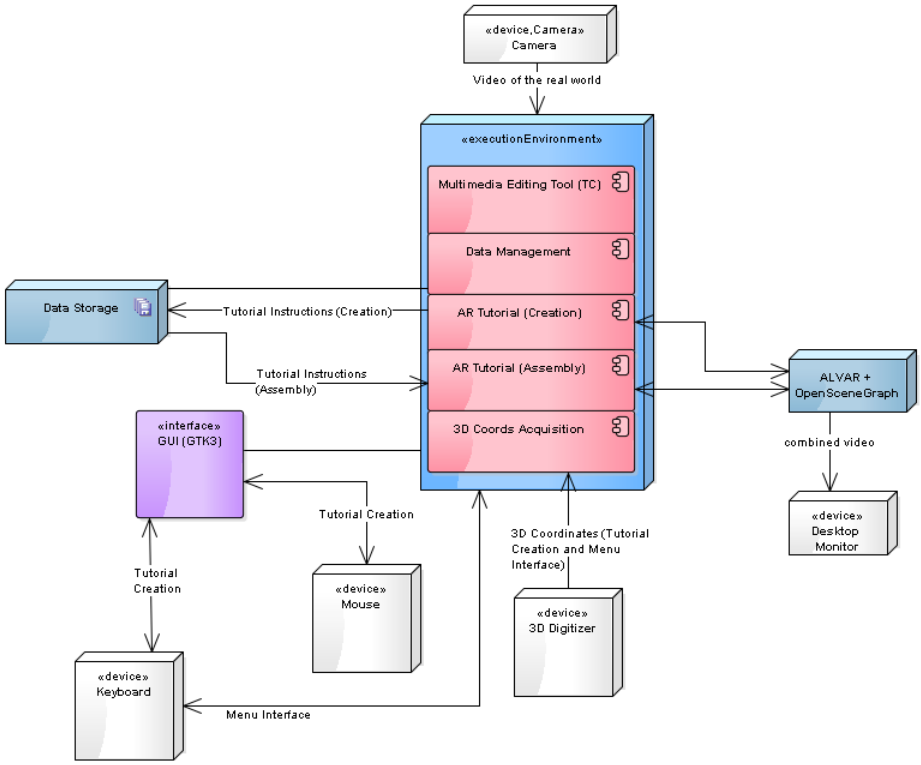


Figure 5.2: Components Interaction

The data storage component (part of the Tutorial application component in the Architecture demonstrated in Figure 5.1) utilizes a variety of XML structures for its components: tutorials, materials used in tutorials, lights, menu layouts, buttons layout used for menus, camera calibration, calibration coordinates, ALVAR-3DDigitizer calibration, configuration and marker data.

The tutorial and ALVAR- 3DDigitizer Calibration are generated by the program as the user interacts with it. The Lights, Menu Layouts, Buttons Layout, Calibration Coordinates, Tutorial Materials and Configuration are pre-created for the user and can be edited. Lastly, the Camera Calibration and Marker Data are created by the Augmented Reality Library Software used in this application, ALVAR.

The XML structures not created by ALVAR and associated to the main configuration of the system will be explained in the following subsection. The calibration methods developed to transform 3D Digitizer Coordinates into ALVAR Coordinates will be explained in section 5.2.2 and the User Interface built for the application will be explained in section 5.2.3 along with its associated *XML* files.

5.1.1 Application Configuration

```
<?xml version="1.0" ?>
<Configuration AlwaysLoadCalib="TRUE">
   <AlvarHapticCalibrationFilename N="resources/AlvarHapticCalibration.xml" />
    <AlvarHapticCalibCoordsFilename N="resources/calibration_coords.xml" />
```

```
    <CurrentButtonsFilename N="resources/Small_Buttons.xml" />
    <DefaultTutorialFilename N="resources/tutorials/Tutorial.xml" />
    <LightsFilename N="resources/Lights.xml" />
    <TutorialMaterialsFilename N="resources/tutorials/Default_Materials.xml" />
</Configuration>
```

The configuration file shown above is an example of the default settings the application is given, unless otherwise changed by the user. All of the files used by the application will be in the *resources* folder which contains two sub-folders: *menus* and *tutorials*. The organization used was the following: the files specific to menus only are placed in the *menus* folder, the files specific to tutorials are placed in the *tutorials* folder and the general files are placed in *resources*.

```
<?xml version="1.0" ?>
<Lights>
    <Light Name="Default" FollowCamera="TRUE">
            <Ambient R="0.1" G="0.1" B="0.1" A="1.0"/>
            <Diffuse R="1.0" G="1.0" B="1.0" A="1.0"/>
            <Specular R="1.0" G="1.0" B="1.0" A="1.0"/>
            <Position X="0.0" Y="0.0" Z="0.0" W="1.0"/>
            <ConstantAttenuation A="1.0"/>
            <LinearAttenuation A="0.7"/>
            <QuadraticAttenuation A="0.08"/>
    </Light>
</Lights>
```

The *Lights* XML file details all the lights the program uses, which an user familiar with OpenGL[30] would not find strange. The settings for ambient, diffuse and specular lights, along with the light's position and its attenuation are all terms related to OpenGL and not the purpose of this manual. The Light can also be set to follow the application's camera.

The application requires an initial calibration if the *AlvarHapticCalibration* XML file does not exist or if it is always set to calibrate in the *Configuration* XML file. An example of the *AlvarHapticCalibration* XML file can be found below along with a detailed explanation on the calibration procedure, regarding what the user must do to perform the calibration.

```
<?xml version="1.0" ?>
<AlvarHapticCalibration>
  <OriginDistance X="-3.67852" Y="11.1456" Z="-107.746" />
  <ScaleFactor X="-0.471317" Y="0.46783" Z="0.450205" />
</AlvarHapticCalibration>
```

A Calibration requires the acquisition of the 3D Digitizer's 3D world coordinates of five distinct points (See *CalibrationCoordinates XML* file above). All the default points marked in the ALVAR's 3D world have as little as possible equal coordinates to the other points.

To perform a calibration, the user must start the application with the 3D Digitizer's stylus placed in the inkwell and then, for every 3D object (shaped like a circle) that appears in the corners of the marker 0 (Figure 5.3 – marker with origin in it), the user must place the tip of the stylus in the point and press the button closest to the tip in the stylus (Dark gray button). This procedure must occur for all five points, including the last one that requires an additional object to successfully pinpoint it. This object was necessary to obtain at least two different values in Z.

The following section will explain how the calibration method transforms 3D coordinates of the 3D Digitizer into ALVAR Coordinates.

30 https://www.opengl.org/

5.1.2 ALVAR & 3D Digitizer Calibration

One of the main points of this dissertation was to connect ALVAR's 3D Coordinate System with the 3D Coordinate System of the 3D Digitizer. Several calibration methods were attempted during the development and will be explained in this section.

The first calibration attempt developed based itself on the concept that the coordinates of the markers which are in parallel lines will have the same X or Y. This calibration required twenty-four points acquired through the 3D Digitizer, four for each of the six markers.

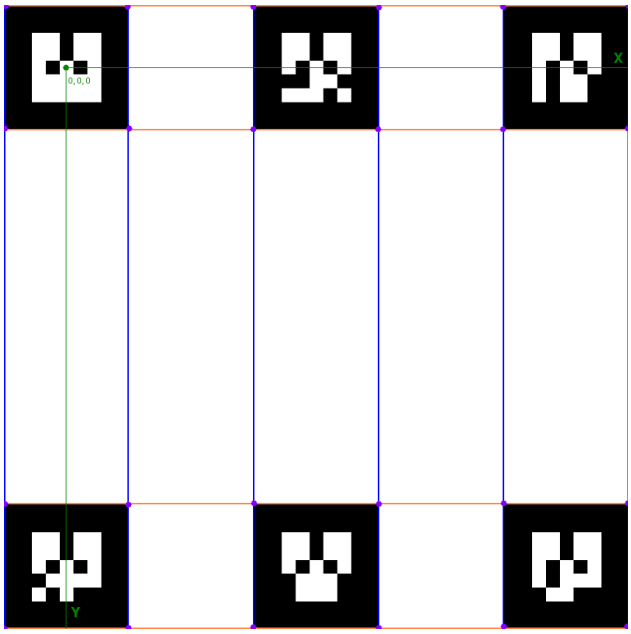


Figure 5.3: 1st Calibration Method

In the Figure 5.3, it's possible to see that X had six equal points per parallel line (blue),Y had four (orange) and Z had twenty-four. This was one of the flaws of this calibration that made it a 2D Calibration, since Z was captured always in the same plane.

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} \quad <=> \quad \begin{cases} x' = ax + by + cz + d \\ y' = ex + fy + gz + h \\ z' = ix + jy + kz + l \end{cases}$$

The averages for the parallel points were calculated, with X having six averages, Y having four and Z one. With those averages and the associated ALVAR 3D Coordinates, the constants a to l displayed above were calculated in the following manner for X, Y and Z:

$$\begin{cases} x_1' = ax_1 + by_1 + cz_1 + d \\ x_2' = ax_2 + by_2 + cz_2 + d \\ x_3' = ax_3 + by_3 + cz_3 + d \\ x_4' = ax_4 + by_4 + cz_4 + d \end{cases}$$

Four equations per axis were needed to obtain the constants. To solve this system, the matrix below was created.

$$\begin{pmatrix} x_1' \\ x_2' \\ x_3' \\ x_4' \end{pmatrix} = \begin{pmatrix} x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ x_3 & y_3 & z_3 & 1 \\ x_4 & y_4 & z_4 & 1 \end{pmatrix} \begin{pmatrix} a \\ b \\ c \\ d \end{pmatrix}$$

And the constants were obtained per axis through:

$$U = M * V <=> M^{-1} * U = M^{-1} * M * V <=> M^{-1} * U = V$$

Where U is the result of multiplying the 3D Digitizer coordinates acquired with the constants. This was performed for all sets of 4 constants.

This calibration method only transformed the 3D Digitizer coordinates into ALVAR's correctly when using the exact points that were used to calibrate it. Any other point would deviate to the side due to precision errors and the fact that only one plane of Z was considered in the formulas. Besides requiring the acquisition of twenty-four points through the 3D Digitizer, this system also didn't consider the rotation between the two 3D Coordinate Systems properly.

The second calibration attempt used the same equations as the first attempt, but only 5 points were required and it calculated Z in different planes. To obtain different heights in Z, a metallic object was previously measured and its height was transformed into the appropriate height in ALVAR's 3D Coordinate System. Since the corner coordinates of each marker were known, it was possible to measure the real world distance in mm of a marker with a digital ruler and obtain the ALVAR equivalent to the object height through cross-multiplication. The metallic object height (28.03mm) was also measured with a digital ruler and its height in ALVAR units was:

$$\begin{matrix} 27\ ALVAR\ units - 62.27\ mm \\ x\ ALVAR\ units - 28.03\ mm \end{matrix} \quad <=> \quad x = \frac{(27 * 28.03)}{(62.27)} = 12.1536865$$

This calibration method incorporated the rotation, translation and scale matrices in one single calculation, which was leading to precision errors that, despite a considerable amount of time spent on, were unable to be fixed and led to the calibration method below being used in the application.

The third and final calibration method relied on three matrices and, similarly to the second method, on five points obtained through the 3D Digitizer. This method was based on the explanations found in the book by Foley et al., Introduction to Computer Graphics (1997). Since the origin of the ALVAR 3D Coordinate System was known to be in the center of marker 0 (the first marker created for the multimarker and top left in the marker Figure in the 1st calibration method), this calibration method used this point plus three more where X and Y were different, and a point where Z's height was equal to the 12.1536856 calculated in the second method.

The three operations required to transform a 3D Digitizer Coordinate into an ALVAR Coordinate were, by the order they are performed, a scale, a rotation and a translation.

The scale matrix utilizes the scale factors for each axis calculated in the following manner:

$$X_{scale} = \frac{x_2 - x_1}{digitizerX_2 - digitizerX_1}$$
$$Y_{scale} = \frac{y_2 - y_1}{digitizerY_2 - digitizerY_1}$$
$$Z_{scale} = \frac{z_2 - z_1}{digitizerZ_2 - digitizerZ_1}$$

The values on top are the ALVAR Coordinates and the ones under are obtained through the 3D Digitizer. With these factors, the scale matrix is built:

$$scaleMatrix = \begin{pmatrix} scaleFactor_x & 0 & 0 & 0 \\ 0 & scaleFactor_y & 0 & 0 \\ 0 & 0 & scaleFactor_z & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The rotation was the only issue this calibration method did not tackle properly. It requires the 3D Digitizer to be correctly aligned with the markers, since the rotation matrix shown below only corrects the orientation of the X axis to align both X axis in the 3D Coordinate Systems involved.

$$rotateMatrix = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(-90) & -\sin(-90) & 0 \\ 0 & \sin(-90) & \cos(90) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The final operation, translation, besides translating the coordinate point also switches the Z and Y 3D Digitizer values because ALVAR's Y axis is located where 3D Digitizer's Z is.

$$translateMatrix = \begin{pmatrix} 1 & 0 & 0 & -1 * originDistance_x \\ 0 & 1 & 0 & -1 * originDistance_z \\ 0 & 0 & 1 & -1 * originDistance_y \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

This calibration method was built with features of each of the previous calibration methods that were tested and failed. It gives the smallest precision error and is as easy to calibrate as the 2nd method. In relation to this section, the application provides an option to load the scale factors and origin to distance point from an XML file, so that the calibration does not need to be performed each time the application is initiated.

5.1.3 User Interface & 3D Digitizer Interaction

In total, twenty-three menus were required to create the menu interface. Each menu has an average of four functions, the max allowed being ten. A list of all the possible functions per menu can be consulted in section 7 of Appendix A.

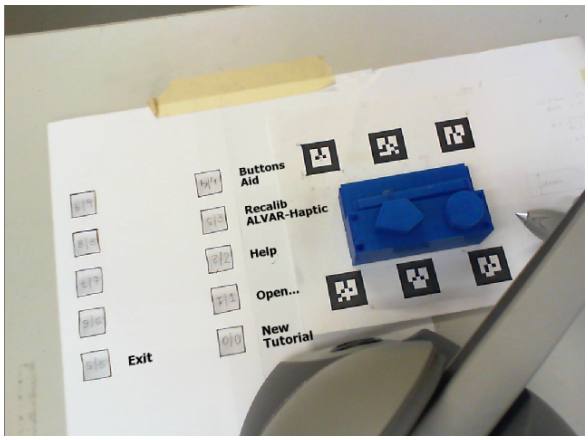


Figure 5.4: Main Menu Screenshot

To interact with the menus, the possible choices are the 3D Digitizer and the keyboard shortcuts. As mentioned in the Solution section, the menu functions are associated to a physical surface with printed buttons that have numbers on them for the keyboard shortcuts and can be pointed by the 3D Digitizer.

While the 3D Digitizer worked perfectly for moving through menus and editing a few of the Object options that only required a simple click, it was not adequate for editing Object parameters such as the position or the text color. For that purpose, GTK3 was required to create additional pop-up windows that unfortunately partially removed the user from the Augmented Reality experience, since he will have to switch his attention to the keyboard and mouse to edit the Object property. However, the functions for these pop-ups were carefully isolated for when the opportunity arrives to possibly include those pop-ups virtually in the application.

The buttons associated to the menu interface are customizable, allowing the user to easily format the shape of the menu interface to his liking. To do so, the editing of the *Buttons* XML file is necessary. The default file can be seen in section A.3.1 of the Application manual.

The general components of the file include the size of the side of the square used for each button, and two variables that enable testing of the visibility of the buttons in case the user is customizing the interface. Each button in the file is associated to an unique color and position. The visibility of the lines around the buttons are decided per button, allowing for example, a counter button to exist without a square wireframe drawn around it in case the button visibility aid is activated.

The button colors are then associated to menu functions. While functions can change positions by assigning a different color, the keyboard shortcuts are always associated to the following button colors: CYAN [0], GREEN [1], ORANGE [2], RED [3], LILAC [4], PURPLE [5], BLUE [6], PINK [7], ORANGEYELLOW [8] and MUSKGREEN [9]. WHITE is not associated to any keyboard number as it is not interactive. It is the color used for counter buttons. The button colors cannot be changed, but their position can be edited along with whether the user would like to draw the lines around them when button visibility aid is turned on. An example of a menu XML file is shown in section A.3.1 of the application manual. In it, it is possible to see the Button Color associated to each function.

Each Menu is associated to a Menu Type (e.g. Main Menu – Figure 5.5 directly uses the Menu Types in the boxes) and can be mirrored, offset in X and Y and the text can be aligned to the left, right and middle (with options to center in all three).

Each button included in the menu has its type, usually Text although an option to include images exists, a menu function (e.g. NEW_FUNCTION – a complete list per menu is shown in section A.7), a button color to connect with the button position explained for the *Buttons* XMLfile and the text editing parameters such as content, color, size and font. The button's menu function must be associated to that menu, otherwise no action will occur when it is chosen by the user. All of the texts or images associated to the buttons are virtual and change per menu according to context.

To resume, each Menu has its type and associated functions. Functions with names similar to Menus call those Menus. It is possible to edit all the parameters associated to each Menu Button, but it is advised to edit the Button Color carefully as to not place two functions in the same position.

5.1.4 Application Features

Through the menus that were explained in the User Interface & 3D Digitizer Interaction section, the application allows the user to create, edit and visualize object maintenance and assembly Tutorials. The flow of the application will be described here and the properties of the virtual helping Objects utilized in the Tutorials will be described in section 5.1.4.1.

The Figure 5.5 details the flow of the first menus that can be accessed when starting the application. Moving between menus happens when the options shown in the Figure are selected.

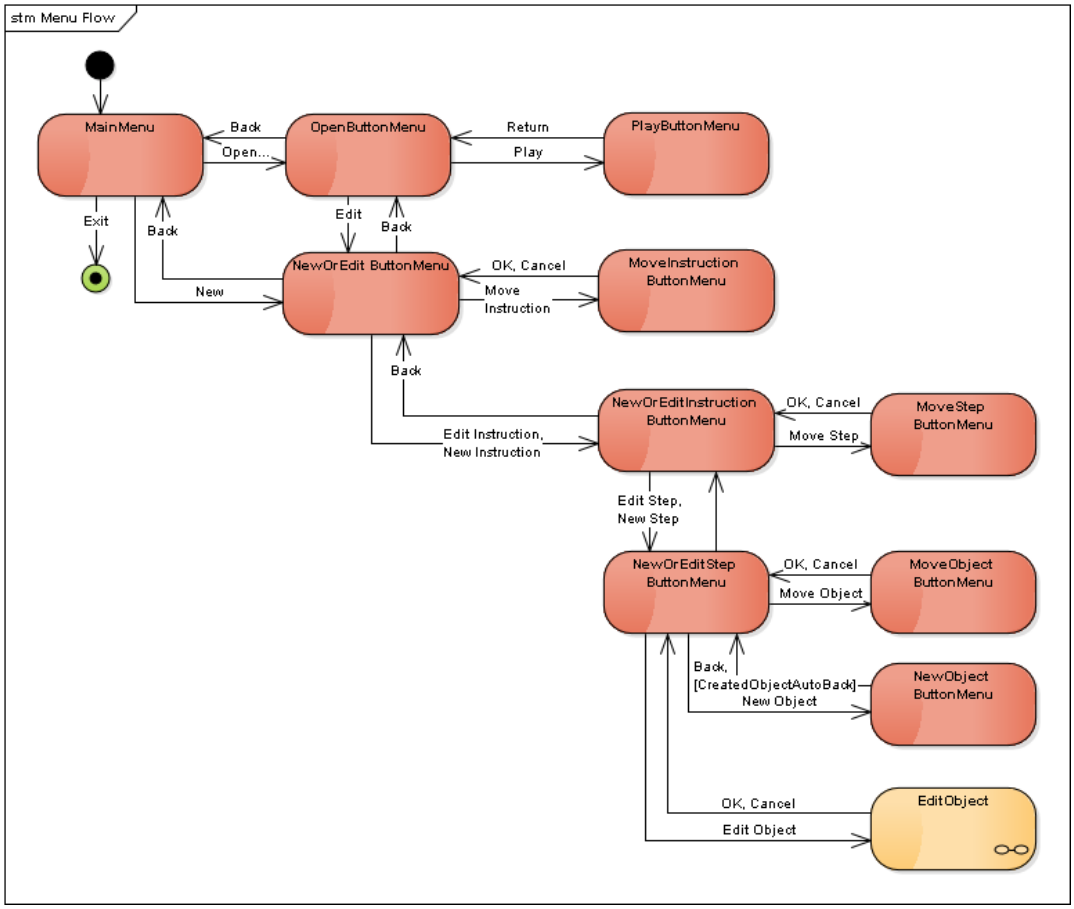


Figure 5.5: Menu Flow

When playing a Tutorial, the menu options required to reach this feature are to choose Open, select the Tutorial and then choose Play. This will lead the user to the following menu in the Figure 5.6.

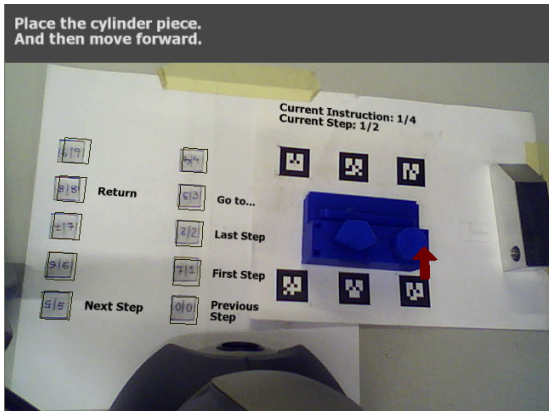


Figure 5.6: Visualization Menu Screenshot

In the Play menu, the user can move sequentially through the steps by clicking on Next or Previous Step. To move to a specific step, the user can move directly to the first Step by clicking the First Step option, to the last Step by clicking the Last Step option or to any other

Step by clicking the Go to option which opens a secondary window that allows the user to choose the Step they would like to visualize. While the secondary window is open, no other menu option will respond to user interaction.

If instead of the Play menu option, the user selects the Edit, he/she is led to the New Or Edit menu that can also be reached by creating a New Tutorial. The New Or Edit Menu has the following options available.

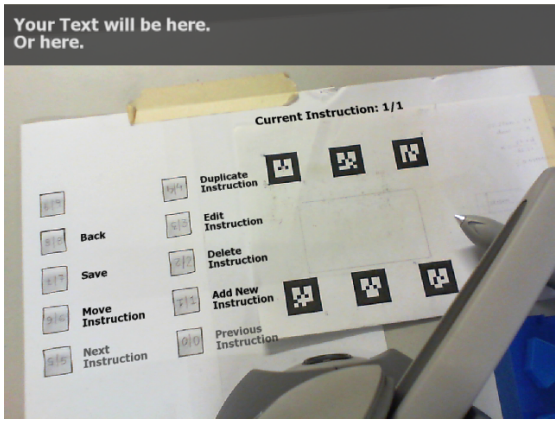


Figure 5.7: New Or Edit Menu - Screenshot

If the Tutorial has only one Instruction similarly to the Figure 5.7, the options that allow the user to move between Instructions will be grayed out since they are unavailable. This also occurs for moving between Steps and Objects. If the Tutorial is empty, all the menu options, with the exception of Back, Save and Add New Instruction, will be grayed out since they require the existence of at least one Instruction.

5.1.4.1 Virtual Helping Objects

In Figure 5.7, the option of editing an Object leads to the first diagram in the Figure 5.8, which redirects to the diagram specific to the Object Type being edited. Only two of the six flow diagrams are shown for the Objects because Arrows and 3D Models have exactly the same flow between menus and the same applies for the Text Objects.

An arrow can be a simple 2D Arrow, a 3D Arrow composed of rectangles or a 3D Cone arrow composed of one cone and one cylinder (see table 3.1 for a list of properties).

Arrow Type	Fixed	Wireframe	Animation	Transform	Material
2D	Yes	Yes	Yes	Yes	Yes
3D	No	Yes	Yes	Yes	Yes
3D Cone	No	No	Yes	Yes	Yes

Table 5.1: Arrow Properties

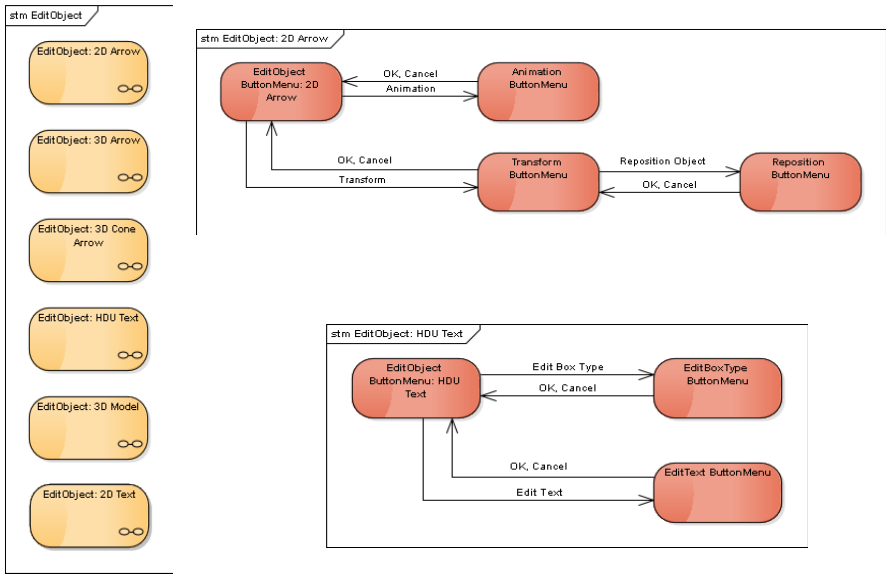


Figure 5.8: Edit Object Menu Flow

The Transform function applies to the scaling, rotating and translation of objects. If the Fixed mode is activated, the arrow will always be rotating towards the camera, hence why the 3D arrows do not have this mode. If they did, they would become 2D. If the fixed mode is active, there will be no visible animation even if the animation is active or detailed in the *XML*. This mode also does not allow the arrow's rotation to be edited.

The 3D Cone Arrow is the only arrow without the Wireframe mode, where only the outline of the arrows is drawn, since it is composed of 2 primitive objects that do not allow this mode (OSG Cylinder and Cone). All arrows can have materials associated to it, similarly to the Figure 5.9.

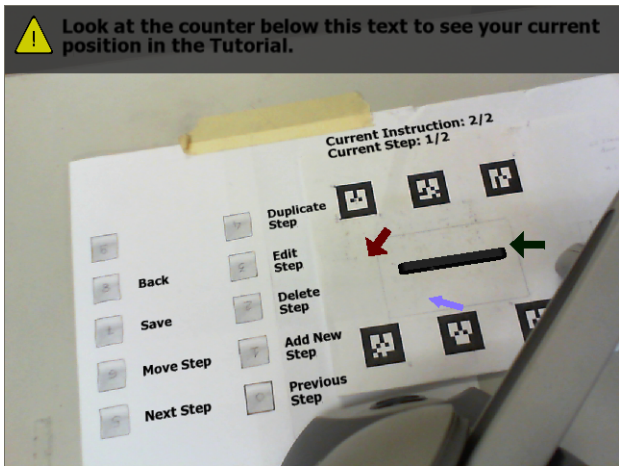


Figure 5.9: 3D Model, 2D, 3D and 3D Cone Arrows

Much like Arrows, 3D Models can be animated, scaled, rotated, translated and of the following extensions: .osg, .3ds, .fbx and .dae among many others[31], but it is recommended to

31 http://trac.openscenegraph.org/projects/osg//wiki/Support/UserGuides/Plugins

use the native osg binary extension for better results. An example of a 3D Model is also seen in the Figure 5.9 (the lever model).

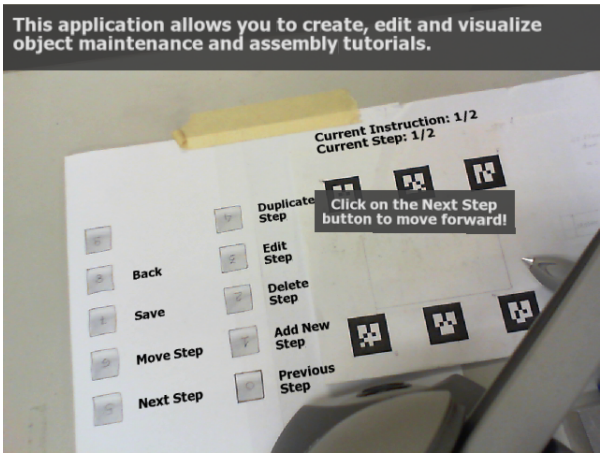


Figure 5.10: 2D Text

Text objects exist in two types: HUD and 2D. HUD Texts are always placed at the top and 2D Texts can be placed anywhere in the field that the 3D Digitizer can reach to position objects (Or beyond it, if the user alters the position manually). The 2D Text will always be facing the user in order to be readable at all times. Their properties per type are listed in Table 5.2.

Text Type	Box Color	Box Type	Text Editing
2D	Yes	Default	Color, Content, Font, Size and Stroke Color
HUD	Yes	Alert, Default	Color, Content, Font, Size and Stroke Color

Table 5.2: Text Properties

5.2 System Evaluation

For the application's performance to be evaluated, a test was created for the usability of the creation and editing tool using the 3D Digitizer (and the keyboard at times if the user so preferred). The visualization was not tested since the main focus and innovation of this dissertation was the creation of tutorials. The group of users that volunteered for the test were qualified personnel associated to maintenance and assembly of equipment, such as researchers, professors, finalists of mechanical engineering and graduates of informatics engineering and architecture who had a moderate degree of computer experience. The type of users chosen played an important part in the evaluation of this application, since it is mainly targeted at users related to the areas where device assembly and maintenance are needed. The fact that one of the users was an architect was an interesting addition to the feedback given.

The procedure of the test consisted of the following steps: after the user confirmed he/she would like to participate in the test and arrived at the workplace, he/she was given the guide (see Appendix B) to read. The time spent reading the guide was not accounted. When the user

finished reading, he had any possible doubts answered related to the guide and application. Later, he was given a period of 15 minutes to familiarize himself with the application where it was suggested to visit the Help menu function and any other area he was curious about. More questions were answered during this period which did not count for the evaluation.

Once the user confirmed he was ready, he was redirected to the guide where the script of the tutorial that he was required to create was located. The user was carefully monitored during the task. The time was measured for the whole duration of this task and for each step. The number of errors were also accounted and included clicking on the wrong menu option, adding an object different from the requested, adding extra Instructions or Steps besides the ones included in the structure given or not adding enough Instructions, Steps or Objects to match the structure. The entire procedure was recorded, so it was requested of the users to please try to think out loud as much as possible. These recordings were beneficial for the author when collecting feedback and suggestions from the tests.

At the end, the user was asked a few questions (see Questionnaire in Appendix C):

1. In a scale of 1-5, how intuitive is the 3D Digitizer as a pointer?
2. In a scale of 1-5, how effective is the 3D Digitizer in pointing and placing Objects?
3. In a scale of 1-5, how would you rate the usability of the editing system?
4. In a scale of 1-5, how would you rate the usability of the overall interface?
5. Did you prefer to use the 3D Digitizer or the keyboard for the menu interface?
6. Would you add another helping Object type to the application?
7. If you answered yes to the previous question, which new helping Objects would you add?
8. Having an overall view about the application, would you suggest any change in the interface?

The users' ages ranged from 18 to 40 and, in total, 8 males and 2 females participated in the test. Seven of the males were associated to mechanical engineering, whether as students, technicians or researchers. The 8th male was associated to informatics engineering along with one of the females. The 2nd female was an architect. This variety in occupation served to increase the variety of feedback produced due to the different points of view from the way the users looked at and analyzed the application.

There was no compensation given nor risks that the user had. The time to complete the task varied between 17 minutes and 1 hour. Of the sample analyzed, there was no preference over the 3D Digitizer or the Keyboard shortcuts when interacting with the menu interface. Four of the users chose the 3D Digitizer in question 5, four chose the keyboard and the other 2 had no preference. The amount of errors averaged on three per person, the most common being the creation of an extra Step instead of creating a new Instruction and the addition of the wrong type of helping object. This happened mostly in the beginning, when the user was either rushing his task, despite being told to take his time, or when the user had not yet understood the interface.

Since the time spent per step was analyzed for all the users, it was possible to determine the learning curve. The Tutorial was purposely patterned in order to check this curve of adaption to the application's interface and structure. Over the creation of the Tutorial, eight steps

were timed. As the users adjusted to the application it was possible to see how the time per step gradually decreased from an average of 5~6 minutes to 2~3 minutes. The time was independent of the interaction method used, keyboard or 3D Digitizer. The only alterations to this time that had to be considered were the additional recalibrations that a few users needed during their task.

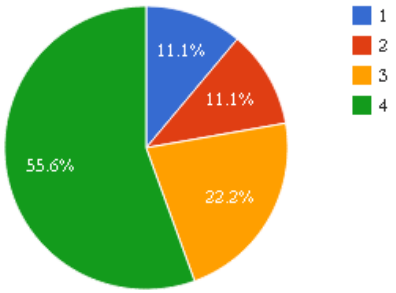


Figure 5.11: How intuitive is the 3D Digitizer as a pointer?

Over half of the users found the 3D Digitizer to be intuitive, where the scale given to them was: 1 for Hard to adapt and 5 for Very Intuitive. This demonstrates that, despite the fact that the application used a stationary camera instead of an HMD and the image of the camera was mirrored due to the position of the camera, the 3D Digitizer's function was still understood successfully for placing virtual helping Objects and for interacting with the interface. The camera's image was mirrored, in comparison to what the user was visualizing when looking

directly at the printed markers in the surface, due to its position in the workplace and could not be adjusted without interfering with the user's space. The only solution would be, as referred, an HMD device that would allow the user to view the application freely from any angle without the negative effect of mirroring. This would also help when placing the virtual Objects, since the stationary camera did not provide sufficient clues when it came to the Z axis.

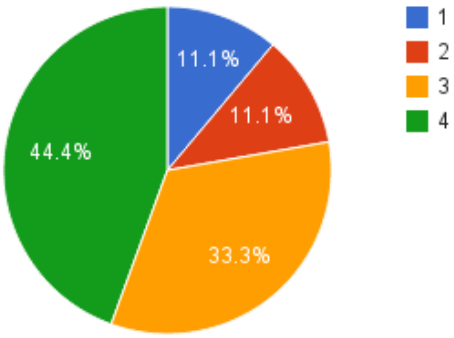


Figure 5.12: How effective is the 3D Digitizer in pointing and placing objects?

In terms of actual effectiveness (see Figure 5.12) of the 3D Digitizer as a pointer and an interacting tool, the results are similar to Figure 5.11, but slightly lower. The scale for this question also ranged from 1 (Very ineffective) to 5 (Perfectly functional). This slightly lower

score can be attributed to the calibration and precision errors when sometimes the 3D Digitizer would place the virtual helping Objects slightly off from the position chosen by the user. Other times, for example when using the 3D Digitizer to interact with the menu, it wasn't as effective because the user was not directly placing the device against the surface where the buttons were printed. Sometimes, the 3D Digitizer would be up in the air as the user looked at the desktop monitor and would end up clicking the wrong function or not choosing any function. While this can be attributed to how the 3D Digitizer was positioned, and how it could occlude the physical buttons printed in the surface, this wasn't a sufficiently valid point since many of the users claimed to have no occlusion issues when using the 3D Digitizer. It seemed to be a matter of positioning the device to obtain the best results. However, it was asked by some of the users if it is possible to track the tip of the 3D Digitizer's stylus through a virtual dot. This is definitely possible and is mentioned in the Future Work section. Another factor to consider in the lowest score given was that the user did not recalibrate the device, despite being told and shown that he could easily do so in five quick steps.

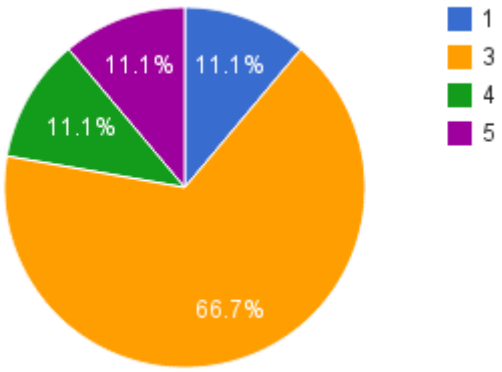


Figure 5.13: How would you rate the usability of the editing system?

The overall usability of the editing system (see Figure 5.13) received many suggestions and scored an average where again, the scale was 1 (Very Intrusive) to 5 (Non-intrusive). The most suggested was to allow the user to edit the text when adding a virtual helping text Object. With the current state of the application, when adding a text Object, a default text is written and then the user has to edit the content. To implement this suggestion, an extra secondary window would be required in the process of adding the Object. When changing the color of the text, the interface chosen also had feedback, where an user suggested possibly adding a palette of colors to make it easier for the user to choose a color. A few other suggestions fell again in relation to the mirroring of the image, where some users suggested editing the keyboard shortcuts to fit the mirrored image. This way, it seemed less confusing to them. Finally, a new structure was suggested to help the user understand in which menu he was in the application's interface. While at first this seemed understandable, the user was later reminded that the counter above the physical markers changes as the menus advance. For example, when creating a New Tutorial, the counter displays only the current Instruction counter. When choosing to edit or add a new Step, the counter now displays the current Instruction and current Step counter. The same also happens for Objects.

The pop-ups were, as predicted, not highly appreciated since they forced the user to switch between grabbing the 3D Digitizer and the mouse plus keyboard, especially if using it as main interacting tool for the menu instead of keyboard. This was most likely the reason for the average score, besides the text being set to default.

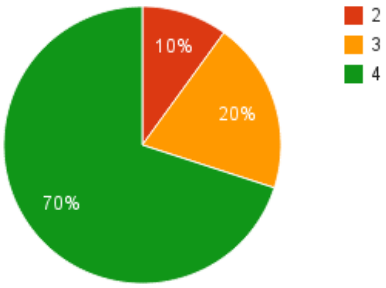


Figure 5.14: How would you rate the usability of the overall interface?

Overall, in a scale of 1 (Hard to adapt) to 5 (Very intuitive), the application was well received by most users (see suggestion 5.14). There were a few more suggestions in regards of the interface, such as the coloring of the buttons in order to easily find them when using a desktop monitor. This was suggested by users who would look at the desktop monitor to visualize the virtual content and then double-check that they were choosing the right button with the 3D Digitizer.

In question 6, where the user was asked if they would add another helping Object to the application, most users did not see the need, with one thinking there were too many arrow and text types. However, there were two interesting suggestions here. One was to add a fourth type of arrow, an U-arrow for steps where the user would like to explain that it is necessary to spin the piece to be assembled in a certain direction. The second suggestion wouldn't be as easy to implement, but would greatly benefit assembly projects of smaller dimensions such as circuits. The suggestion was to add a free-form virtual helping Object that would be drawn by the user to not only point but to contour the location.

Overall, despite the small sample, there was a great amount of feedback collected and it was possible to see how quick the user adapted to the interface's logic. The personality of the users came through in their tutorials, where some would customize every possible option given and the others would only position the Objects carefully. Despite the high level of customization, the time spent per Step was still not affected, since some of the users who customized were the fastest. This can be attributed to a possible faster comprehension of the application's interface since no user had used the application before their test.

5.3 Summary

This chapter explained the development and final state of the application, along with paths that were discarded due to the impossibility of their development. The description of the solution was firstly presented through its architecture which is compared to the one mentioned in the Conception chapter.

It was then followed by an explanation of the application configurations and how the calibration was developed between ALVAR's 3D Coordinates System and the 3D Coordinates System of the 3D Digitizer. It is believed that in the end, a simple calibration was achieved with moderate to very effective results.

The User Interface and its interaction with the 3D Digitizer and the keyboard, along with the features of the application were also explained in this chapter.

Finally, an evaluation of the creation of tutorials was performed and its results were analyzed. From the tests that were performed, there was no preference between the usage of the 3D Digitizer or the keyboard for the menu interface. Similarly to other applications, while it allows an action to be carried out through the 3D Digitizer (as a replacement for the common pointer), it also provides keyboard shortcuts for a quicker interaction.

In terms of usability and effectiveness of the 3D Digitizer as a pointer and interaction tool with the menu interface, despite the occasional recalibration, the feedback was still overall positive. While there were many suggestions to improve the application, such as the addition of new virtual helping Objects and the prompting of the user to insert the text directly when creating a virtual helping text Object instead of editing, the usability of the overall interface was also quite effective. This allows the conclusion that an authoring tool in this area, with the use of a 3D Digitizer and possibly the eventual shift to a different tracking method for the Augmented Reality (for bigger maintenance and assembly projects) would be well received.

6 Conclusions and Future Work

This dissertation presented an authoring application that allowed the user to create, edit and visualize assembly and maintenance tutorials based on Augmented Reality. The user was able to procedurally create Tutorials that followed the Tutorial→Instruction→Step→Object structure further detailed in the Conception section. This structure allowed the application to give the user some roaming space in the creation area, letting him choose the best way to approach his assembly or maintenance task. This way he is free to include examples in an Instruction as Steps and easily organize information inside it.

Also, through the usage of a 3D Digitizer, the user was mostly able to interact with the application directly in the workplace, with the exception of a few editing actions that required the use of the mouse and keyboard due to restrictions in the Augmented Reality user interfaces currently existent. This necessity was however carefully isolated in the application's code, for when the opportunity arrives to possibly include directly the editing actions, that were placed in secondary windows, in the virtual interface.

The evaluation performed scored an overall positive amongst the users in terms of 3D Digitizer effectiveness and intuitiveness, along with the overall interface's intuitiveness.

6.1 Goal Satisfaction

The Assembly and Maintenance applications based in Augmented Reality researched demonstrated various benefits of Augmented Reality such as reducing the attention split on the worker's focus, memory, skill growth and reducing the learning curves. Augmented Reality's challenges were also discussed along with the comparison of marker-based and markerless tracking methods.

This dissertation's main goals were successfully accomplished through the research of the respective State of the Art and required technologies to develop the application. An authoring application based on Augmented Reality was successfully created for assembly and maintenance Tutorials. Procedural instructions were the basis of the Tutorial structure created

for this application in order to enhance task performance. A 3D Digitizer was calibrated with the Augmented Reality 3D Coordinate System and used as the physical interaction device with the user interface and the creation of Tutorials. Through this application, it was possible to test its benefits and it was seen in action how the application was welcomed by the users. Despite the fact that an HMD display device was not used, due to lack of time to integrate it, and that the desktop monitor plus the camera's location mirrored the image, overall the application's logic was still gradually understood by the users as they progressed through the tutorial creation. Once the purpose of the Tutorial structure being split in Instructions, Steps and Virtual Objects was explained, the users easily understood why each Instruction was split into two steps: one to explain what the user had to do and the second to allow the user to confirm its action was correct. This based itself on procedural instructions, which are as mentioned in Chapter 4, a type of instructions that follows the procedure form and describes how to complete tasks in a stepwise manner.

6.2 Future Work

Despite the satisfactory development of an application that allows the user to create, edit and visualize object maintenance and assembly tutorials, the application can still be improved. The initial goal was to integrate it with an HMD display device, but due to time constraints, a desktop monitor was used instead.

2D Text Objects could have had 3D Digitizer reposition along with the arrows and 3D models, but were given the same options as the HUD Text Objects by lapse. The current menu would need to be altered since it wouldn't be the same as any other object.

An update on the calibration between ALVAR and the 3D Digitizer, so that it would consider rotation between the two 3D Coordinate Systems, would also greatly reduce the number of tries when interacting with the menu interface and the 3D Digitizer isn't correctly aligned. Also, given that the 3D Digitizer was a Haptic device, another possible addition to the application would be to add more feedback regarding adding objects, such as an applied strength when placing an object.

On a more technical level, when the tutorial is saved, all the paths for the objects will be absolute. Since it is recommended to include all models and 3D objects in the resources folder, this was only seen as a possible future improvement.

Finally, to eliminate the mouse and keyboard, a touch-sensitive user interface or voice activated would be required with the possible chance of the latter not being very effective. A virtual keyboard next to the menu interface would also be a possible choice for eliminating the physical keyboard, but the need for secondary windows would be harder to eliminate in order to not overflow the user with too much information in the workplace. A suggestion provided by some of the users that could help in this situation was to track the tip of the 3D Digitizer's stylus by constantly drawing a dot. This is possible since the 3D Digitizer's position is constantly being read by the device.

Appendix A: Application Manual

A.1 Purpose of this Manual

This manual is aimed at the users of the Tutorial System based on Augmented Reality application and seeks to provide clear guidelines on how to interact and achieve the desired results in tutorial creation, editing and visualization.

Firstly, the application structure and configuration is detailed, explaining the *XML* structures associated and how to edit them. It is then followed by an explanation of the 3D Digitizer Interaction with the Augmented Reality component of the application, along with the menu interface that can utilize both the 3D Digitizer and keyboard shortcuts. All the *XMLs* associated with this interaction and menu will be described here.

In the next section of this manual, the tutorial structure (and respective associated *XMLs*) that the application utilizes will be detailed in order to increase the user's comprehension for the following subsections. The object types available are also detailed.

The following section demonstrates how the first instruction of the Main Menu → Help option was created using the application, and how to create and/or edit instructions, steps and objects in a step-by-step approach. Screenshots are supplied in both this section and the following where it is explained how to run a tutorial in order to visualize it. The final section details all the functions available per menu for a more detailed reading.

The sections recommended for ambiance and adaption to the application by the user are 3, 4, 5 and 6.

A.2 Application Configuration

This application was developed using ALVAR[32] for the Augmented Reality component, OSG[33] for the CG Interface, Phantom Omni Device[34] for the calibration and interaction and GTK3[35] for the GUI of a few editing menu options.

The Phantom Omni Device was not used as a Haptic device, but rather as a mean to acquire 3D coordinates that would allow the user to position the stylus in the desired place where he would like to place an object. Those 3D Coordinates would then be transformed into the 3D World coordinates of the Augmented Reality Library system, as it will be explained in section 3. For the purpose of reinforcing the idea that this device was not used as a Haptic device, it will be referred to as a 3D Digitizer.

It also utilizes a variety of XML structures for its components: tutorials, materials used in tutorials, lights, menu layouts, buttons layout used for menus, camera calibration, calibration coordinates, ALVAR-Haptic calibration, configuration and marker data.

The tutorial and ALVAR-Haptic Calibration are generated by the program as the user interacts with it. The Lights, Menu Layouts, Buttons Layout, Calibration Coordinates, Tutorial Materials and Configuration are pre-created for the user and can be edited. Lastly, the Camera Calibration and Marker Data are created by the Augmented Reality Library Software used in this application, ALVAR.

For the XML structures to be explained in a timely manner, the Configuration, Camera Calibration and Marker Data files will be analyzed inside this section, in the following subsections.

A.2.1 Configuration

```
<?xml version="1.0" ?>
<Configuration AlwaysLoadCalib="TRUE">
   <AlvarHapticCalibrationFilename N="resources/AlvarHapticCalibration.xml" />
    <AlvarHapticCalibCoordsFilename N="resources/calibration_coords.xml" />
    <CurrentButtonsFilename N="resources/Small_Buttons.xml" />
    <DefaultTutorialFilename N="resources/tutorials/Tutorial.xml" />
    <LightsFilename N="resources/Lights.xml" />
    <TutorialMaterialsFilename N="resources/tutorials/Default_Materials.xml" />
</Configuration>
```

The configuration file shown above is an example of the default settings the application is given, unless otherwise changed by the user. All of the files used by the application will be in the *resources* folder which contains two sub-folders: *menus* and *tutorials*. The organization used was the following: the files specific to menus only are placed in the *menus* folder, the files specific to tutorials are placed in the *tutorials* folder and the general files are placed in *resources*.

32 http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/

33 http://www.openscenegraph.org/

34 http://www.dentsable.com/haptic-phantom-omni.htm

35 http://www.gtk.org/

A.2.2 Lights

```
<?xml version="1.0" ?>
<Lights>
    <Light Name="Default" FollowCamera="TRUE">
            <Ambient R="0.1" G="0.1" B="0.1" A="1.0"/>
            <Diffuse R="1.0" G="1.0" B="1.0" A="1.0"/>
            <Specular R="1.0" G="1.0" B="1.0" A="1.0"/>
            <Position X="0.0" Y="0.0" Z="0.0" W="1.0"/>
            <ConstantAttenuation A="1.0"/>
            <LinearAttenuation A="0.7"/>
            <QuadraticAttenuation A="0.08"/>
    </Light>
</Lights>
```

The *Lights* XML file details all the lights the program uses, which an user familiar with OpenGL[36] would not find strange. The settings for ambient, diffuse and specular lights, along with the light's position and its attenuation are all terms related to OpenGL and not the purpose of this manual. The Light can also be set to follow the application's camera.

The two following XML files are generated by ALVAR's marker making and calibration programs, which come available with the library. They are merely shown to remind the user that he can improve efficiency of tracking by calibrating his own camera and replacing the camera calibration file with his own, and to also show how the multi-marker system works in ALVAR.

A.2.3 Camera Calibration

```
<?xml version="1.0"?>
<opencv_storage>
<intrinsic_matrix type_id="opencv-matrix">
 <rows>3</rows>
 <cols>3</cols>
 <dt>d</dt>
 <data>
  6.2302155380919908e+002 0. 3.0971598843194295e+002 0.
  6.4228962693016297e+002 2.4582638188195088e+002 0. 0. 1.</data></intrinsic_matrix>
<distortion type_id="opencv-matrix">
 <rows>4</rows>
 <cols>1</cols>
 <dt>d</dt>
 <data>
  1.9681420063581109e-001 -5.6177754718785178e-001
  -4.8192723184511337e-002 -5.8415393257333368e-003</data></distortion>
<width>640</width>
<height>480</height>
</opencv_storage>
```

Again, as a reminder, if the user desires, he can calibrate his own camera by following the procedures given by ALVAR in its User Manual (section 7.1 of ALVAR's User Manual[37] - Utility Programs - SampleCamCalib.exe).

36 https://www.opengl.org/

37 http://virtual.vtt.fi/virtual/proj2/multimedia/media/ALVAR_v2_User_Manual_v1.1.pdf

A.2.4 Marker Data

```
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<multimarker markers="6">
  <marker index="0" status="1">
    <corner x="-4.500000" y="-4.500000" z="0.000000" />
    <corner x="4.500000" y="-4.500000" z="0.000000" />
    <corner x="4.500000" y="4.500000" z="0.000000" />
    <corner x="-4.500000" y="4.500000" z="0.000000" />
  </marker>
  <marker index="1" status="1">
    <corner x="13.500000" y="-4.500000" z="0.000000" />
    <corner x="22.500000" y="-4.500000" z="0.000000" />
    <corner x="22.500000" y="4.500000" z="0.000000" />
    <corner x="13.500000" y="4.500000" z="0.000000" />
  </marker>
  <marker index="2" status="1">
    <corner x="31.500000" y="-4.500000" z="0.000000" />
    <corner x="40.500000" y="-4.500000" z="0.000000" />
    <corner x="40.500000" y="4.500000" z="0.000000" />
    <corner x="31.500000" y="4.500000" z="0.000000" />
  </marker>
  <marker index="3" status="1">
    <corner x="-4.500000" y="-40.500000" z="0.000000" />
    <corner x="4.500000" y="-40.500000" z="0.000000" />
     <corner x="4.500000" y="-31.500000" z="0.000000" />
    <corner x="-4.500000" y="-31.500000" z="0.000000" />
  </marker>
  <marker index="4" status="1">
    <corner x="13.500000" y="-40.500000" z="0.000000" />
    <corner x="22.500000" y="-40.500000" z="0.000000" />
    <corner x="22.500000" y="-31.500000" z="0.000000" />
    <corner x="13.500000" y="-31.500000" z="0.000000" />
  </marker>
  <marker index="5" status="1">
    <corner x="31.500000" y="-40.500000" z="0.000000" />
    <corner x="40.500000" y="-40.500000" z="0.000000" />
    <corner x="40.500000" y="-31.500000" z="0.000000" />
    <corner x="31.500000" y="-31.500000" z="0.000000" />
  </marker>
</multimarker>
```

The multi-marker system chosen for this application, in order to reduce tracking issues such as no visible markers for the program to track and update the application, envelops six markers, in two parallel lines each containing three markers. This XML details the four corners of each marker and places them all in a tracked status (status="1"). It is possible to change the markers by creating new ones, using the *SampleMarkerCreator.exe* given by ALVAR, which allows the user to create new multi-markers. However, it is not recommended to change the marker used to one under 6 markers, as it could severely reduce the tracking abilities of the application when physical objects are being assembled since it would hide a few markers.

If the user decides to change the multi-marker, he will have to update the *CalibrationCoordinates* XML file as well, in order to align the positions chosen with the corners of a marker, preferably the marker 0 as it is by default.

A.3 ALVAR-Haptic Calibration

The application requires an initial calibration if the *AlvarHapticCalibration* XML file does not exist or if it is always set to calibrate in the *Configuration* XML file. An example of the *AlvarHapticCalibration* XML file can be found below along with a detailed explanation on the calibration procedure, regarding what the user must do to perform the calibration.

```
<?xml version="1.0" ?>
<AlvarHapticCalibration>
  <OriginDistance X="-3.67852" Y="11.1456" Z="-107.746" />
  <ScaleFactor X="-0.471317" Y="0.46783" Z="0.450205" />
</AlvarHapticCalibration>
```

A Calibration requires the acquirement of the 3D Digitizer's 3D world coordinates of five distinct points (See *CalibrationCoordinates XML* file above). All the default points marked in the ALVAR's 3D world have as little as possible equal coordinates to the other points.

To perform a calibration, the user must start the application with the 3D Digitizer's stylus placed in the inkwell and then, for every 3D object that appears in the corners of the marker, the user must place the tip of the stylus in the point and press the button closes to the tip in the stylus (Dark gray button). This procedure must occur for all five points, including the last one that requires an additional object to successfully pinpoint it. This object was necessary to obtain at least two different values in Z.

A.3.1 Menu Interaction & Interface

As for the interaction through the 3D Digitizer, in the same way the user calibrated the application, it is also possible to use the Stylus to interact with the Menus. For that purpose, it is necessary to define the *Buttons* XML file, like the one listed below.

```
<?xml version="1.0" ?>
<Buttons SQUARE_SIDE_LENGTH="3.5" TESTING_BUTTON_POSITION="TRUE">
    <!-- Left Column -->
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="CYAN"/>
            <Position X="-29.25" Y="-44.0" Z="0.0"/>
    </Button>
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="GREEN"/>
            <Position X="-29.25" Y="-34.0" Z="0.0"/>
    </Button>
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="ORANGE"/>
            <Position X="-29.25" Y="-23.25" Z="0.0"/>
    </Button>
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="RED"/>
            <Position X="-29.25" Y="-13.0" Z="0.0"/>
    </Button>
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="LILAC"/>
            <Position X="-29.25" Y="-2.0" Z="0.0"/>
    </Button>
    <!-- Right Column -->
```

```
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="PURPLE"/>
            <Position X="-62.0" Y="-44.0" Z="0.0"/>
    </Button>
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="BLUE"/>
            <Position X="-62.0" Y="-34.0" Z="0.0"/>
    </Button>
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="PINK"/>
            <Position X="-62.0" Y="-23.25" Z="0.0"/>
    </Button>
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="ORANGEYELLOW"/>
            <Position X="-62.0" Y="-13.0" Z="0.0"/>
    </Button>
    <Button DRAW_SQUARE_LINES="TRUE">
            <Color C="MUSKGREEN"/>
            <Position X="-62.0" Y="-2.0" Z="0.0"/>
    </Button>
    <!-- Text Counter placeholder (Currently placed above the markers) -->
    <Button DRAW_SQUARE_LINES="FALSE">
            <Color C="WHITE"/> <!-- For Instruction and Step Counters -->
            <Position X="-12.0" Y="15.0" Z="0.0"/>
    </Button>
</Buttons>
```

Another way to interact with the buttons is through the keyboard. Each color is associated to a number: CYAN [0], GREEN [1], ORANGE [2], RED [3], LILAC [4], PURPLE [5], BLUE [6], PINK [7], ORANGEYELLOW [8] and MUSKGREEN [9]. WHITE is not associated to any keyboard number as it is not interactive. The Button Colors are predefined in the application and cannot be changed, but their position can be edited along with whether the user would like to draw the lines around it when button visibility aid is turned on.

These buttons are used for all the menus and counters available in the XMLs of the menus. To use a button position in the interface, the color of the button must be associate with the menu button. An example of a Menu can be found below.

```
<?xml version="1.0" ?>
<Menu Type="MAIN_MENU" Mirror="FALSE" X_OFFSET="7.0" Y_OFFSET="0.0" TEXT_ALIGN="LEFT_CENTER">
    <Button Type="TEXT" MenuFunction="NEW_FUNCTION">
            <ButtonColor C="CYAN"/>
            <TextColor R="0.0" G="0.0" B="0.0" A="1.0"/>
            <Text T="New Tutorial"/>
            <TextSize S="3.0"/>
            <Font FontName="fonts/tahomabd.TTF"/>
    </Button>
    <Button Type="TEXT" MenuFunction="OPEN_FUNCTION">
            <ButtonColor C="GREEN"/>
            <TextColor R="0.0" G="0.0" B="0.0" A="1.0"/>
            <Text T="Open..."/>
            <TextSize S="3.0"/>
            <Font FontName="fonts/tahomabd.TTF"/>
    </Button>
    <Button Type="TEXT" MenuFunction="HELP_FUNCTION">
            <ButtonColor C="ORANGE"/>
            <TextColor R="0.0" G="0.0" B="0.0" A="1.0"/>
```

```
            <Text T="Help"/>
            <TextSize S="3.0"/>
            <Font FontName="fonts/tahomabd.TTF"/>
    </Button>
    <Button Type="TEXT" MenuFunction="RECALIBRATE_ALVAR_HAPTIC_FUNCTION">
            <ButtonColor C="RED"/>
            <TextColor R="0.0" G="0.0" B="0.0" A="1.0"/>
            <Text T="Recalib"/>
            <Text T="ALVAR-Haptic"/>
            <TextSize S="3.0"/>
            <Font FontName="fonts/tahomabd.TTF"/>
    </Button>
    <Button Type="TEXT" MenuFunction="BUTTON_TRACK_AID_FUNCTION">
            <ButtonColor C="LILAC"/>
            <TextColor R="0.0" G="0.0" B="0.0" A="1.0"/>
            <Text T="Buttons Aid"/>
            <TextSize S="3.0"/>
            <Font FontName="fonts/tahomabd.TTF"/>
    </Button>
    <Button Type="TEXT" MenuFunction="EXIT_FUNCTION">
            <ButtonColor C="PURPLE"/>
            <TextColor R="0.0" G="0.0" B="0.0" A="1.0"/>
            <Text T="Exit"/>
            <TextSize S="3.0"/>
            <Font FontName="fonts/tahomabd.TTF"/>
    </Button>
</Menu>
```

Each Menu has its type and associated functions. Functions with names similar to Menus call those Menus. It is possible to edit all the parameters associated to each Menu Button, but it is advised to edit the Button Color carefully as to not place two functions in the same position.

The possible Menus available are listed in the annex with the functions that connect them.

A.4 Tutorial Structure

A Tutorial contains an ordered sequence of Instructions where each instruction contains an ordered sequence of steps and each step contains the objects that the user can visualize. Each object is of one of six different types: a 2D arrow, a 3D arrow, a 3D cone arrow, an HUD text, a 2D Text or a 3D Model. The hierarchy used to detail the Tutorials created, visualized and edited by the application is shown on the picture below.

This hierarchy was chosen in order to allow, for example, a tutorial instruction to have two steps: the first where the user is shown what to place where, and the second step as a confirmation of what should now be the final result.

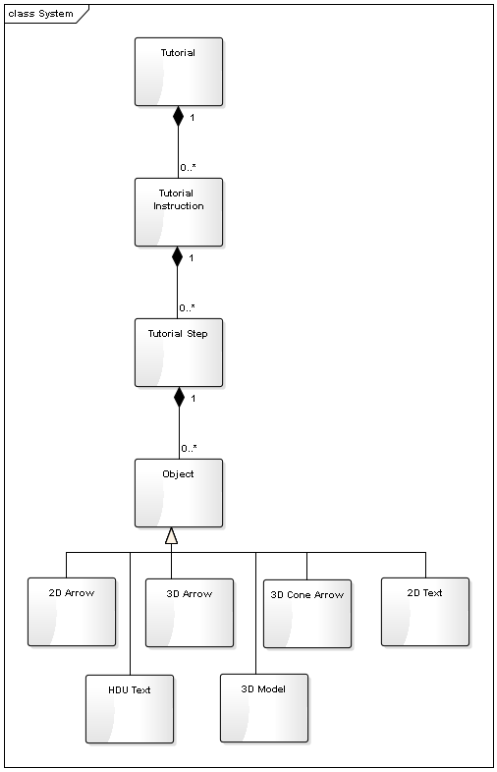


Figure A.1: Tutorial Structure

An example of a XML file using this hierarchy would be the following:

```
<?xml version="1.0" ?>
<Tutorial Materials="resources/tutorials/Materials.xml">
   <!-- Tutorial Instructions -->
   <Instruction>
      <Step>
         <Object Type="ARROW_3D">
            <Pos X="30.5" Y="-30" Z="24" />
            <Scale X="3" Y="3" Z="3" />
            <Rotate AngleX="0" AngleY="0" AngleZ="-90" />
            <TextColor R="0" G="0" B="1" A="1" />
            <Wireframe W="FALSE" />
            <Material Name="Red" />
            <Animation PathType="SWING">
               <ControlPoint X="0" Y="-1" Z="0" Time="0" />
               <ControlPoint X="0" Y="1" Z="0" Time="2" />
            </Animation>
         </Object>
         <Object Type="HUD_TEXT">
            <Pos X="10" Y="447.5" Z="0" />
            <TextColor R="0.88" G="0.88" B="0.88" A="1" />
            <Text T="Place the cylinder piece." />
            <Text T="And then move forward." />
            <TextSize S="18" />
            <Font FontName="fonts/tahomabd.TTF" />
            <StrokeColor R="0" G="0" B="0" A="0" />
            <BoxType BT="DEFAULT" />
            <BoxColor R="0.25" G="0.25" B="0.25" A="1" />
         </Object>
```

```
    </Step>
    <Step>
      <Object Type="HUD_TEXT">
        <Pos X="10" Y="447.5" Z="0" />
        <TextColor R="0.88" G="0.88" B="0.88" A="1" />
        <Text T="The cylinder piece should be placed." />
        <TextSize S="18" />
        <Font FontName="fonts/tahomabd.TTF" />
        <StrokeColor R="0" G="0" B="0" A="0" />
        <BoxType BT="DEFAULT" />
        <BoxColor R="0.25" G="0.25" B="0.25" A="1" />
      </Object>
      <Object Type="MODEL_3D">
        <Pos X="25" Y="-29" Z="15" />
        <Scale X="0.4" Y="0.4" Z="0.4" />
        <Rotate AngleX="0" AngleY="0" AngleZ="0" />
        <Name Filename="resources/tutorials/3D_Models/cilindro.osg" />
        <Material Name="Silver" />
        <Animation PathType="SWING">
          <ControlPoint X="0" Y="0" Z="-1" Time="0" />
          <ControlPoint X="0" Y="0" Z="1" Time="2" />
        </Animation>
      </Object>
    </Step>
  </Instruction>
</Tutorial>
```

A.4.1 Types of Objects

As briefly mentioned before, the objects can be of one of six different types: a 2D arrow, a 3D arrow, a 3D cone arrow, an HUD text, a 2D Text or a 3D Model. This section will serve to detail the characteristics that can be edited in each object.

A.4.1.1 Arrows

An arrow can be a simple 2D Arrow, a 3D Arrow composed of rectangles or a 3D Cone arrow composed of one cone and one cylinder.

Arrow Type	Fixed	Wireframe	Animation	Transform	Material
2D	Yes	Yes	Yes	Yes	Yes
3D	No	Yes	Yes	Yes	Yes
3D Cone	No	No	Yes	Yes	Yes

Table A.1: Arrow Properties

Transform applies to the scaling, rotating and repositioning of objects. If the Fixed mode is activated, the arrow will always be rotating towards the camera, hence why the 3D arrows do not have this mode. If they did, they would become 2D. If the fixed mode is active, there will be no visible animation even if the animation is active or detailed in the *XML*. This mose also does not allow the arrow's rotation to be edited.

The 3D Cone Arrow is the only arrow without the Wireframe mode, where only the outline of the arrows is drawn, since it is composed of 2 primitive objects that do not allow this mode (OSG Cylinder and Cone).

All arrows can have materials associated or a colour if the user prefers.

A.4.1.2 3D Models

3D Models can be animated, scaled, rotated, repositioned and of the following extensions: .osg, .3ds, .fbx and .dae among many others[38], but it is recommended to use the native osg binary extension for better results.

A.4.1.3 Text

Text objects exist in two types: HUD and 2D. HUD Texts are always placed at the top and 2D Texts can be placed anywhere in the field that the 3D Digitizer can reach to position objects (Or beyond it, if the user alters the position manually). The 2D Text will always be facing the user in order to be readable at all times. Their properties per type are the following:

Text Type	Box Color	Box Type	Text Editing
2D	Yes	Default	Color, Content, Font, Size and Stroke Color
HUD	Yes	Alert, Default	Color, Content, Font, Size and Stroke Color

Table A.2: Text Properties

A.5 Creating & Editing a Tutorial

To demonstrate how a tutorial can be created and edited, this manual will show how the first step in each of the two instructions in the XML associated to the Help menu function was created

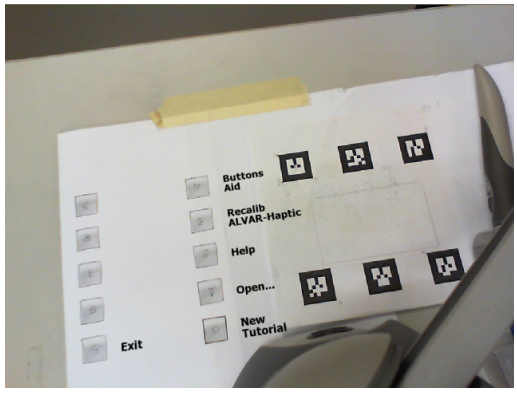


Figure A.2: Main Menu Screenshot

38 http://trac.openscenegraph.org/projects/osg//wiki/Support/UserGuides/Plugins

using the application. It will also provide a step-by-step approach in creating and editing instructions, steps and objects.

To prepare for the application launch, the 3D Digitizer's Stylus must be in the inkwell, in order to calibrate the device's 3D World. When the application is started, if no default configurations were altered, then the Main Menu will be displayed in a similar manner to the screenshot above.

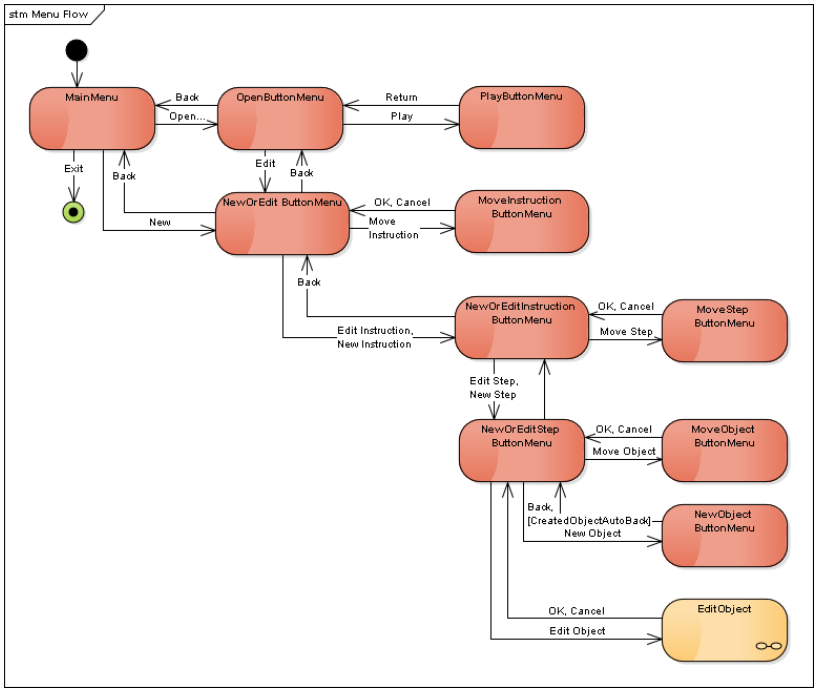


Figure A.3: Menu Flow

The current position in the menus available is seen in the Figure above, where the application is now at the Main Menu. To create a new tutorial, the number 0 can be pressed or the darkest gray button in the 3D Digitizer's Stylus after positioning it in the New Tutorial button square.

From the NewOrEdit Menu, it is only possible to create a New Instruction since the Tutorial is currently empty. All other instructions will appear grayed out. Through the creation of a new instruction, the user is led to the NewOrEditInstruction Menu where again, only one option is available due to the instruction being empty. A step must be created by choosing New Step which leads the user to the New OrEditStep Menu. In this menu, it is possible to choose New Object and add the first object of the Help Menu, a HUD Text. The HUD Text requires no positioning of the object itself since it is always placed at the top, but the text inside it can be repositioned.

After creating the HUD Text, the application goes back to the NewOrEditStep Menu where the user can add a new object or edit the current one. The options that are now available after creating an object are: delete, duplicate and move.

To edit the HUD Text in order to change the text, the user has to position the 3D Digitizer's Stylus in the Edit Object option or choose the appropriate number (default is 3 – RED Button Color). The application then leads the user to HUD Text's edit menu. All objects have a different menu, as the Figure above demonstrates.

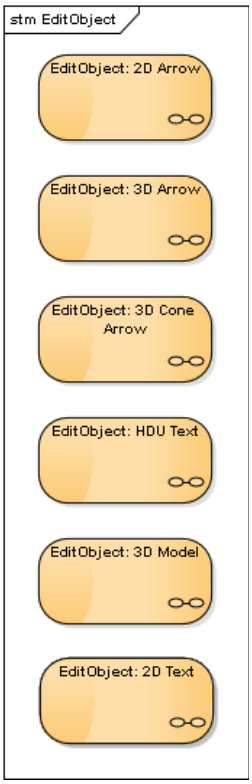


Figure A.4: Edit Object Menu Flow

In this case, the flow of both the HUD Text Menu and the 2D Text Menu would be like the Figure below. The HUD Edit Object Menu is linked to two menus and contains other functions not connected to menus, such as the reposition and the box color (available for consulting in the annex). Those two will open a secondary window that will not allow the user to perform another action until the window is closed.

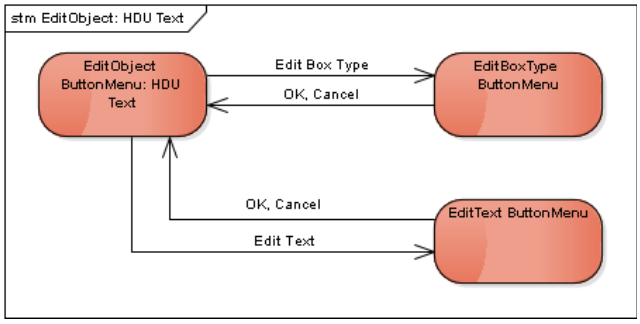


Figure A.5: HUD Text Menu Flow

The next object in the first step of the first instruction is a 2D Text. The procedure is similar to the HUD Text, but when the object is chosen to add to the step, it is not immediate. Instead, the user must choose where he would like to position it by using the Haptic Device. Once positioned, the user is led back to the NewOrEditStep Menu where the 2D Text will now be the highlighted and has become the current object, which he can edit to remove the default text.

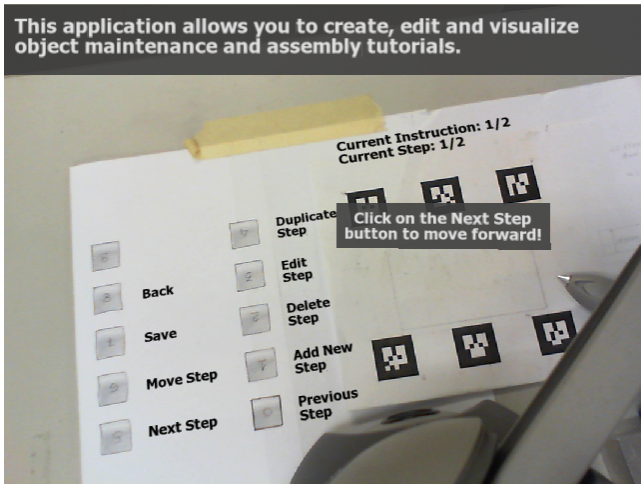


Figure A.6: First Step of the First Instruction

The first step of the first instruction will now look like the following Figure.

The second step of the first Instruction will have again a HUD Text and 2D Text so the following screenshot is related to the first step of the second Instruction. In it it is possible to see all types of arrows, a 3D model and the alert version of the HUD Text.

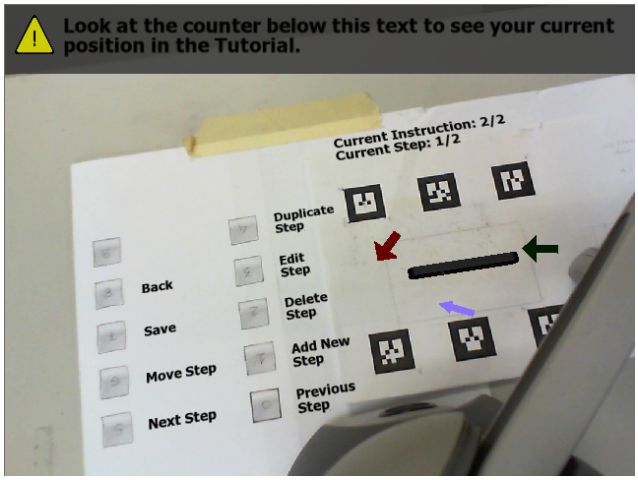


Figure A.7: 3D Model, 2D, 3D and 3D Cone Arrows

The procedure for adding arrows and 3D models is exactly the same as the 2D Text. All of them require the 3D Digitizer input to position them, as a message on the screen will notify. The menu flows for all the arrows after choosing Edit Object is shown in the following Figure.

All three arrow menus flows look exactly the same and are related to mostly the same functions, with the exception that 2D allows the Fixed mode, to always see the arrow properly as mentioned in section 4.1.1 and the 3D Cone doesn't allow neither fixed or wireframe modes due to the primitives that it is composed of.

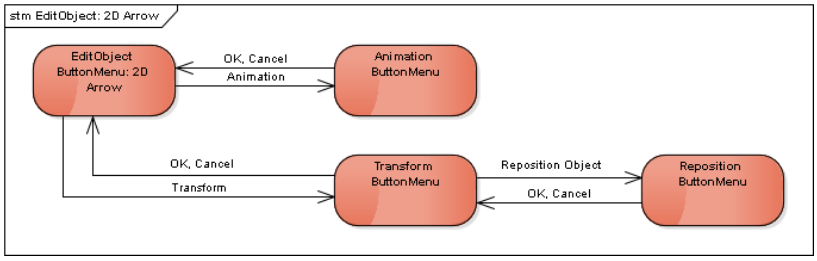


Figure A.8: 2D, 3D and 3D Cone Arrow Menu Flow

The 3D Model Menu flow is shown also for demonstration despite looking exactly the same as the Menu flow for the arrows since it links to the menus that allow animation, transform and reposition as well. However, 3D Models do not have fixed or wireframe mode.

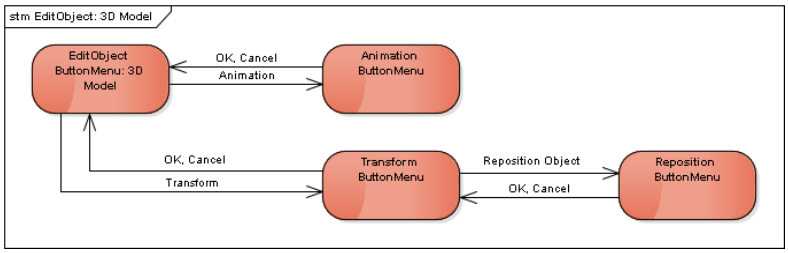


Figure A.9: Edit 3D Model Menu Flow

Summarizing, the creation of a instruction with one step and one object step-by-step would be performed in the following manner if a new tutorial is being created:

1. Navigate through the Main Menu and choose New Tutorial.
2. Choose New Instruction.
3. Choose New Step.
4. Choose New Object and select the object Type. Follow the on-screen instructions if it is not a HUD Text object.

For existing Tutorials, the first step would be replaced by choosing “Open...” instead of New Tutorial and then “Edit”. It is a good idea to pay attention to the counters above the markers as the tutorial is created.

A.6 Playing/Running a Tutorial

To play a tutorial, the following steps must be made. The user must have an existing tutorial to visualize and has to choose the “Open...” option in the Main Menu. From there, he can choose to “Play” which will visualize the tutorial in a manner similar to the Figure below. All the menu options are explained in the following annex.

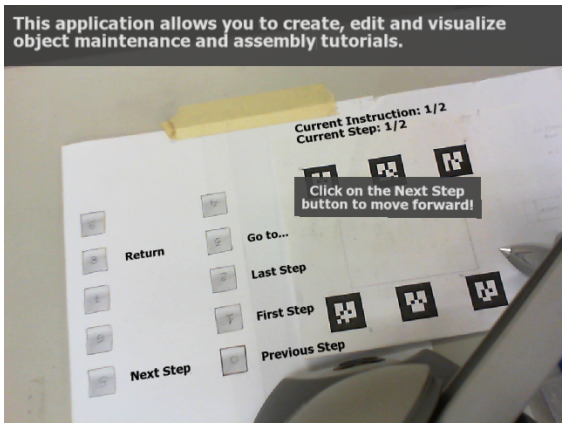


Figure A.10: Play Menu Screenshot

A.7 Annex - Functions available per Menu

Function	Action
NEW_FUNCTION	Opens the NEW_OR_EDIT_BUTTON_MENU.
OPEN_FUNCTION	Opens the OPEN_BUTTON_MENU if an XML tutorial file is chosen by the user.
HELP_FUNCTION	Opens the HELP_BUTTON_MENU.
RECALIBRATE_ALVAR_HAPTIC_FUNCTION	Recalibrates the connection between the 3D worlds of ALVAR and the Haptic Device.
BUTTON_TRACK_AID_FUNCTION	Turns on/off the menu buttons visibility aid.
EXIT_FUNCTION	Closes the application.

Table A.3: Main Menu Functions

Function	Action
PREVIOUS_INST_FUNCTION	Changes the current Instruction being visualized to its previous one, if it is not already visualizing the first Instruction.
NEXT_INST_FUNCTION	Changes the current Instruction being visualized to its next one, if it is not already visualizing the last Instruction.
NEW_INST_FUNCTION	Creates a new Instruction and opens the NEW_OR_EDIT_INST_BUTTON_MENU to edit it.
DELETE_INST_FUNCTION	Deletes the current Instruction if the Tutorial has any Instructions. Otherwise this function will be grayed out and unavailable.
EDIT_INST_FUNCTION	Opens the NEW_OR_EDIT_INST_BUTTON_MENU to edit the current Instruction if the Tutorial has any Instructions. Otherwise this function will be grayed out and unavailable.
DUPLICATE_INST_FUNCTION	Duplicates the current Instruction if the Tutorial has any Instructions. Otherwise this function will be grayed out and unavailable.
MOVE_INST_FUNCTION	Opens the MOVE_INST_BUTTON_MENU to move the current Instruction to another position if the Tutorial has any Instructions. Otherwise this function will be grayed out and unavailable.
SAVE_TO_XML_FUNCTION	Saves the current Tutorial to XML.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.4: New Or Edit Menu Functions

Function	Action
PREVIOUS_INST_FUNCTION	Moves the current Instruction to the previous position if it is not in the first position.
NEXT_INST_FUNCTION	Moves the current Instruction to the next position if it is not in the last position.
MOVE_TO_FUNCTION	Opens a secondary window that allows the user to choose the position to move the current Instruction to.
CANCEL_MOVE_FUNCTION	Resets all changes made to the Tutorial and goes back to NEW_OR_EDIT_BUTTON_MENU.
BACK_FUNCTION	Returns to NEW_OR_EDIT_BUTTON_MENU while keeping the changes made.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.5: Move Instruction Menu Functions

Function	Action
PREVIOUS_STEP_FUNCTION	Changes the current Step being visualized to its previous one, if it is not already visualizing the first Step.
NEXT_STEP_FUNCTION	Changes the current Step being visualized to its next one, if it is not already visualizing the last Step.
NEW_STEP_FUNCTION	Creates a new Step and opens the NEW_OR_EDIT_STEP_BUTTON_MENU to edit it.
DELETE_STEP_FUNCTION	Deletes the current Step if the current Instruction has any Steps. Otherwise this function will be grayed out and unavailable.
EDIT_STEP_FUNCTION	Opens the NEW_OR_EDIT_STEP_BUTTON_MENU to edit the current Step if the current Instruction has any Steps. Otherwise this function will be grayed out and unavailable.
DUPLICATE_STEP_FUNCTION	Duplicates the current Step if the current Instruction has any Steps. Otherwise this function will be grayed out and unavailable.
MOVE_STEP_FUNCTION	Opens the MOVE_STEP_BUTTON_MENU to move the current Step to another position in the current Instruction or another Instruction if the current Instruction has any Steps. Otherwise this function will be grayed out and unavailable.
SAVE_TO_XML_FUNCTION	Saves the current Tutorial to XML.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.6: New Or Edit Instruction Menu Functions

Function	Action
PREVIOUS_STEP_FUNCTION	Moves the current Step to the previous position if it is not in the first position.
NEXT_STEP_FUNCTION	Moves the current Step to the next position if it is not in the last position.
MOVE_TO_FUNCTION	Opens a secondary window that allows the user to choose the position to move the current Step to.
CANCEL_MOVE_FUNCTION	Resets all changes made to the Tutorial and goes back to NEW_OR_EDIT_INST_BUTTON_MENU.
BACK_FUNCTION	Returns to NEW_OR_EDIT_INST_BUTTON_MENU while keeping the changes made.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.7: Move Step Menu Functions

Function	Action
PREVIOUS_OBJ_FUNCTION	Changes the current Object being visualized to its previous one, if it is not already visualizing the first Object.
NEXT_OBJ_FUNCTION	Changes the current Object being visualized to its next one, if it is not already visualizing the last Object.
NEW_OBJ_FUNCTION	Opens the NEW_OBJ_BUTTON_MENU to choose the Object to add from the existing types.
DELETE_OBJ_FUNCTION	Deletes the current Object if the current Step has any Objects. Otherwise this function will be grayed out and unavailable.
EDIT_OBJ_FUNCTION	Opens the edit menu for the current Object Type to edit the current Object if the current Step has any Objects. Otherwise this function will be grayed out and unavailable.
DUPLICATE_OBJ_FUNCTION	Duplicates the current Object if the current Step has any Objects. Otherwise this function will be grayed out and unavailable.
MOVE_OBJ_FUNCTION	Opens the MOVE_OBJ_BUTTON_MENU to move the current Object to another position in the current Step or another Step if the current Step has any Objects. Otherwise this function will be grayed out and unavailable.
SAVE_TO_XML_FUNCTION	Saves the current Tutorial to XML.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.8: New Or Edit Step Menu Functions

Function	Action
PREVIOUS_OBJ_FUNCTION	Moves the current Object to the previous position if it is not in the first position.
NEXT_OBJ_FUNCTION	Moves the current Object to the next position if it is not in the last position.
MOVE_TO_FUNCTION	Opens a secondary window that allows the user to choose the position to move the current Object to.
CANCEL_MOVE_FUNCTION	Resets all changes made to the Tutorial and goes back to NEW_OR_EDIT_STEP_BUTTON_MENU.
BACK_FUNCTION	Returns to NEW_OR_EDIT_STEP_BUTTON_MENU while keeping the changes made.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.9: Move Object Menu Functions

Function	Action
NEW_2D_ARROW	Creates a 2D Arrow and returns to the NEW_OR_EDIT_STEP_BUTTON_MENU with the new Object as the currently focused Object.
NEW_3D_ARROW	Creates a 3D Arrow and returns to the NEW_OR_EDIT_STEP_BUTTON_MENU with the new Object as the currently focused Object.
NEW_3D_CONE_ARROW	Creates a 3D Cone Arrow and returns to the NEW_OR_EDIT_STEP_BUTTON_MENU with the new Object as the currently focused Object.
NEW_3D_MODEL	Creates a 3D Model and returns to the NEW_OR_EDIT_STEP_BUTTON_MENU with the new Object as the currently focused Object.
NEW_HUD_TEXT	Creates a HUD Text and returns to the NEW_OR_EDIT_STEP_BUTTON_MENU with the new Object as the currently focused Object.
NEW_2D_TEXT	Creates a 2D Text and returns to the NEW_OR_EDIT_STEP_BUTTON_MENU with the new Object as the currently focused Object.
BACK_FUNCTION	Returns to NEW_OR_EDIT_STEP_BUTTON_MENU without creating a new Object.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.10: New Object Menu Functions

Function	Action
BACK_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU without keeping the changes made.
TRANSFORM_FUNCTION	Opens the TRANSFORM_OBJECT_BUTTON_MENU to reposition, rotate or scale the current Object.
EDIT_MATERIAL_FUNCTION	Opens a secondary window that allows the user to pick a new material from the combo box given. New materials can be added while editing a Tutorial as this function always updates the combo box when launched.
ANIMATION_FUNCTION	Opens the ANIMATION_BUTTON_MENU to animate the current Object.
WIREFRAME_ARROW_FUNCTION	Turns on/off the wireframe mode of the arrow.
FIXED_2D_ARROW_FUNCTION	Turns on/off the fixed mode of the arrow. If this mode is on, there will be no animation.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.11: Edit 2D Arrow Menu Functions

Function	Action
BACK_FUNCTION	Goes back to the Edit Object Menu it came from while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to the Edit Object Menu it came from without keeping the changes made.
REPOSITION_FUNCTION	Opens the REPOSITION_BUTTON_MENU to reposition the current Object.
SCALE_OBJECT_FUNCTION	Opens a secondary window that allows the user to scale the current Object by altering the values in the spin buttons.
MANUAL_ROTATION_FUNCTION	Opens a secondary window that allows the user to rotate the current Object by altering the values in the spin buttons.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.12: Transform Object Menu Functions

Function	Action
BACK_FUNCTION	Goes back to TRANSFORM_OBJECT_BUTTON_MENU while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to TRANSFORM_OBJECT_BUTTON_MENU without keeping the changes made.
HAPTIC_REPOSITION_FUNCTION	Allows the user to reposition the current Object by using the Haptic Device to pinpoint the wanted location.
MANUAL_REPOSITION_FUNCTION	Opens a secondary window that allows the user to reposition the current Object by altering the values in the spin buttons.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.13: Reposition Menu Functions

Function	Action
BACK_FUNCTION	Goes back to the Edit Object Menu it came from while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to the Edit Object Menu it came from without keeping the changes made.
REMOVE_ANIMATION_FUNCTION	Allows the user to reposition the current Object by using the Haptic Device to pinpoint the wanted location.
POINT_X_FUNCTION	Creates an animation in the X axis with Swing Mode as Default.
POINT_Y_FUNCTION	Creates an animation in the Y axis with Swing Mode as Default.
POINT_Z_FUNCTION	Creates an animation in the Z axis with Swing Mode as Default.
NO_LOOP_MODE_FUNCTION	Alters the animation loop mode to No Loop Mode (Only moves once in the direction towards the current Object location in the 3D World).
LOOP_MODE_FUNCTION	Alters the animation loop mode to Loop Mode (Only moves in the direction towards the current Object location in the 3D World).
SWING_MODE_FUNCTION	Alters the animation loop mode to Swing Mode (Moves in the direction towards the current Object location in the 3D World and in the reverse direction).
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.14: Animation Menu Functions

Function	Action
BACK_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU without keeping the changes made.
TRANSFORM_FUNCTION	Opens the TRANSFORM_OBJECT_BUTTON_MENU to reposition, rotate or scale the current Object.
EDIT_MATERIAL_FUNCTION	Opens a secondary window that allows the user to pick a new material from the combo box given. New materials can be added while editing a Tutorial as this function always updates the combo box when launched.
ANIMATION_FUNCTION	Opens the ANIMATION_BUTTON_MENU to animate the current Object.
WIREFRAME_ARROW_FUNCTION	Turns on/off the wireframe mode of the arrow.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.15: Edit 3D Arrow Menu Functions

Function	Action
BACK_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU without keeping the changes made.
TRANSFORM_FUNCTION	Opens the TRANSFORM_OBJECT_BUTTON_MENU to reposition, rotate or scale the current Object.
EDIT_MATERIAL_FUNCTION	Opens a secondary window that allows the user to pick a new material from the combo box given. New materials can be added while editing a Tutorial as this function always updates the combo box when launched.
ANIMATION_FUNCTION	Opens the ANIMATION_BUTTON_MENU to animate the current Object.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.16: Edit 3D Cone Arrow Menu Functions

Function	Action
BACK_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU without keeping the changes made.
FILENAME_3D_MODEL_FUNCTION	Opens a secondary window that allows the user to pick a new 3D Model file to change the model associated to the current Object.
TRANSFORM_FUNCTION	Opens the TRANSFORM_OBJECT_BUTTON_MENU to reposition, rotate or scale the current Object.
EDIT_MATERIAL_FUNCTION	Opens a secondary window that allows the user to pick a new material from the combo box given. New materials can be added while editing a Tutorial as this function always updates the combo box when launched.
ANIMATION_FUNCTION	Opens the ANIMATION_BUTTON_MENU to animate the current Object.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.17: Edit 3D Model Menu Functions

Function	Action
BACK_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU without keeping the changes made.
REPOSITION_FUNCTION	Opens a secondary window that allows the user to reposition the current Object by altering the values in the spin buttons.
EDIT_BOX_TYPE_FUNCTION	Opens the EDIT_BOX_TYPE_BUTTON_MENU to change the box type of the current Object.
EDIT_BOX_COLOR_FUNCTION	Opens a secondary window that allows the user to pick a new box color by altering the values in the spin buttons.
EDIT_TEXT_FUNCTION	Opens the EDIT_TEXT_BUTTON_MENU to edit the text of the current Object.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.18: Edit HUD Text Menu Functions

Function	Action
BACK_FUNCTION	Goes back to EDIT_HUD_TEXT_BUTTON_MENU while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to EDIT_HUD_TEXT_BUTTON_MENU without keeping the changes made.
DEFAULT_BOX_FUNCTION	Changes the box type of the current Object to Default.
ALERT_BOX_FUNCTION	Opens a secondary window that allows the user to choose the image file that will be placed at the left of the text in the box and changes the box type of the current Object box to Alert.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.19: Edit Box Type Menu Functions

Function	Action
BACK_FUNCTION	Goes back to the Edit Text Object Menu it came from (HUD or 2D) while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to the Edit Text Object Menu it came from (HUD or 2D) without keeping the changes made.
EDIT_TEXT_SIZE_FUNCTION	Opens a secondary window that allows the user to change the text size of the current Object by altering the value in the spin button.
EDIT_TEXT_STROKE_COLOR_FUNCTION	Opens a secondary window that allows the user to change the text stroke color of the current Object by altering the values in the spin buttons.
EDIT_TEXT_CONTENT_FUNCTION	Opens a secondary window that allows the user to change the text content of the current Object by altering the text.
EDIT_TEXT_FONT_FUNCTION	Opens a secondary window that allows the user to change the text font of the current Object by choosing a different font name in the combo box.
EDIT_TEXT_COLOR_FUNCTION	Opens a secondary window that allows the user to change the text color of the current Object by altering the values in the spin buttons.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.20: Edit Text Menu Functions

Function	Action
BACK_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU while keeping the changes made.
CANCEL_EDIT_FUNCTION	Goes back to NEW_OR_EDIT_STEP_BUTTON_MENU without keeping the changes made.
REPOSITION_FUNCTION	Opens a secondary window that allows the user to reposition the current Object by altering the values in the spin buttons.
EDIT_BOX_COLOR_FUNCTION	Opens a secondary window that allows the user to pick a new box color by altering the values in the spin buttons.
EDIT_TEXT_FUNCTION	Opens the EDIT_TEXT_BUTTON_MENU to edit the text of the current Object.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.21: Edit 2D Text Menu Functions

Function	Action
PLAY_FUNCTION	Opens the PLAY_BUTTON_MENU and the interactive visualization of the tutorial.
EDIT_FUNCTION	Opens the NEW_OR_EDIT_BUTTON_MENU that allows the editing of the chosen tutorial.
BACK_FUNCTION	If the tutorial was changed and not saved, the user is asked if he wants to save. Goes back to MAIN_MENU and removes the current tutorial data from the application.

Table A.22: Open Menu Functions

Function	Action
PREVIOUS_STEP_FUNCTION	Changes the current Step being visualized to its previous one, if it is not already visualizing the first Step.
NEXT_STEP_FUNCTION	Changes the current Step being visualized to its next one, if it is not already visualizing the last Step.
FIRST_STEP_FUNCTION	Changes the current Step being visualized to the first Step of the Tutorial.
LAST_STEP_FUNCTION	Changes the current Step being visualized to the last Step in the Tutorial.
GO_TO_FUNCTION	Opens a secondary window that allows the user to choose the Step he wants to visualize in the Tutorial.
BACK_FUNCTION	Goes back to the OPEN_BUTTON_MENU.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

Table A.23: Play Menu Functions

Function	Action
PREVIOUS_STEP_FUNCTION	Changes the current Step being visualized to its previous one, if it is not already visualizing the first Step.
NEXT_STEP_FUNCTION	Changes the current Step being visualized to its next one, if it is not already visualizing the last Step.
BACK_FUNCTION	Goes back to the MAIN_MENU.
COUNTER_FUNCTION	Associated by default to the button color White, it serves as a counter area for Instructions, Steps and Objects associated to the Tutorial. It is highly advised to not remove from the menu.

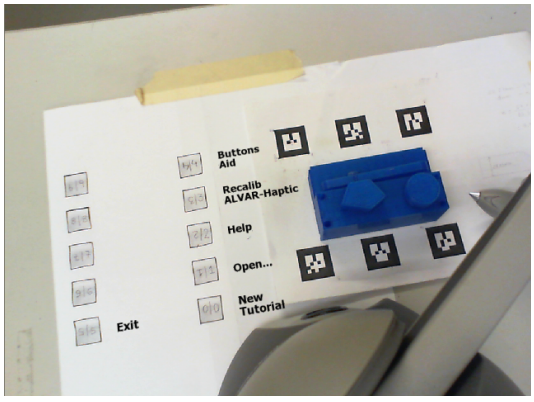
Table A.24: Help Menu Functions

Appendix B: Tutorial System Application Guide

This guide is for the *Tutorial System based on Augmented Reality Application* which was created for the dissertation “The Augmented Reality Systems in a Maintenance of Equipment tutorial context” in order to guide the testers.

The application allows the user to create, edit and visualize augmented reality tutorials that demonstrate how to assemble or disassemble complex objects, for example for maintenance proposals. Its physical components are two surfaces with predefined drawings (markers + menu buttons), a calibration object and a device which is used to obtain 3D Coordinates (therefore referred from here on as a 3D Digitizer).

The buttons in one of the mentioned surfaces are used as menu elements and the 3D Digitizer is used to interact with the menu through its “arm” (technically referred from here on as stylus). The menu can also be used through the keyboard by using the number printed in each button.



Tutorial System Application Guide

Each Tutorial is stored in an XML file and, similarly to a classical user's manual, is composed by an ordered sequence of Instructions. Each Instruction may be composed by an ordered sequence of Steps and each Step uses Objects. The Objects can be one of six different types: a 2D arrow, a 3D arrow, a 3D cone arrow, an HUD Text, a 2D Text or a 3D Model. These objects may be used to point a detail in a 3D real object, to transmit written instructions, or to add synthetic objects.

To exemplify, the creation of an instruction with one step and one object step-by-step would be performed in the following manner if a new tutorial is being created:

1. In the first menu, also known as Main Menu, choose New Tutorial by clicking on the button in the paper (number 0) with the dark gray button of the stylus. Follow the same procedure for the remaining steps.
2. Choose New Instruction.
3. Choose New Step.
4. Choose New Object and select the object Type. Follow the on-screen instructions if it is not a HUD Text object.

For an existing Tutorial, the first step would be replaced by choosing "Open..." instead of New Tutorial and then "Edit". It is a good idea to pay attention to the counters above the markers as the tutorial is created.

After creating an Instruction similar to the above one, a new Instruction may be created by clicking the "Back" button until you see the "New Instruction" option.

For the evaluation test, you will be given a period of maximum 15 minutes to familiarize yourself with the application before starting the test and any questions you have will be answered. The test you will perform is the creation of a simple tutorial following the structure given below. You will need to place the main structure of the object in the square drawn between the markers in the orientation that is specified in the image above.

The time spent on each Step will be tracked and the errors will also be accounted. Possible errors will include clicking on the wrong menu option, adding an object different from requested, adding extra Instructions or Steps besides the ones included in the structure given or not adding enough Instructions, Steps or Objects to match the structure. The entire procedure will be recorded, so please try to think out loud as much as possible.

Please fill the first page of the form that you will receive before using the application.

Structure of Tutorial to be created in the test:

- The Tutorial contains 4 Instructions
  - Instruction 1 contains 2 Steps:
    - Step 1 contains 2 Objects: Arrow and HUD Text that explain how to place the cylinder piece.
    - Step 2 contains 2 Objects: 3D Model and HUD Text that demonstrate what should now be the result of assembling the cylinder piece.
  - Instruction 2 contains 2 Steps:
    - Step 1 contains 2 Objects: Arrow and HUD Text that explain how to place the trapezoid piece.

        - Step 2 contains 2 Objects: 3D Model and HUD Text that demonstrate what should now be the result of assembling the trapezoid piece.
    - Instruction 3 contains 2 Steps:
        - Step 1 contains 2 Objects: Arrow and HUD Text that explain how to place the lever piece.
        - Step 2 contains 2 Objects: 3D Model and HUD Text that demonstrate what should now be the result of assembling the lever piece.
    - Instruction 4 contains 2 Steps:
        - Step 1 contains 2 Objects: Arrow and HUD Text that explain how to place the drawer piece.
        - Step 2 contains 2 Objects: 3D Model and HUD Text that demonstrate what should now be the result of assembling the drawer piece.

Please remember to save the tutorial occasionally. When you finish creating the tutorial, fill the 2nd page of the distributed form.

Appendix C: Tutorial System Application Questionnaire

Please remember to save the tutorial occasionally. When you finish creating the tutorial, fill the 2nd page of the distributed form.

Page 1

Please fill the first part of the following form before using the application.

1. Name:
2. Age
    1. 18-24
    2. 25-30
    3. 31-35
    4. 36-40
    5. >40
3. Gender
    1. Female
    2. Male
4. Current Occupation
    1. Student
    2. Technician
    3. Teacher
    4. Other
5. Do you have any experience with Augmented Reality (AR)?
    1. Yes
    2. No

Page 2

Now that you completed the test, please answer the remaining questions in the form.

6. How intuitive was the 3D Digitizer as a pointer?
    1. Help Text: Considering it was used for the Menu Interface.
    2. Scale: 1 (Hard to adapt) to 5 (Very intuitive)
7. How effective was the 3D Digitizer in pointing and placing objects?
    1. Scale: 1 (Very ineffective) to 5 (Perfectly functional)
8. How would you rate the usability of the editing system?
    1. Help Text: Was the 3D Digitizer constantly blocking your view?
    2. Scale: 1 (Very intrusive) to 5 (Non-intrusive)
9. How would you rate the usability of the overall interface?
    1. Help Text: Please consider both the 3D Digitizer interaction with the menu and objects, as well as the keyboard shortcuts if you used them.
    2. Scale: 1 (Hard to adapt) to 5 (Very intuitive)
10. Did you prefer to use the 3D Digitizer or the keyboard for the menu interface?
    1. 3D Digitizer
    2. Keyboard Shortcuts
11. Would you add another helping object type to the application?
    1. Help Text: Considering the existing helping objects (3 Types of Arrows, 2 Types of Text and 3D Models), do you think that other alternatives should be provided to point to a certain location or present text?
    2. Multiple choice question: Yes or No
12. If you answered yes to the previous question, which new helping objects would you add?
13. Having an overall view about the application, would you suggest any change in the interface?

References

Álvarez, H., I. Aguinaga, and D. Borro. 2011. "Providing guidance for maintenance operations using automatic markerless augmented reality system."

ARToolworks. Accessed January. http://www.artoolworks.com/.

Azuma, R. T. 1997. "A survey of augmented reality." *Presence: Teleoperators and Virtual Environments* 6 (4):355-385.

Baird, K. M., and W. Barfield. 1999. "Evaluating the effectiveness of augmented reality displays for a manual assembly task." *Virtual Reality* 4 (4):250-9.

Barakonyi, Istvan, Tamer Fahmy, and Dieter Schmalstieg. 2004. "Remote collaboration using augmented reality videoconferencing." Proceedings of Graphics interface 2004.

Barandiaran, Iñigo, Céline Paloc, and Manuel Graña. 2010. "Real-time optical markerless tracking for augmented reality applications." *Journal of Real-Time Image Processing* 5 (2):129-138.

Benko, H., and S. Feiner. 2007. "Balloon Selection: A Multi-Finger Technique for Accurate Low-Fatigue 3D Selection." 3D User Interfaces, 2007. 3DUI '07. IEEE Symposium on, 10-11 March 2007.

Blum, Tobias, Valerie Kleeberger, Christoph Bichlmeier, and Nassir Navab. 2012. "mirracle: An augmented reality magic mirror system for anatomy education." Virtual Reality Short Papers and Posters (VRW), 2012 IEEE.

Carmigniani, J., B. Furht, M. Anisetti, P. Ceravolo, E. Damiani, and M. Ivkovic. 2011. "Augmented reality technologies, systems and applications." *Multimedia Tools and Applications* 51 (1):341-77. doi: 10.1007/s11042-010-0660-6.

Caudell, T. P., and D. W. Mizell. 1992. "Augmented reality: an application of heads-up display technology to manual manufacturing processes." System Sciences, 1992. Proceedings of the Twenty-Fifth Hawaii International Conference on, 7-10 Jan 1992.

Chen, Chih-Ming, and Yen-Nung Tsai. 2012. "Interactive augmented reality system for enhancing library instruction in elementary schools." *Computers & Education* 59 (2):638-652. doi: http://dx.doi.org/10.1016/j.compedu.2012.03.001.

Chen, Qian, Haiyuan Wu, and Toshikazu Wada. 2004. "Camera calibration with two arbitrary coplanar circles." In *Computer Vision-ECCV 2004*, 521-532. Springer.

Cooper, Nicholas, Aaron Keatley, Maria Dahlquist, Simon Mann, Hannah Slay, Joanne Zucco, Ross Smith, and Bruce H Thomas. 2004. "Augmented reality Chinese checkers."

Proceedings of the 2004 ACM SIGCHI International Conference on Advances in computer entertainment technology.

Costanza, Enrico, and John Robinson. 2003. "A Region Adjacency Tree Approach to the Detection and Design of Fiducials."

Dedual, Nicolas J., O. Oda, and Steven K. Feiner. 2011. "Creating hybrid user interfaces with a 2D multi-touch tabletop and a 3D see-through head-worn display." Mixed and Augmented Reality (ISMAR), 2011 10th IEEE International Symposium on, 26-29 Oct. 2011.

Di Serio, Ángela, María Blanca Ibáñez, and Carlos Delgado Kloos. 2013. "Impact of an augmented reality system on students' motivation for a visual art course." *Computers & Education* 68 (0):586-596. doi: http://dx.doi.org/10.1016/j.compedu.2012.03.002.

Eiriksdottir, Elsa, and Richard Catrambone. 2011. "Procedural Instructions, Principles, and Examples How to Structure Instructions for Procedural Tasks to Enhance Performance, Learning, and Transfer." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 53 (6):749-770.

Feiner, S., Blair MacIntyre, T. Hollerer, and A. Webster. 1997. "A touring machine: prototyping 3D mobile augmented reality systems for exploring the urban environment." Wearable Computers, 1997. Digest of Papers., First International Symposium on, 13-14 Oct. 1997.

Feiner, Steven, Blair Macintyre, Dor, #233, and e Seligmann. 1993. "Knowledge-based augmented reality." *Commun. ACM* 36 (7):53-62. doi: 10.1145/159544.159587.

Feldman, Assaf, Emmanuel Munguia Tapia, Sajid Sadi, Pattie Maes, and Chris Schmandt. 2005. "ReachMedia: On-the-move interaction with everyday objects." Wearable Computers, 2005. Proceedings. Ninth IEEE International Symposium on.

Feng, Zhou, H. B. L. Duh, and M. Billinghurst. 2008. "Trends in augmented reality tracking, interaction and display: a review of ten years of ISMAR." 7th IEEE International Symposium on Mixed and Augmented Reality 2008, 15-18 Sept. 2008, Piscataway, NJ, USA.

Fiala, M. 2005. "ARTag, a fiducial marker system using digital techniques." Computer Vision and Pattern Recognition, 2005. CVPR 2005. IEEE Computer Society Conference on, 20-25 June 2005.

Foley, James D., Richard L. Phillips, John F. Hughes, Andries van Dam, and Steven K. Feiner. 1997. "Transformations as a Change in Coordinate System." In *Introduction to Computer Graphics*, 187-192. Addison-Wesley Longman Publishing Co., Inc.

Henderson, S., and S. Feiner. 2011. "Exploring the benefits of augmented reality documentation for maintenance and repair." *IEEE Transactions on Visualization and Computer Graphics* 17 (10):1355-1368.

Henderson, S. J., and S. Feiner. 2009. *Evaluating the Benefits of Augmented Reality for Task Localization in Maintenance of an Armored Personnel Carrier Turret*. Edited by G. Klinker, H. Saito and T. Hollerer, *2009 8th Ieee International Symposium on Mixed and Augmented Reality*.

References

Hollerer, Tobias, Steven Feiner, and John Pavlik. 1999. "Situated documentaries: Embedding multimedia presentations in the real world." Wearable Computers, 1999. Digest of Papers. The Third International Symposium on.

Höllerer, Tobias, Steven Feiner, Tachio Terauchi, Gus Rashid, and Drexel Hallaway. 1999. "Exploring MARS: developing indoor and outdoor user interfaces to a mobile augmented reality system." *Computers & Graphics* 23 (6):779-785.

Hou, L., X. Wang, L. Bernold, and P. E. D. Love. 2013. "Using animated augmented reality to cognitively guide assembly." *Journal of Computing in Civil Engineering* 27 (5):439-451.

Hou, Lei, and Xiangyu Wang. 2013. "A study on the benefits of augmented reality in retaining working memory in assembly tasks: A focus on differences in gender." *Automation in Construction* 32 (0):38-45. doi: http://dx.doi.org/10.1016/j.autcon.2012.12.007.

Juan, M Carmen, and Jérôme Calatrava. 2011. "An Augmented Reality System for the Treatment of Phobia to Small Animals Viewed Via an Optical See-Through HMD: Comparison With a Similar System Viewed Via a Video See-Through HMD." *International Journal of Human-Computer Interaction* 27 (5):436-449.

Kato, Hirokazu, and Mark Billinghurst. 1999. "Marker tracking and hmd calibration for a video-based augmented reality conferencing system." Augmented Reality, 1999.(IWAR'99) Proceedings. 2nd IEEE and ACM International Workshop on.

Kato, Hirokazu, Mark Billinghurst, Ivan Poupyrev, Kenji Imamoto, and Keihachiro Tachibana. 2000. "Virtual object manipulation on a table-top AR environment." Augmented Reality, 2000.(ISAR 2000). Proceedings. IEEE and ACM International Symposium on.

Kaufmann, Hannes, and Dieter Schmalstieg. 2003. "Mathematics and geometry education with collaborative augmented reality." *Computers & Graphics* 27 (3):339-345.

Klein, Alexandre, and Gilda Aparecida de Assis. 2013. "A Markeless Augmented Reality Tracking for Enhancing the User Interaction during Virtual Rehabilitation." Virtual and Augmented Reality (SVR), 2013 XV Symposium on.

Koehler, Johannes, Alain Pagani, and Didier Stricker. 2010. "Robust Detection and Identification of Partially Occluded Circular Markers." VISAPP (1).

Köhler, Johannes, Alain Pagani, and Didier Stricker. 2011. "Detection and identification techniques for markers used in computer vision." OASIcs-OpenAccess Series in Informatics.

Lee, Jae-Young, Seok-Han Lee, Hyung-Min Park, Sang-Keun Lee, Jong-Soo Choi, and Jun-Sik Kwon. 2010. "Design and implementation of a wearable AR annotation system using gaze interaction." Consumer Electronics (ICCE), 2010 Digest of Technical Papers International Conference on.

Liverani, A., G. Amati, and G. Caligiana. 2004. "A CAD-augmented Reality Integrated Environment for Assembly Sequence Check and Interactive Validation." *Concurrent Engineering Research and Applications* 12 (1):67-77.

Marescaux, Jacques, Francesco Rubino, Mara Arenas, Didier Mutter, and Luc Soler. 2004. "Augmented-reality–assisted laparoscopic adrenalectomy." *Jama* 292 (18):2211-2215.

References

Medicherla, Padmavathi S., George Chang, and Patricia Morreale. 2010. "Visualization for increased understanding and learning using augmented reality." 2010 ACM SIGMM International Conference on Multimedia Information Retrieval, MIR 2010, March 29, 2010 - March 31, 2010, Philadelphia, PA, United states.

Milgram, Paul, and Fumio Kishino. 1994. "Taxonomy of mixed reality visual displays." *IEICE Transactions on Information and Systems* E77-D (12):1321-1329.

Mistry, Pranav, Pattie Maes, and Liyan Chang. 2009. "WUW-wear Ur world: a wearable gestural interface." CHI'09 extended abstracts on Human factors in computing systems.

Miyashita, Tsutomu, P Meier, Tomoya Tachikawa, Stephanie Orlic, Tobias Eble, Volker Scholz, Andreas Gapel, Oliver Gerl, Stanimir Arnaudov, and Sebastian Lieberknecht. 2008. "An augmented reality museum guide." Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality.

Mohring, Mathias, Christian Lessig, and Oliver Bimber. 2004. "Video see-through ar on consumer cell-phones." Proceedings of the 3rd IEEE/ACM International Symposium on Mixed and Augmented Reality.

Neumann, Ulrich, and Anthony Majoros. 1998. "Cognitive, performance, and systems issues for augmented reality applications in manufacturing and maintenance." Proceedings of the 1998 IEEE Virtual Reality Annual International Symposium, VRAIS, March 14, 1998 - March 18, 1998, Atlanta, GA, USA.

Nicolau, Stéphane, Alain Garcia, Xavier Pennec, Luc Soler, and Nicholas Ayache. 2005. "An augmented reality system to guide radio-frequency tumour ablation." *Computer animation and virtual worlds* 16 (1):1-10.

Nicolau, Stéphane, Luc Soler, Didier Mutter, and Jacques Marescaux. 2011. "Augmented reality in laparoscopic surgical oncology." *Surgical Oncology* 20 (3):189-201. doi: http://dx.doi.org/10.1016/j.suronc.2011.07.002.

Ong, S. K., M. L. Yuan, and A. Y. C. Nee. 2008. "Augmented reality applications in manufacturing: A survey." *International Journal of Production Research* 46 (10):2707-2742. doi: 10.1080/00207540601064773.

Pathomaree, N., and Siam Charoenseang. 2005. "Augmented reality for skill transfer in assembly task." Robot and Human Interactive Communication, 2005. ROMAN 2005. IEEE International Workshop on, 13-15 Aug. 2005.

Platonov, Juri, Hauke Heibel, Peter Meier, and Bert Grollmann. 2007. "A mobile markerless AR system for maintenance and repair." ISMAR 2006: 5th IEEE and ACM International Symposium on Mixed and Augmented Reality, October 22, 2006 - October 25, 2006, Santa Barbara, CA, United states.

Raghavan, V., J. Molineros, and R. Sharma. 1999. "Interactive evaluation of assembly sequences using augmented reality." *Robotics and Automation, IEEE Transactions on* 15 (3):435-449. doi: 10.1109/70.768177.

Reiners, D., D. Stricker, G. Klinker, and S. Muller. 1999. "Augmented reality for construction tasks: doorlock assembly." Proceedings of IWAR'98: First International Workshop on Augmented Reality, 1 Nov. 1998, Natick, MA, USA: A K Peters, Ltd., 1999, pp.31-46.

References

Reinhart, G., and C. Patron. 2003. "Integrating Augmented Reality in the Assembly Domain - Fundamentals, Benefits and Applications." *CIRP Annals - Manufacturing Technology* 52 (1):5-8. doi: http://dx.doi.org/10.1016/S0007-8506(07)60517-4.

Rekimoto, J. 1998. "Matrix: a realtime object identification and registration method for augmented reality." Computer Human Interaction, 1998. Proceedings. 3rd Asia Pacific, 15-17 Jul 1998.

Rolland, Jannick P, and Henry Fuchs. 2000. "Optical versus video see-through head-mounted displays in medical visualization." *Presence: Teleoperators and Virtual Environments* 9 (3):287-309.

Rosenberg, Louis B. 1995. "Virtual haptic overlays enhance performance in telepresence tasks." Photonics for Industrial Applications.

Salonen, T., J. Sääski, M. Hakkarainen, T. Kannetis, M. Perakakis, S. Siltanen, A. Potamianos, O. Korkalo, and C. Woodward. 2007. "Demonstration of assembly work using augmented reality."

Sandor, Christian, Alex Olwal, Blaine Bell, and Steven Feiner. 2005. "Immersive mixed-reality configuration of hybrid user interfaces." Mixed and Augmented Reality, 2005. Proceedings. Fourth IEEE and ACM International Symposium on.

Sausman, J., A. Samoylov, S. H. Regli, M. Hopps, Ieee, and Acm. 2012. *Effect of Eye and Body Movement on Augmented Reality in the Manufacturing Domain*, *2012 Ieee International Symposium on Mixed and Augmented Reality*.

Schmalstieg, Dieter, Anton Fuhrmann, and Gerd Hesina. 2000. "Bridging multiple user interface dimensions with augmented reality." Augmented Reality, 2000.(ISAR 2000). Proceedings. IEEE and ACM International Symposium on.

Schmalstieg, Dieter, Anton Fuhrmann, Gerd Hesina, Zsolt Szalavári, L Miguel Encarnaçao, Michael Gervautz, and Werner Purgathofer. 2002. "The studierstube augmented reality project." *Presence: Teleoperators and Virtual Environments* 11 (1):33-54.

Sinem, G, and Steven Feiner. 2003. "Authoring 3D hypermedia for wearable augmented and virtual reality." 2012 16th International Symposium on Wearable Computers.

Stork, S., and A. Schubö. 2010. "Human cognition in manual assembly: Theories and applications." *Advanced Engineering Informatics* 24 (3):320-328.

Sutherland, Ivan E. 1968. "A head-mounted three dimensional display." Proceedings of the December 9-11, 1968, fall joint computer conference, part I, San Francisco, California.

Tang, Arthur, Charles Owen, Frank Biocca, and Weimin Mou. 2003. "Comparative effectiveness of augmented reality in object assembly." SIGCHI Conference on Human Factors in Computing Systems, CHI 2003, April 5, 2003 - April 10, 2003, Ft. Lauderdale, FL, United states.

Thomas, Bruce, Benjamin Close, John Donoghue, John Squires, Phillip De Bondi, Michael Morris, and Wayne Piekarski. 2000. "ARQuake: An outdoor/indoor augmented reality first person application." Wearable Computers, The Fourth International Symposium on.

References

Ullmer, Brygg, and Hiroshi Ishii. 1997. "The metaDESK: models and prototypes for tangible user interfaces." Proceedings of the 10th annual ACM symposium on User interface software and technology.

Van Krevelen, DWF, and R Poelman. 2010. "A survey of augmented reality technologies, applications and limitations." *International Journal of Virtual Reality* 9 (2):1.

Vlahakis, Vassilios, Nikolaos Ioannidis, John Karigiannis, Manolis Tsotros, Michael Gounaris, Didier Stricker, Tim Gleue, Patrick Daehne, and Luís Almeida. 2002. "Archeoguide: an augmented reality guide for archaeological sites." *IEEE Computer Graphics and Applications* 22 (5):52-60.

Wagner, Daniel, and Dieter Schmalstieg. 2007. "Artoolkitplus for pose tracking on mobile devices." Proceedings of 12th Computer Vision Winter Workshop (CVWW'07).

Wiedenmaier, S., O. Oehme, L. Schmidt, and H. Luczak. 2003. "Augmented Reality (AR) for Assembly Processes Design and Experimental Evaluation." *International Journal of Human-Computer Interaction* 16 (3):497-514.

Ying, Li. 2010. "Augmented reality for remote education." 2010 3rd International Conference on Advanced Computer Theory and Engineering (ICACTE 2010), 20-22 Aug. 2010, Piscataway, NJ, USA.

Yuan, M. L., S. K. Ong, and A. Y. C. Nee. 2008. "Augmented reality for assembly guidance using a virtual interactive tool." *International Journal of Production Research* 46 (7):1745-1767, http://www.tandfonline.com/.

Zauner, J., M. Haller, A. Brandl, and W. Hartman. 2003. "Authoring of a mixed reality assembly instructor for hierarchical structures." Proceedings the Second IEEE and ACM International Symposium on Mixed and Augmented Reality, 7-10 Oct. 2003, Los Alamitos, CA, USA.

Zendjebil, Imane, Fakhr-eddine Ababsa, Jean-Yves Didier, Jacques Vairon, Luc Frauciel, Martin Hachet, Pascal Guitton, and Romuald Delmont. 2008. "Outdoor augmented reality: State of the art and issues." 10th ACM/IEEE Virtual Reality International Conference (VRIC 2008).