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Departamento de Sistemas Informáticos y Computación

Master Thesis work

Natural user interfaces and autostereoscopy for learning in dentistry

A Thesis submitted by David Rodríguez for the Artificial Intelligence, Pattern Recognition and Digital Imaging Master Program

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"Everything should be made as simple as possible, but no simpler."

–Albert Einstein

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Abstract

In this thesis, we present the development of a new "serious" game that combines autostereoscopy[1] and Natural User Interface (NUI)[2] for dental learning in higher education. To our knowledge, this is the first time a game of these characteristics has been presented. We developed a NUI game that can work in two modes, with a real background and with a neutral background. In the two modes, two avatar hands appear in the position where the users' hands are. In the real-background mode, the avatar hands are over the hands of the user, and the users can see the rest of their own body. In the neutral background mode, the users know their hand position from the avatar hands.

Our hypothesis was that since the real-world background offers more cues than the neutral background for a more effective NUI, there would be a statistically significant improvement in knowledge. We tested the systems with thirty-three dentistry students. The students had divided in two groups to test the systems.

We carried out a study to test our hypothesis. We perform a statistical analysis of the results obtained in the tests. We obtained that the users increased their knowledge about the topic of the game (teeth morphology), and the increment of knowledge in both (real-world and neutral background) systems was similar. Most of the users preferred the neutral background for a dental application because it disturbed them less than the real-world background.

As a final conclusion, the game has been well received by students and professors who recommend us to continue working in the system and to develop new applications about learning in dentistry.

[1] Autostereoscopy is any method of displaying stereoscopic images (adding binocular perception of 3D depth) without the use of special headgear or glasses on the part of the viewer.

[2] Natural User Interface is the common definition used by designers and developers of human-computer interfaces to refer to a user interface that is effectively invisible, or becomes invisible with successive learned interactions, to its users, and is based on nature or natural elements.

Resumen

En este trabajo de fin de máster, presentamos el desarrollo de un juego "serio" que combina autoestereoscopía[3] e interfaces naturales de usuario (NUI)[4] en un entorno de educación superior. Por lo que sabemos, es la primera vez que una aplicación de estas características es desarrollada y probada. Hemos desarrollado un juego que puede trabajar en dos modos, con un fondo real o con un fondo neutro. En los dos modos, dos manos virtuales se sitúan superpuestas a las manos del usuario en la pantalla. En el modo real, las manos del avatar se sitúan encima de las manos del usuario, y el usuario puede ver el resto de su cuerpo. En el modo neutro, los usuarios saben dónde están situadas las manos gracias a las manos virtuales, ya que no pueden ver su propio cuerpo.

Nuestra hipótesis inicial era que, ya que el fondo real ofrece más ayudas de la posición del usuario que el fondo neutro, habrá diferencias estadísticas significativas en el conocimiento adquirido. Treinta y tres estudiantes de odontología probaron el sistema. Los estudiantes se dividieron en dos grupos para probar los dos sistemas.

Realizamos un estudio para corroborar nuestra hipótesis. Hicimos un análisis estadístico de los resultados obtenidos en las pruebas. En los resultados obtuvimos que los usuarios aumentaban su conocimiento sobre el tópico del juego (morfología dental), y el incremento de conocimiento en los dos grupos fue muy similar. La mayoría de los usuarios preferían el fondo neutro ya que este fondo les distraía menos de la actividad que estaban realizando.

[3]La Autoestereoscopia es el método para reproducir imágenes tridimensionales que puedan ser visualizadas sin que el usuario tenga que utilizar ningún dispositivo especial ni necesite condiciones especiales de luz.

[4]La interfaz natural de usuario es aquella en las que se interactúa con un sistema sin utilizar sistemas de mando o dispositivos de entrada habituales y en su lugar, se utiliza partes del propio cuerpo para manejar el sistema.

Como conclusión final, el juego ha tenido una buena aceptación entre los estudiantes y los profesores, quienes nos recomendaron seguir trabajando en la aplicación y desarrollar nuevos sistemas sobre aprendizaje dental.

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Listings

Definitions and abbreviations

- **Three-dimensional (3D):** Three-dimensional model that displays a picture or item in a form that appears to be physically present with a designated structure. Essentially, it allows items that appeared flat to the human eye to be display in a form that allows for various dimensions to be represented. These dimensions include width, depth, and height.
- **Application Programming Interface (API):** An Application Programming Interface is a library that includes specifications for routines, data structures, object classes, and variables.
- **Augmented Reality (AR):** Augmented Reality is the term used to define a direct or indirect view of a physical real-world environment whose elements are combined with virtual elements to create a real-time mixed reality.
- **Autostereoscopy:** Autostereoscopy is any method of displaying stereoscopic images (adding binocular perception of 3D depth) without the use of special headgear or glasses on the part of the viewer.
- **Computer Assisted Learning (CAL):** The term Computer Assisted Learning covers a range of computer-based packages, which aim to provide interactive instruction usually in a specific subject area.
- **Frames Per Second (FPS):** Frames Per Second is the frequency rate at which an imaging device produces unique consecutive images called frames.
- **Fmod :** Fmod is a programming library and toolkit for the creation and playback of interactive audio.
- **Human Computer Interaction (HCI):** Human Computer Interaction is a very active research area where the interaction with computers is studied, and usually involves highly multidisciplinary studies. It also refers to any kind of possible interaction and communication between a machine and a person.

- **High-definition (HD):** High-Definition video is video of higher resolution than standard. While there is no specific meaning for high-definition, generally any video image with more than 480 horizontal lines (North America) or 570 lines (Europe) is considered high-definition. 720 scan lines are generally the minimum even though many systems greatly exceed that.

- **HTML5 :** HTML5 is a markup language used for structuring and presenting content for the World Wide Web and a core technology of the Internet.

- **Head-Up Display (HUD):** The Head-Up Display is the method by which information is visually relayed to the player as part of a game's user interface.

- **Liquid cristal display (LCD):** A Liquid-Crystal Display is a flat panel display, electronic visual display, or video display that uses the light modulating properties of liquid crystals. Liquid crystals do not emit light directly.

- **Mixed Reality (MR):** Mixed Reality refers to the synthesis of virtual and real imagery that creates a combined scene of virtual and real information in any kind of proportion.

- **Natural User Interface (NUI):** Natural User Interface is the common definition used by designers and developers of human-computer interfaces to refer to a user interface that is effectively invisible, or becomes invisible with successive learned interactions, to its users, and is based on nature or natural elements.

- **Open Graphics Library (OPENGL):** Open Graphics Library is a cross-language, multi-platform Application Programming Interface for rendering 2D and 3D computer graphics.

- **Open Natural Interaction (OpenNI):** OpenNI is a framework that provides a set of open source APIs. These APIs are intended to become a standard for applications to access natural interaction devices.

- **Open Scene Graph (OSG):** The OpenSceneGraph is an open source high performance 3D graphics toolkit, used by application developers in fields such as visual simulation, games, virtual reality, scientific visualization and modelling.

- **Plug-in:** A Plug-in is a software component that adds a specific feature to an existing software application.

- **RGB:** The RGB color model is an additive color model in which red, green, and blue light are added together in various ways to reproduce a broad array of colors. The name of the model comes from the initials of the three additive primary colors, red, green, and blue.

- **Software Development Kit (SDK):** A Software Development Kit is typically a set of software development tools that allows for the creation of applications for a certain software package, software framework, hardware platform, computer system, video game console, operating system, or similar development platform.

- **Toolkit:** A Toolkit is a set of tools designed to be used together or for a particular purpose.

- **Virtual Reality (VR):** Virtual Reality is a computer-simulated environment that can simulate physical presence in places in the real world or imagined worlds.

I

Introduction

CHAPTER 1

Introduction

1.1 Motivation

The rapid development of new technologies has provided many new systems that were unimaginable just a few years ago. Natural User Interfaces (NUI)[1] have become more and more common. They facilitate our interaction with systems without having to use extra devices; we can use our body to communicate with the systems. The Kinect is one of this NUI. This device contents two RGB[2] cameras, one infra-red camera and a microphone array. Kinect was originally developed to play games, but nowadays its possibilities go far beyond this area.

In the field of dental learning there are few applications for learning. Most of these applications are pretty basic, they use web technologies or multimedia material. Within the state of the art there is not application as of today in which mix the autoesterocopy[3] vision and NUI for dental learning. In this thesis we are going to develop a application that combines these technologies to dental learning. This is the first time that an application with these characteristics has been developed and tested in a dental learning environment.

[1]NUI is the common definition used by designers and developers of human-computer interfaces to refer to a user interface that is effectively invisible, or becomes invisible with successive learned interactions, to its users, and is based on nature or natural elements.

[2] The RGB color model is an additive color model in which red, green, and blue light are added together in various ways to reproduce a broad array of colors. The name of the model comes from the initials of the three additive primary colors, red, green, and blue.

[3]Autostereoscopy is any method of displaying stereoscopic images (adding binocular perception of 3D depth) without the use of special headgear or glasses on the part of the viewer.

In the validation of the application, we have to measure the influence of the selfrepresentation in the NUI. We will compare the real-world background with a neutral background. We are going to compare among other things the immersion factor and the facility to adapt to the system.

Our research group has collaborated with a School of Dentistry: "Folguera Vicent Escuela Protesis Dental — Higiene Bucodental". This school has helped us to develop the application by providing the necessary technical information about dentistry and in its validation with students attending to this school.

1.2 Goals

The main objective of this thesis is to develop a dental learning application that includes NUI and autostereoscopic technologies, and to determine what is the influence of the background in the user's experience. To achieve this, we have established several goals:

- To develop a video-game using NUI and autostereoscopic system.
- To provide our video game the option to set the background to real world or neutral.
- To design that video game with educational background. Letting the dentist to increase their knowledge about the teeth morphology.
- To design a game with a log that obtain some information about user interaction.
- To study the user interaction with natural user interface technology.
- To test the systems with a statistically significant number of users.
- To design some questionnaires capable of retrieve data for analysis.
- To measure learning and satisfaction outcomes from the answers to those questionnaires.
- To provide a thorough statistical analysis of the results.
- To extract conclusion viewing the results.

Our hypothesis is that since the real-world background offers more cues than the neutral background for a more effective NUI, there would be a statistically significant improvement in knowledge and would affect the user's experience.

1.3 Thesis structure

The thesis document is structured in five chapters as follows:

- **Chapter 1 Introduction:** In the first chapter we explain the motivation of this thesis. We explain the hypothesis of our work and and the goals that we are going to check to prove our hypothesis.

- **Chapter 2 State of the art:** This chapter includes a brief description of the state of the art of the different technologies that we are going to use to develop our application (NUI and Autostereoscopy). We describe something about the computer assisted learning in dentistry and some of the recently developed computer applications to dentistry.

- **Chapter 3 Developments:** In this chapter we describe the software and hardware used to develop the application and we describe the application that we have developed.

- **Chapter 4 Validations:** In this section we describe the tests that we have performed, raise the proceeding for doing the tests and describe the groups that have tested the system, and the results we have obtained from the tests.

- **Chapter 5 Discussions:** In this part we analyze the results we have obtained and raise any future work that can enhance continuing with this line.

II

State of the art

CHAPTER 2

State of the art

2.1 Introduction

The natural user interfaces can be used to learning outcomes. Villaroman et al. [VRS11] expose how some applications based in natural user interfaces can be used to learn. The use of NUI to facilitate the interaction between the user and the system has been exposed in some cases. Boulos et al. [BBW+11] designed an application that facilitated the user to navigate in google Earth with the gestures of his body. Vera et al. [VGCF11] propose an application that combines Augmented Reality (AR)[1] with NUI. It consists of a large screen that is like a mirror. The user saw his reflex but in his position has a 3D[2] avatar that has the same pose of his body.

2.2 Autostereoscopy

Autostereoscopy is a method of displaying stereoscopic images without the use of special glasses on the part of the viewer. Since the publication of the first papers about stereoscopy in the 90s [Hal97], some articles have been published. Sandin et al. [SMG+04] developed a Virtual Reality (VR)[3] immersive experience

[1]Augmented reality is the term used to define a direct or indirect view of a physical real-world environment whose elements are combined with virtual elements to create a real-time mixed reality.

[2]Three-dimensional model that displays a picture or item in a form that appears to be physically present with a designated structure.

[3]Virtual reality is a computer-simulated environment that can simulate physical presence in places in the real world or imagined worlds.

using 35" Liquid Cristal Display (LCD)[4] 3D displays using the parallax barrier technique. And most recently have been published several articles related to this topic. Maimone et al. [MBPF12] developed an application with Kinect Fusion that can capture de 3D image of the real world scene and that 3D image is reproduced in an autostereoscopic display. Taherkhani and Kia [TK12] describe the design and building of a low cost autostereoscopic display, they used the parallax barrier technique to turn a LCD into an autostereoscopic display. Nocent et al. [NPB+12] propose a plugin-free solution using the new features of HTML5[5] in order to handle stereoscopic display within the web browser.

In this thesis, we are going to work with a lenticular lens display technology, it is one of the most used technology to develop multiview displays [Dod05]. That technology is recently used for creating some 3D applications [MP04]. Figure 3.7 shows the developed system by Matusik and Pfister [MP04].

(a) Array of 16 cameras and projectors.

(b) Rear-projection 3D display with double lenticular screen.

(c) Front-projection 3D display with single lenticular screen.

Figure 2.1: Autoestereoscopic TV system developed by Matusik and Pfister [MP04][MP04].

2.3 Natural User Interfaces

The natural user interfaces give us the possibility to interact with an application with some part of our body. According to Fishkin [Fis04], NUI facilitates the acceptance of an application by users. However, the young people are more receptive

[4]A liquid-crystal display is a flat panel display, electronic visual display, or video display that uses the light modulating properties of liquid crystals. Liquid crystals do not emit light directly.

[5]HTML5 is a markup language used for structuring and presenting content for the World Wide Web and a core technology of the Internet.

to use this technology, and need less effort than the old people. For example, the study of Carvalho et al. [CBO+12] presented a multi-touch game that was envisioned to encourage and teach digitally excluded people. From its results, they found that the use of NUI may be beneficial to help overcome some difficulties produced by the digital divide. Gallo et al. [GPC11] developed an open-source system using Microsoft Xbox Kinect that allow users to interact at a distance through hand and arm gestures. They use this system to explore medical image data as can be seen in Figure 2.2.

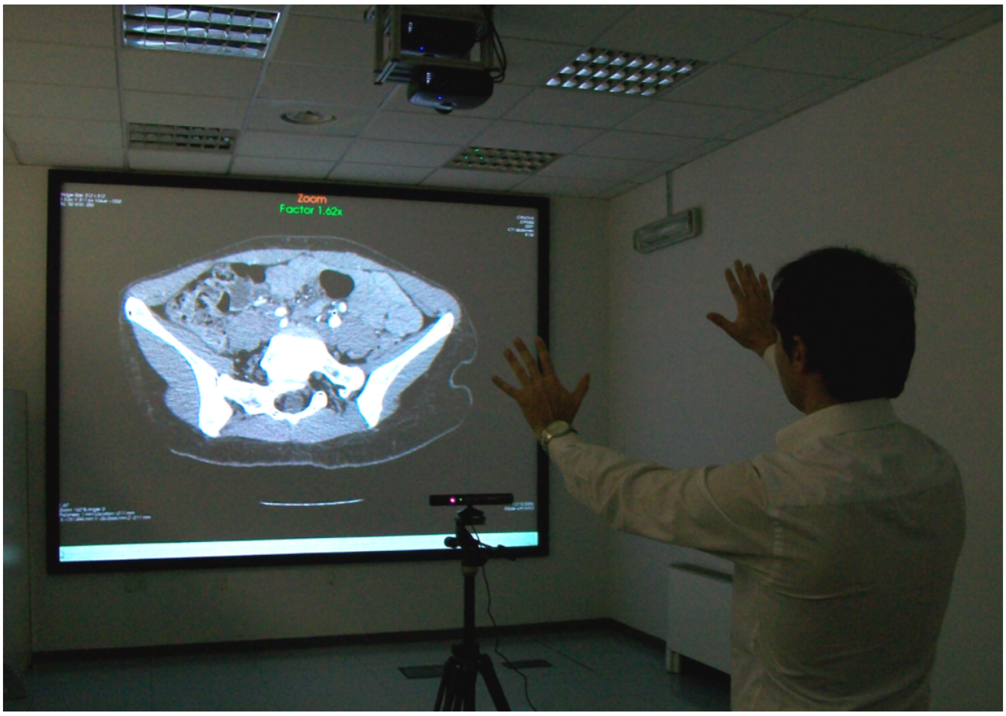


Figure 2.2: Natural User Interface system.

As mentioned above, NUI are being incorporated in a large number of different types of applications: for physical rehabilitation; for training individuals with cognitive impairments [CCC11]; for navigating with Google Earth [BBW+11]; for video conference in which depth perception was added to attendants [DYIR11]; or interaction with 3D objects from touch screen inputs [CH12], in which non-technical users tended to interact with the objects by 3D cube manipulations. One of the objectives of their work was to find out the most widely used strategies for manipulating the 3D objects. The hardware used in that study was a TouchCo 13" multi-touch surface and an Optima video-projector, which was placed perpendicularly to the table. The users stay in front of the video-projector and were asked to interact with the objects.

2.4 Learning with new technologies

Some applications and games have been designed to learn, but only a few have a deep analysis of the results of the learning process. Sandin et al. [SMG+04] explain how the games can be used for learning environment, and Prensky [Pre03] suggested that playing "action" video and computer games has the positive effect of enhancing student's visual selective attention.

In our research group, several AR systems have been developed and tested like a system for learning the interior of the human body [JBC08]; an AR iPhone game for learning multiculturalism [DSM+13b]; an application about the water cycle [DSM+13a]; or a study using autostereoscopic display with augmented and virtual reality [JMJR], which presents the first study that compares different aspects using an autostereoscopic display with AR and VR.

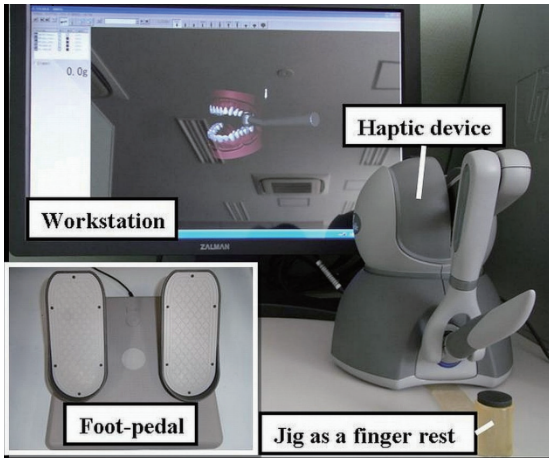
2.5 New technologies in dentistry

The possibility to integrate the computer and the dentistry was analyzed in some papers time ago. In 1997, Grigg and Stephens [GS98] evaluate the knowledge of their time in an objective manner to make some predictions such as Computer Assisted Learning (CAL)[6] would have an impact not only on how dentists are trained, but also on the skills they would need to acquire in the future to keep up with these new technologies.

Walmsley [Wal03] explains that the computer-aided dental learning programmes are either more effective than or equally effective as other methods of education. And Welk et al. [WSW+06] show that the benefits of computer-assisted learning are seen for example in self-paced and self-directed learning and increased motivation. Rosenberg et al. [RGM03] that execute an analysis of the effectiveness of Computer-aided programs in dental education, they conclude that CAL can provide innovative and interactive ways of presenting material and therefore should be used with the conventional teaching or as a means of self-instruction CAL can elicit positive response from students and can motivate them. A CAL program that is at least as effective as other methods of learning has several potential value

[6] The term Computer Assisted Learning covers a range of computer-based packages, which aim to provide interactive instruction usually in a specific subject area.

(a) Dental simulator



(b) Haptic simulator

Figure 2.3: Dental learning applications.

added advantages.

Some applications were developed that leverage the benefits of the computers to dentistry, Urbankova and Engebreston [UE11] developed a simulator that allowed the students to practice with a simulate patient and to learn with this practice, it includes a monitor to show inside the mouth and the instruments of a dentist to interact with the dummy. We can see the dental simulator in Figure 2.3a. Meckfessel et al. [MSB+11] developed an online courseware, including an interactive-learning module, the students had access to the e-program from any networked computer at any time. It contains animated videos, dental information and some questions about the lessons. The results showed, two years after initiating the e-course, that the failure rate in the final examination dropped significantly, from 40% to less than 2%. Boer et al. [dBWV13] describe the development and opportunities of the implementation of virtual teeth with and without pathology for use in a virtual learning environment in dental education, and provide examples of realistic virtual teeth with and without pathology that can be used for dental education. Salajan and Mount [SM12] develop a web system in a learning environment in dental education, it provides a lot of media and interactive examples to the students similar to Meckfessel et al. [MSB+11] courseware. Yoshida et al. [YYK+11] developed a virtual reality haptic dental training system, with this system the students can interact with a virtual model in a monitor screen on a PC, the students can use the system at their convenience without having a trainer. The system developed can be seen in Figure 2.3b.

Figure 2.4: Web application for dental learning.

Rosenberg et al. [RPT+10] evaluated the efficiency of the orthodontic diagnosis electronic tutorial and expose that the students are not prepared to replace the classical learning with CAL programs. From the student perspective, the CAL programs should continue to be used with traditional modes of learning. The CAL programs help students to learn, Woelber et al. [WHRK12] tested two programs of CAL, one of them is a high-interactive e-learning program and the other a low-interactive learning environment (Easy-to-use). They obtained statistically significant differences in the level of knowledge acquired, the students that use the easy-to-use program obtained better results on the post-test. This proves that you do not need to do very complex applications to teach students. The applications that are easy-to-use help users focus more on what they are learning and facilitating the interaction with the system.

III

Developments

CHAPTER 3

Developments

3.1 Introduction

In this section we expose the two systems that we have developed and their relations with the technology. Also, we explain the game developed, its structure, and a detailed of every stage of the game.

3.2 Autostereoscopy and Natural User Interfaces

Our system combines auto visualization and natural interaction. The scene was captured by the camera and the system tracks the user's movements each frame thanks to Kinect and the system allows users to interact with the virtual world with their hands. To give the users the idea that they can interact with their own hands, the system draws two virtual hands in the position of user hands on the screen, so the user can quickly understand that the way to interact with the system is using his own hands.

The screen is over a table near a wall, in front of the user. The Microsoft Kinect was placed over the table, a few centimetres in front of the screen. The users should stay in front of the display two meters away. We can see the test environment in Figure 3.1

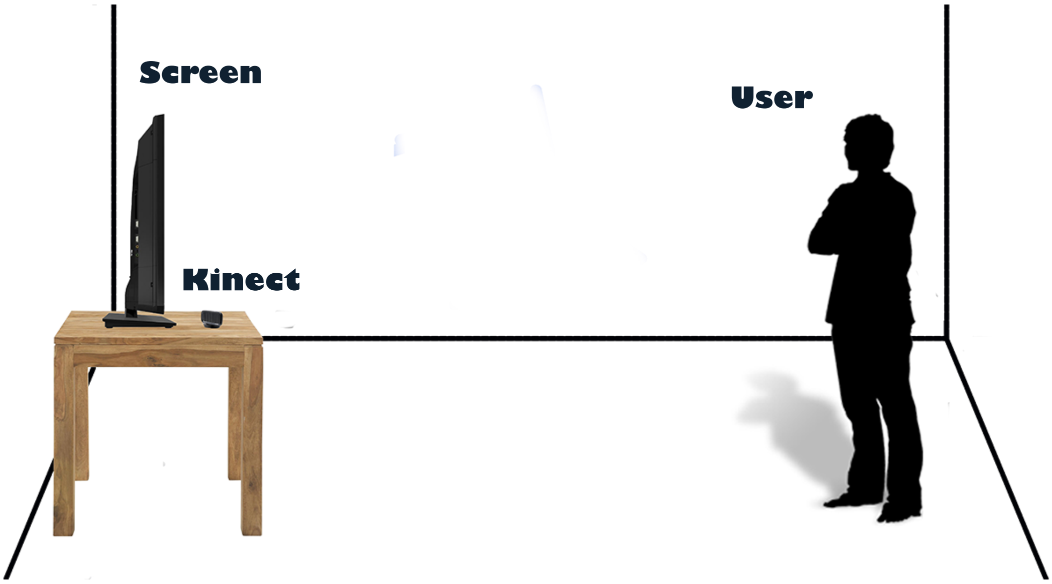


Figure 3.1: Test Environment

3.2.1 Hardware

We use a Microsoft Kinect device to capture the image of the real world and track the user. Also, we use an autoestereoscopic display to get the 3D effect. That display is a XYZ diplay(model XYZ3d8V46) that generate 8 different points of view. The display has 46" and full HD[1] (1920x1080 pixels). The user does not need any more device to interact with the system because the Kinect tracks the hand position of the user and that is all we need to interact with the system, Figure 3.2.

3.2.2 Software

We use OSG[2] to create our application. It is an open source high performance 3D graphics toolkit[3]. It has been writing in standard C++ and OpenGL[4] library.

[1]High-Definition video is video of higher resolution is standard. While there is no specific meaning for high-definition, generally any video image with more than 480 horizontal lines (North America) or 570 lines (Europe) is considered high-definition. 720 scan lines are generally the minimum even though many systems greatly exceed that.

[2]The OpenSceneGraph is an open source high performance 3D graphics toolkit, used by application developers in fields such as visual simulation, games, virtual reality, scientific visualization and modelling.

[3]A toolkit is a set of tools designed to be used together or for a particular purpose.

[4]Open Graphics Library is a cross-language, multi-platform Application Programming Interface for rendering 2D and 3D computer graphics.

(a) Autostereoscopic display (b) Microsoft Kinect

Figure 3.2: Hardware

Open scene graph based in graph scene method, that help us to create the scene easily. The OSG has a lot of Plug-ins[5] and extra content that we can use to develop our application.

In OSG, the main rendering loop has a scene render each loop. We used this advantage to make an update of the data that we receive from the user, before each rendering phase to update the game state before each render.

According to that, the principal loop of our game is as follow:

Listing 3.1: Main loop

```
while(!done){
   Update Kinect data
   Update game status
   Render Scene
}
```

We use OSG to create this application. We will create a scene graph which allows us to move the user between the different stages of the game, for this, we split the main graph into five graphs.

- Graph 1 (**Loading**): This graph contents only the loading state screen. This

[5] A Plug-in is a software component that adds a specific feature to an existing software application.

screen has showed when the program is loading the models to the memory of the computer.

- Graph 2 (**Learning**): This graph contents the nodes of the teeth that was showed in the first stage of the game. There are fourteen tooth models and the names textures associated to them. All models are grouped into a switch node, this node allows us to turn on or to turn off visibility, it allow us show the tooth that we need only with one instruction of code.

- Graph 3 (**Interaction**): This graph contains the nodes that had shown in the second stage of the game. There are fourteen tooth models and a model of the lower gums.

- Graph 4 (**HUD**): This graph contents the nodes that was showed in the second stage of the game. This contents the buttons that the user use to interact with the system. Also contains a node that has the avatar hands, this way if we want that one tooth is over the hands of the user the only thing to do is put the object below the node.

- Graph 5 (**Background**): This graph contents the background of the application, it is not in 3D because the camera of the Kinect can not capture the 3D scene of the real world.

We can see the node graph division in Figure 3.3.

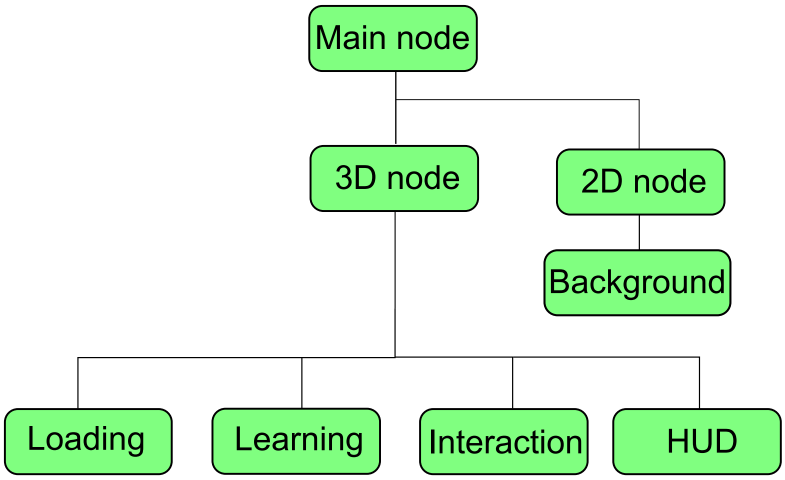
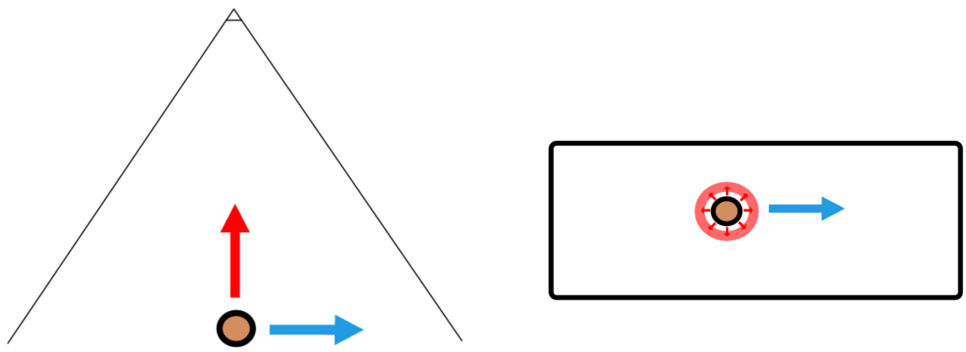


Figure 3.3: OSG graph node scene used to create the 3D scene and include the 2D image that provide the Kinect.

To generate the 3D image in the stereoscopic display we use the Mirage SDK[6] library that facilitate us to generate the 8 views necessary to the screen from our scene. Introducing all our scene in the OSG node that library provide us, we get the image displaying in 3D.

To be able to perform the user interaction with the computer, we need a Kinect device. We use the OpenNI[7] library that provides us the user position respect to the device and will allow us to perform the interaction. Once we have the position of the hands in the real world, we have to move them inside the virtual world, so we use the OSGintersector, that can create a line perpendicular to the screen to give us the object that the user is touching with the virtual hand.



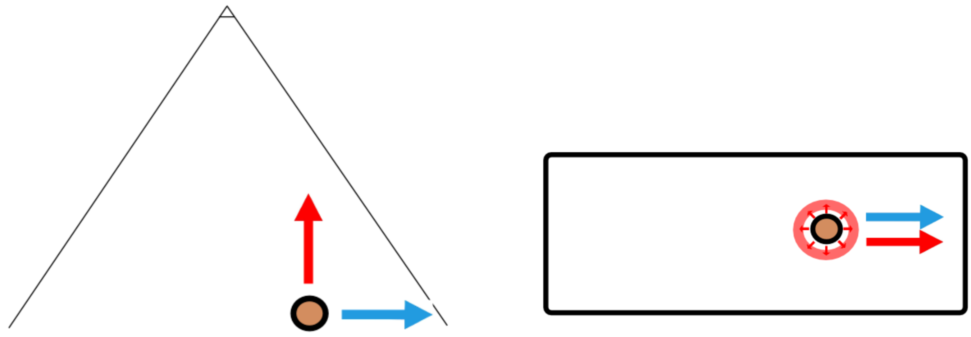
(a) Top-view of the environment. (b) Screen image.

Figure 3.4: Positioning error

We had one problem with the Kinect, it gave us the position of the hands in the 3D real-world environment. And the Kinect gave us a perspective image, we could not give the coordinates to the OSG node because they have positioning errors. We can see a detail graphic of the perspective error in Figure 3.4 and Figure 3.5. To solve this problem, we had to add a compensation coefficient(k). This coefficient was added to the X(3.1) and Y(3.1) components, and after adding these coefficients we have corrected the positioning error and the virtual hands were in

[6] A Software Development Kit is typically a set of software development tools that allows for the creation of applications for a certain software package, software framework, hardware platform, computer system, video game console, operating system, or similar development platform.

[7] OpenNI is a framework that provides a set of open source APIs. These APIs are intended to become a standard for applications to access natural interaction devices.



(a) Top-view of the environment. (b) Screen image.

Figure 3.5: Positioning error

the same position of the user's hands.

$$x = x_0 + k * z_0 \tag{3.1}$$

$$y = y_0 + k * z_0 \tag{3.2}$$

Another problem was at the start of the application, if the Kinect found several users within its field of vision, it does not know which one of them was going to play. We proposed that the user that is going to play the game has to start waving to the screen.

The scene that Kinect records of the real world is not in 3D. The Kinect device only has one RGB camera and our 3D screen needs 8 cameras that capture the real world from the correct positions to generate the 3D effect. The audio reproduced in the game are made by the open source library FMod[8]. All our sound files are in WAV format. We can reproduce the sound only with one code instruction. All the sound files were pre-load on memory to avoid some delay when the game is running.

Our OSG application has the structure shown in Figure 3.6.

[8]Fmod is a programming library and toolkit for the creation and playback of interactive audio.

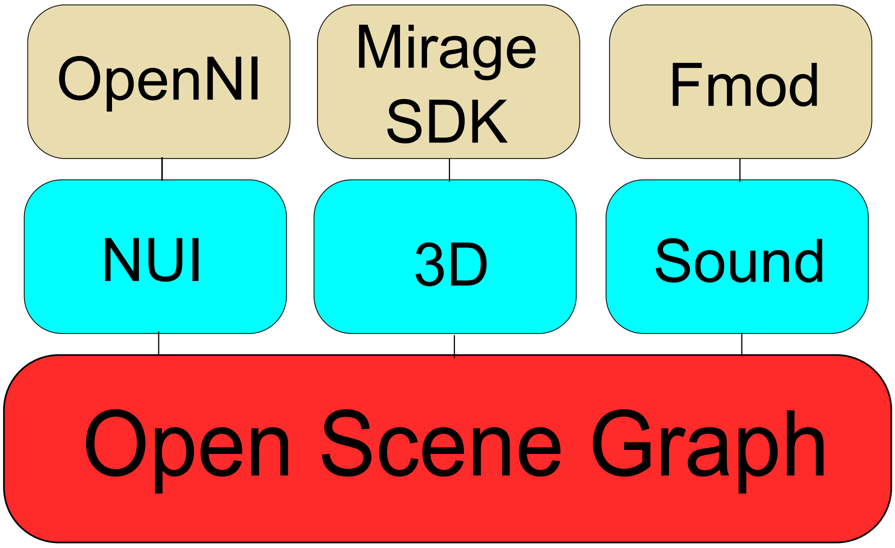


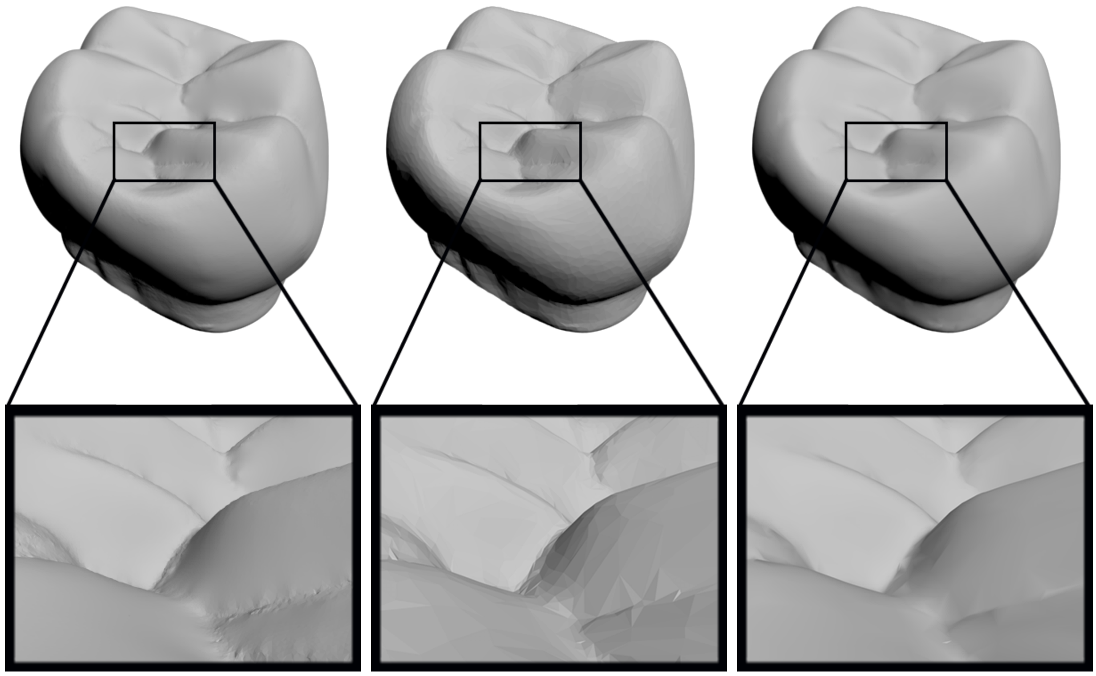
Figure 3.6: System architecture

3.3 Models

The models included in the games are plaster models made by dentistry expert. These models have been scanned with a laser scan. These models have to render 8 times each frame (once for each camera in the scene) to get the 3D image. This fact makes it impossible to display complex models on the screen. If the models have too many faces the FPS[9] of the application fall down and it hinders the interaction with the system.

At first the scanned models had a definition of 700,000 faces. For reducing the faces number of the models, we used an optimization algorithm and we got 12,000 faces. With this value of faces the graphic card can work with more efficiency. After this optimization of faces, we have applied a smoothing algorithm using the normals to give more realism to the model. Thus the model does not lose graphic quality and graphic load is reduced by 98.3%. We can see that there are not any significant visual difference between the original model (Figure 4.4a) and the optimized model (Figure 4.4c).

[9]FPS is the frequency rate at which an imaging device produces unique consecutive images called frames



(a) 700000 faces (b) 12000 faces (c) 12000 faces + smooth

Figure 3.7: Model optimization

3.4 The application

Our application incorporates autostereoscopic visualization and NUI. In this section the game design principles, learning background, and a description of its functionalities and stages are explained.

3.4.1 Design

The subject of the game is the teeth morphology. The dentists of "Folguera Vicent" specified the functional requirements of the application. Traditionally, the dentistry students do not have any 3D virtual models to learn their morphology. They have a 3D real models made of plater, or 3D models drawn on paper. Thanks to autostereoscopy the user can see the model in 3D, and they can appreciate their morphology much better than in the learning books. We can see an user testing the system in Figure 3.8.

The main goal of the user is to put each tooth in its own position. This is possible because each tooth has a particular morphology, and the students can see

Figure 3.8: Student from the School of Dentistry testing our neutral background system

the teeth for all angles. Looking at the 3D models, they can decide which tooth is each one.

3.4.2 How it works

The game has been divided in two principal stages and the loading stage. We can see the flow map in the Figure 4.1.

Stage 0: Loading

In this stage, the models and the resources were load on memory and the hardware is initialized to play the game.

Stage 1: Learning stage

In this stage, the user can see all the 3D model of teeth, and the game shows and reproduces its scientific name. The principal goal of this stage is that the users can see the each tooth, and they can learn about its morphology. When all the fourteen teeth have been shown, the game change to the next stage.

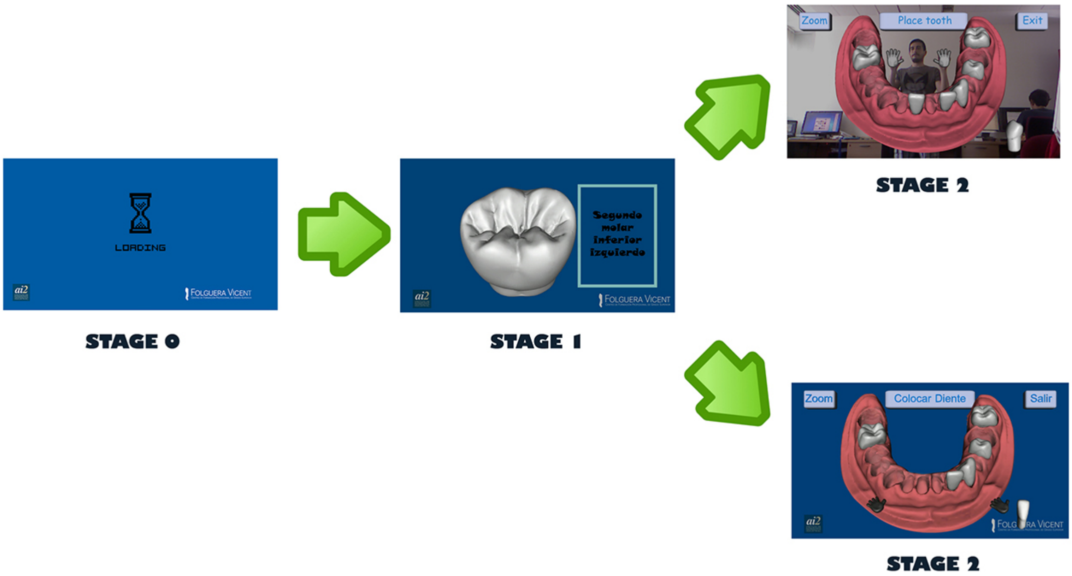


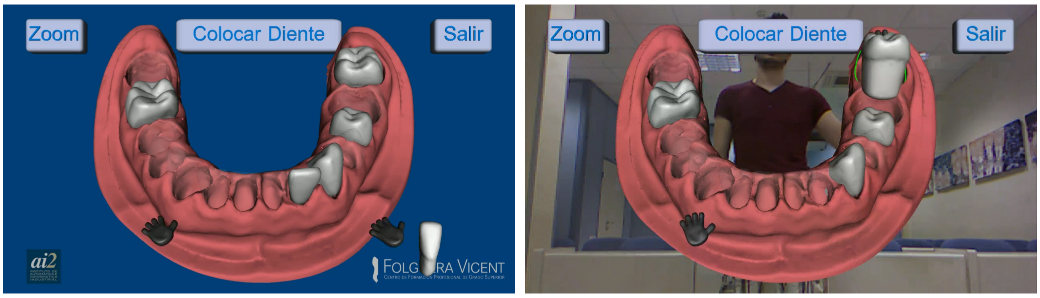
Figure 3.9: Application flow.

Stage 2: Interactive stage

At this stage, we can see a lower jaw in the center of the screen with fourteen holes, one hole for each tooth. Also, we can see three buttons in the top of the screen that the users can click to perform some actions. Firstly, at left top, we have the "Zoom Button", when the user clicks this button the game helps presenting a more detailed view of the tooth that the user wants to place. With this detailed view, the user can appreciate better the morphology of the tooth. Secondly, in the middle top of the screen, we have the "Place tooth button". It allows to put the selected tooth in one of the fourteen holes. To get this, the user has to put the hand that holds the tooth over the hole of its correct position, and with the other hand the user has to click the button. Finally, at top right, we have the "Exit button", this button allows the user to exit the zoom version of the game.

This stage has two possibilities depends on the version that the user is going to play:

- 2A-With neutral background: The user is represented with the avatar hands only, and the background is setting to blue.
- 2B-With a real-world background: The real-world and the user were drawn



(a) Neutral background. (b) Real-world background.

Figure 3.10: Game modes.

in the background of the screen, and the two avatar hands were placed over the hands of the user.

In the zoom version, the user can see a tooth ten times bigger than the normal tooth. It facilitates the choose of the correct position of the tooth. Also the tooth can be spun clockwise or counter-clockwise. When the zoom version is activated the "Place tooth button" disappeared and two arrows and a stop button appeared. Each one of the arrow spins the tooth in one of the two directions. To click the buttons, the user only needs to move his hand over the arrows or the stop. If the user clicks one of the arrows the tooth starts to spin in one direction if the user clicks the other arrow, the tooth starts to move in another direction, and if the user clicks the stop the tooth stop, its spinning move (Figure 3.11).

Figure 3.11: Zoom option.

In this stage, the user has to put, one by one, all the teeth on their own position. The game shows the different teeth for their collocation and the user can watch the teeth in a zoom version of them.

IV

Validations

CHAPTER 4

Validation: Real-world background or neutral background

4.1 Introduction

We carried out a study to test how the self-representation of users with the real world affects their capacity of interacting with the system by a NUI. We have compared the real world appearance as a background and as a neutral background. The rest of the functionality is exactly the same in the two different modes.

4.2 Study

4.2.1 Participants

We tested the application in "Folguera Vicent" School of Dentistry. They are specialised in Prosthesis and dental Hygiene. We tested the application with Thirty-three students from the School of Dentistry (18 men and 15 women with 23.4 ± 4.43 years old). They were specializing in two areas: Hygiene and Prosthesis. We placed students from both specialities in each group (Group A and Group B).

4.2.2 Measurement

To collect the data, that we have analyzed, we designed three different tests. The pre-test (Figure A.1) was developed to evaluate the students knowledge about teeth morphology. They have to connect with arrows each tooth with its position.

The post-test (Table A.1) has some usability questions about the opinion of the students that have tested the system. There was a last questionnaire (Table A.2) that includes usability questions and some questions about user's preferences. The game is also able to collect data on each execution. The game stores information about the time that the user expends to complete the game and the errors that the users have committed.

4.2.3 Proceeding

The two groups filled out a pre-test questionnaire about their previous knowledge of dental morphology. Afterwards, group A played the neutral-background version of the game and group B played the real-world background version. Then, both groups filled out the post-test questionnaire about their knowledge of dental morphology and other topics. Then, each group played the game with the mode that they had not previously played. When both groups had played both modes, they filled out a final questionnaire designed to compare the two modes. The estimated duration to complete the procedure is thirty minutes for each user.

Figure 4.1: Proceeding schedule.

The participants were assigned to one of the following two groups:

- Group A: Participants that played with the real-world background configuration and afterwards played with the neutral background configuration.
- Group B: Participants that played with the neutral background configuration and afterwards played with the real-world background configuration.

4.3 Results

At this point, we will show the results of the tests. First based on the knowledge outcomes and then based on the user's personal preferences.

4.3.1 Knowledge outcomes

Several t-tests were performed to determine if there were statistically significant differences in the knowledge acquired. To measure the knowledge acquired, we take the score that they have obtained in the pre-test questionnaire (Figure A.1).

The users filled out twice the first questionnaire (Figure A.1). Once in the pre-test and once more in the post-test. The score which can be obtained in each test is from zero to seven hundred. They obtain a hundred points for each tooth positioned correctly, twenty-five being placed in the correct dental group, and twenty-five more by placing the tooth symmetrical or located on the correct side.

We called the final score of the tests (Figure A.1) knowledge variable. We can see the knowledge variable of Group A(GA) and Group B(GB) in pre-test and post-test in Figure 4.2. All tests are shown in the format: (statistic [degrees of freedom], p-value, Cohen's d); and the "*" character indicates statistical significance at level $\alpha = 0.05$.

First, we checked whether there were statistically significant differences between the pre-tests regarding the previous knowledge of the students in the two groups. From a t-test, the scores of the knowledge variable between GApre-test (mean 420.62 ± 134.65) and GBpre-test (mean 380.88 ± 168.8) showed that there was no statistically significant difference ($t[31] = -0.72, p = 0.476, d = 0.25$). Since, no statistically significant differences were found, the previous knowledge was considered to be similar in the two groups. A paired t-test revealed that there was a statistically significant difference between the scores of the knowledge variable in GApre-test (mean 420.62 ± 134.65) and GApost-test (mean 526.26 ± 84.07) ($t[15] = -2.80, p = 0.014*, d = -0.70$). For the another group, the paired t-test revealed that there was statistically significant difference between the ratings of the knowledge variable between GBpre-test (mean 380.88 ± 168.8) and GBpost-test (mean 550.00 ± 103.26), ($t[16] = -4.21, p < 0.001*, d = -1.02$). In the last t-test, we checked if there were statistically significant differences between the post-tests about the acquired knowledge of the two groups, GApost-test (mean 526.26 ± 84.07) and GBpost-test (mean 550.00 ± 103.26), and no statistically sig-

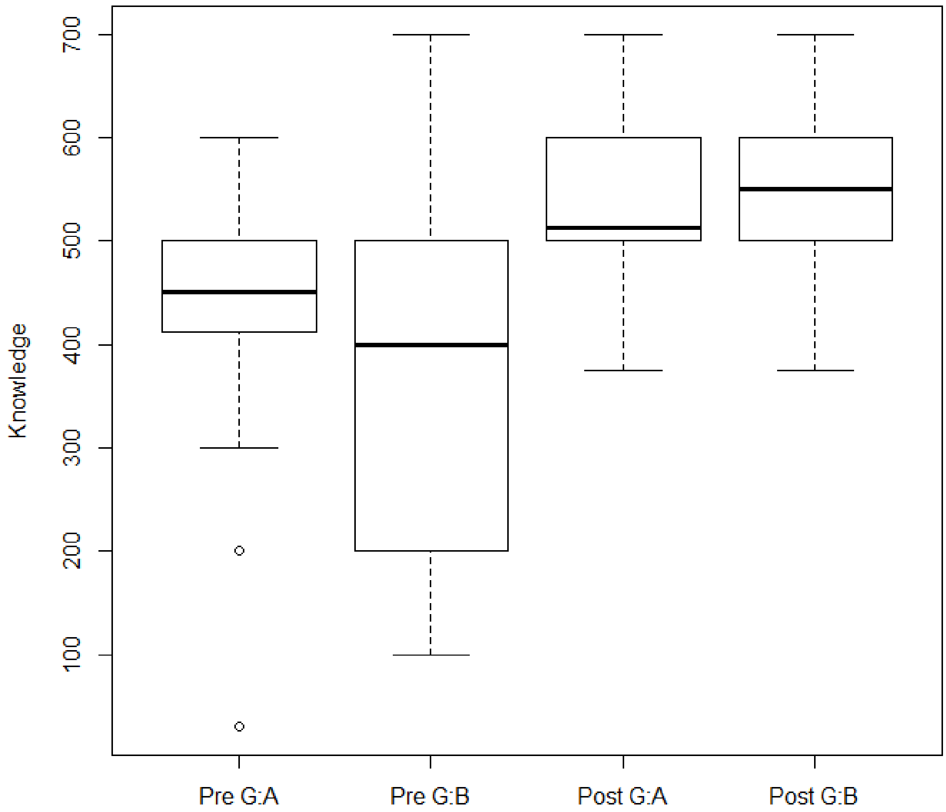


Figure 4.2: Knowledge variable results.

nificant difference was found, $(t[31] = -0.69, p = 0.495, d = -0.24)$.

Since there were no statistically significant differences, the students acquired similar knowledge using the two modes. From these results, we can say that our game has been effective when it comes to transmitting dental knowledge. From our point of view, having significant differences regarding the acquired knowledge is a very good result. This implies that the students had indeed learned new concepts after using the two modes.

With regard the time the students spent to complete the game, Group A (mean 326.94.26±58.52) and group B (mean 335.41±92.15), $(t[31] = -0.3, p = 0.764, d =$

-0.11) there was no statistically significant difference between the groups. Moreover, the learning curve grew quickly and is similar in the two modes of the game.

We used a multifactorial ANOVA analysis to take several factor simultaneously. We analyzed the time required to complete the first game, and the number of trials with gender, group, and specialization factors. The effect size used was the generalized Eta-squared (η_G^2) [OA03] because it is very suitable for mixed design analyzes and it takes into account the repeated measures and the observed and manipulated factors [Bak05].

We can observe in Figure 4.1 that the women spent significantly more time completing the game.

Table 4.1: Multifactorial ANOVA for the knowledge variable. $N = 31$

Factor	d.f	F	p	η_G^2
Gender	1	5.55	0.017*	0.25
Group:Gender	1	4.17	0.054	0.17
Group:Specialization	1	3.77	0.066	0,16
Other interactions	1	<2.65	>0.119	<0.12

4.3.2 Background comparative outcomes

In the post-test, we included questions related to the usability, the fun experienced, the perceived depth perception, and the perceived learning. There were no statistically significant differences between the two modes. We can see the modes[1] of questions and the result of the analysis in Table 4.4. These results indicate that the dental students did not consider the real-world background to be a more effective NUI than the neutral background. These results imply that our hypothesis has not been corroborated.

To measure the preference of the students that had while playing the application, several chi-squared (χ^2) tests were preformed for the satisfaction question. The Table A.2 shows the questions (Q212 -Q220). The χ^2 test revealed that were no any statistically significant differences.

In the final questionnaire A.2, the students were explicitly asked which of the two modes they considered better based on different aspects. For the best option

[1]The mode is the value that appears most often in a set of data.

Table 4.2: Modes of questions for the post-test and Chi-squared analysis.

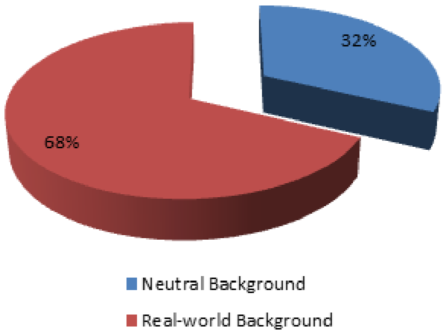
Question	Mode real	Mode neutral	χ^2	d.f	N	p	Cramer's V
Q212	2 Neutral	1 Real-world	1.087	1	32	0.297	0.184
Q213	2 Neutral	2 Neutral	0.068	1	31	0.795	0.047
Q214	2 Neutral	1 Real-world	1.807	1	27	0.179	0.259
Q215	2 Neutral	1 Real-world	1.284	1	26	0.257	0.222
Q216	2 Neutral	1 Real-world	1.200	1	32	0.273	0.194
Q217	2 Neutral	2 Neutral	0.778	2	28	0.678	0.167
Q218	2 Neutral	2 Neutral	0.268	2	30	0.875	0.094
Q219	2 Neutral	1 Real-world	5.298	2	30	0.071	0.420
Q220	2 Neutral	2 Neutral	1.503	3	29	0.682	0.228

for dental learning (Q213), 68% (Figure 4.3a) preferred the neutral background; 63% (Figure 4.3b) considered the neutral background to be easier to manipulate (Q214); the 58% considered the neutral background to be more comfortable (Q215); 64% considered that, the images/models looked better in the neutral background (Q217). With regard to their recommendation for using the two systems at school (Q220), their preferences were the following: 55% for the neutral background, 24% for both, 14% for the real-world background, and 7% for neither of them. A total of 53% of the participants liked the real world background the most (Q212). For the most fun mode (Q219): 43% selected the real-world background, 37% selected both, and 20% selected the neutral background.

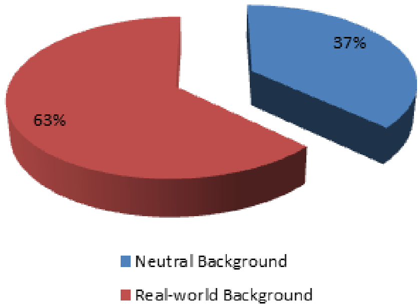
From these preferences and the results of the χ^2 test, we can deduce that although there were no statistically significant differences between the two modes, the dental students considered the neutral background to be more suitable for their studies. Two of their arguments that support our deduction were: “The real world in the game distracts me” or “With the neutral background, I could focus on the morphology of the teeth”.

4.3.3 Satisfaction comparative outcomes

We have some satisfaction questions in pre-test (Table A.1)(Q201-Q211) and post-test (Table A.2) (Q301-Q311). We performed several t-test to found possible statistically significant differences between the two groups. But there are no any statistically significant difference. The students have a similar satisfaction in the two versions of the game.



(a) Answer to question Q213



(b) Answer to question Q214

Figure 4.3: Percentages

Table 4.3: Means and standard deviations of questions for the Group A Post-test and Group B Post-test, and the t-test analysis. $d.f. = 31$

Question	Real	Neutral	t	p	Cohen's d
Q201	4.25 ± 0.56	4.12 ± 0.58	0.64	0.524	0.22
Q202	4.62 ± 0.48	4.76 ± 0.42	-0.86	0.399	-0.30
Q203	3.94±0.56	3.71 ± 0.75	0.97	0.338	0.34
Q204	3.00 ± 0.00	3.00 ± 0.00	0.00	1.000	0.00
Q205	3.69 ± 0.46	3.71 ± 0.67	-0.09	0.930	-0.03
Q206	4.00 ± 0.35	4.06 ± 0.42	-0.42	0.675	-0.15
Q207	3.69 ± 0.58	3.71 ± 0.67	-0.08	0.935	-0.03
Q208	4.88 ± 0.86	4.12 ± 1.97	1.38	0.1799	0.48
Q209	5.25 ± 1.03	4.94 ± 1.21	0.76	0.452	0.27
Q210	5.06 ± 1.14	4.59 ± 1.42	1.02	0.315	0.36
Q211	8.06 ± 1.25	8.00 ± 1.37	0.13	0.896	0.05

Generally, the students had fun playing (Q201: 4.06 ± 0.69 over 5). Most of them recommend the application for their partners (Q202: 4.55 ± 0.61 over 5). They thought that the game had medium difficulty (Q203: 3.64 ± 0.73 over 5). They always understood the games rules (Q204: 3 ± 0.2 over 3). To select the game elements have medium dificulty (Q205: 3.33 ± 0.84 over 5). They liked the models that the game shows on the screen (Q206: 3.94 ± 0.55 over 5). They thought that they have learn something playing the game (Q207: 3.55 ± 0.7 over 5).

With regard to the 3D sensation (Q208-Q210), the users think that the models

Table 4.4: Means and standard deviations of questions for the Group A Final-test and Group B Final-test, and the t-test analysis. $d.f. = 31$

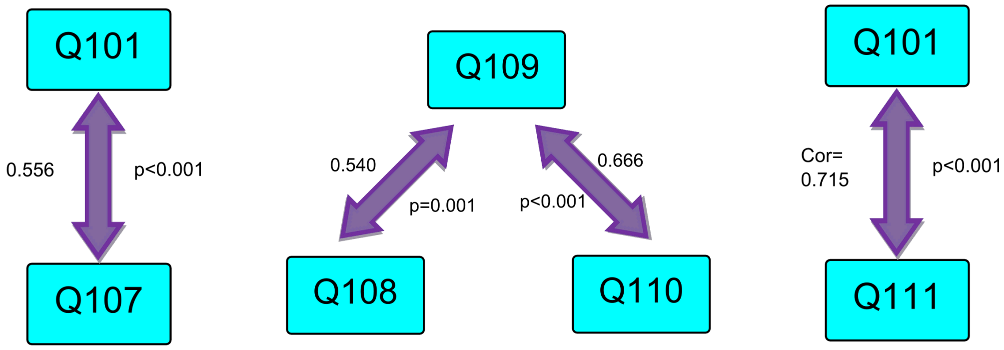
Question	Real	Neutral	t	p	Cohen's d
Q301	4.06 ± 0.66	4.06 ± 0.73	0.01	0.988	0.01
Q302	4.44 ± 0.61	4.65 ± 0.59	-0.97	0.337	-0.34
Q303	3.75 ± 0.75	3.53 ± 0.70	0.85	0.402	0.30
Q304	3.00 ± 0.00	2.94 ± 0.24	0.97	0.340	0.34
Q305	3.19 ± 0.81	3.47 ± 0.85	-0.95	0.349	-0.33
Q306	3.88 ± 0.60	4.00 ± 0.49	-0.64	0.527	-0.22
Q307	3.62 ± 0.60	3.47 ± 0.78	0.62	0.542	0.22
Q308	4.69 ± 0.98	3.71 ± 1.84	1.84	0.076	0.64
Q309	5.38 ± 1.11	4.76 ± 1.35	1.37	0.181	0.48
Q310	4.69 ± 1.45	4.35 ± 1.23	0.69	0.493	0.24
Q311	8.00 ± 1.32	7.76 ± 1.26	0.51	0.616	0.18

look real plaster models sometimes (Q208: 4.2 ± 1.6 over 7). The sensation that the teeth can go out of the screen is considerable (Q209: 5.06 ± 1.28 over 7). And they think that the sensation that users can touch a tooth was slightly lower (Q210: 4.5 ± 1.4 over 7).

Finally the last question of satisfaction was that the user has to score the experience from zero to ten. And from results they like the game experience (Q211: 7.88 ± 1.3 over 10).

4.3.4 Correlation comparative outcomes

The correlation analysis in the post-test (Table A.1) is shown in Figure 4.4. A correlation was found between Q101 and Q107. This correlation means that users think they have learned more if they had a good time using the application. Another two correlations were found between Q109 with Q108 and Q110. These questions are about the feeling of 3D sensation that the models produce, and it is a very good result that they are correlated. The last correlation was found between Q101 and Q111. This correlation is that users rate the system better depending on how fun they have experienced.



(a) Q101-Q107 Correlation (b) Q109-Q108 & Q109-Q110 Correlation (c) Q101-Q111 Correlation

Figure 4.4: Significant correlations for questions

4.3.5 Professors' Opinion

We also tested the system with four professors. All of them liked the system. Most of them were amazed and rated the system as an excellent tool for dental learning. We asked for their opinion about the system, and some of the answers were the following.

- The system is very useful to dental learning because the models look real.
- The methodology of teaching through a game is more entertaining.
- These games motivate the learning of students.
- This system could be used for the recognition of teeth, and could include the design of prostheses and orthodontic appliances.

V

Discussion

CHAPTER 5

Conclusions

5.1 Conclusions

We had developed a new "serious" game that combines autostereoscopy and NUI for dental learning in higher education. To our knowledge, this is the first time a game of these characteristics has been presented.

Also, The application is going to be used during the next course in the Folguera Vicent School of Dentistry.

The most important conclusions that can be deduced from this work are:

- To our knowledge, this is the first time a game of these characteristics has been presented.
- Users increased their knowledge about the topic of the game(teeth morphology), and the increment of knowledge in both (real world and neutral background) systems was similar.
- The users preferred the neutral background for this application because the real world background disturbed them more than a neutral background.
- The users said that the real world background is funnier.
- The adaptability to the interface is very fast, the users took, in general, the half time to complete the game the second time they played.
- In our opinion, the new technologies like NUI are appropriated for game-based learning in dentistry.

- As a final conclusion, the game has been well received by students and professors who recommended us continue to work in the system and to develop new applications that help learning in dentistry.

5.2 Scientific contributions

Actually, we are writing a paper to be sent to the European Journal of Dental Education (journal indexed in JCR).

Also, we are going to register the code in “CARTA” (UPV).

5.3 Future works

With regard to future work, the autostereoscopic system could be improved by displaying the video image in 3D and not just the virtual objects, this can be done by using several cameras to capture the real-world image. The interaction could also be improved, adding the recognition of new gestures.

The autostereoscopic displays are a little expensive. To reduce the equipment cost we can use two projectors with polarized filters. But this would force the user to wear glasses and that could hinder the application usability.

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VI

Appendices

APPENDIX A

Questionnaires

In these appendices, all the questionnaires that had been used in this experiment are presented. The possible choices to select as answers are placed below the questions.

A.1 Pretest

In this test, the students have to do the exercise as show in Figure A.1. The students have to match each tooth with its correct position in the jaw. There are seven different teeth but there is only one correct position for each tooth.

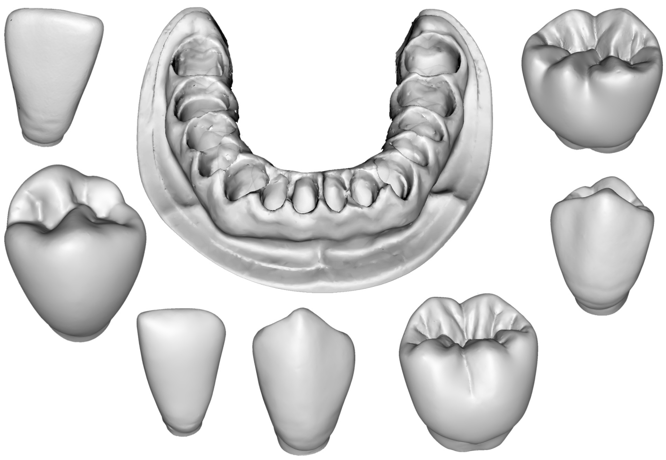

Figure A.1: Learning test

A.2 Post-test

The post-test includes the questionnaire of the Figure A.1 and the questions of the table A.1. This way, we have an appreciation of the initial knowledge level of the students, an appreciation of their knowledge after playing the first game, and their opinion about the game.

Table A.1: Post-test

Number	Question
Q101	How much fun did you have? [1 – 5]
Q102	Would you recommend this application to your partners? [1.Nobody / 2.Almost none / 3.I do not know / 4.Somebody / 5.Everybody]
Q103	What was the difficulty of the game? [1.Very difficult / 2.Difficult / 3.Regular / 4.Easy / 5.Very easy]
Q104	Did you understand the game rules? [1.No / 2.Not always / 3.Yes]
Q105	Was selecting the answers easy? [1.Very difficult / 2.Difficult / 3.Regular / 4.Easy / 5.Very easy]
Q106	How much did you like the images of the game? [1 – 5]
Q107	How much did you learn during the game? [1 – 5]
Q108	Evaluate the sensation of the teeth are made of plaster [1 – 7]
P109	Evaluate the sensation of viewing the teeth. Did it look like coming out of the screen? [1 – 7]
Q110	Have you the sensation that you can touch some teeth? [1 – 7]
Q111	Evaluate from 1 to 10 the experience [1 – 10]

A.3 Final test

In the final test (Table A.2) the users have to answer questions about their opinion of the system.

Table A.2: Final test

Number	Question
Q201	How much fun did you have? [1 – 5]
Q202	Would you recommend this application to your partners? [1.Nobody / 2.Almost none / 3.I do not know / 4.Somebody / 5.Everybody]
Q203	What was the difficulty of the game? [1.Very difficult / 2.Difficult / 3.Regular / 4.Easy / 5.Very easy]
Q204	Did you understand the game rules? [1.No / 2.Not always / 3.Yes]
Q205	Was selecting the answers easy? [1.Very difficult / 2.Difficult / 3.Regular / 4.Easy / 5.Very easy]
Q206	How much did you like the images of the game? [1 – 5]
Q207	How much did you learn during the game? [1 – 5]
Q208	Evaluate the sensation of the teeth are made of plaster [1 – 7]
P209	Evaluate the sensation of viewing the teeth. Did it look like coming out of the screen? [1 – 7]
Q210	Have you the sensation that you can touch some teeth? [1 – 7]
Q211	Evaluate from 1 to 10 the experience [1 – 10]
Q212	Which system do you like the most? [1.Real-world background / 2.Neutral background]
Q213	Which system is better for dental learning? [1.Real-world background / 2.Neutral background]
Q214	Which system is easier to interact with? [1.Real-world background / 2.Neutral background]
Q215	Which system is more comfortable? [1.Real-world background / 2.Neutral background]

Q216	Which system do you use better? [1.Real-world background / 2.Neutral background]
Q217	In which system the images look better? [1.Real-world background / 2.Neutral background]
Q218	Do you recommend these systems to your class partner? [1.Real-world background / 2.Neutral background / 3.Both / 4.Neither]
Q219	Which system is more fun? [1.Real-world background / 2.Neutral background / 3.Both / 4.Neither]
Q220	Which system do you want that your teacher uses in class? [1.Real-world background / 2.Neutral background / 3.Both / 4.Neither]
Q221	What is the funniest fact of the experience?
Q222	What is the bad fact of the experience?
Q223	What would you change in the systems?
Q224	What would you use the systems?
Q225	Write all the comments that you need.