Individual Diploma Thesis

USERS' COGNITIVE AND EMOTIONAL RESPONSES IN A VIRTUAL AND MIXED REALITY SCENARIO: THE USE OF MS HOLOLENS AND EMOTIV EPOC+

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Users' Cognitive and Emotional responses in a Virtual and Mixed Reality scenario: The use of MS HoloLens and Emotiv EPOC+.

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Summary

The following thesis discusses the use of two different tools on users' cognitive and emotional responses. The first scenario is an MR environment in HoloLens and the second scenario is on EEG data and a sandbox game.

Augmented Reality and Mixed Reality bring revolutionary changes in the word of technology, with a plethora of applications and research. The tool that the MR part of my thesis is based on, is HoloLens. HoloLens is a headset that projects holograms in user's real world and lets the user interact with them. From HoloLens we used an application called "Galaxy Explorer", as it is open source, it can provide a log file. The log file from "Galaxy Explorer" had to be analyzed, having that in mind I developed a web application that divides the logfile and stores the data in a specific table. In addition, to compare adults' interaction with children's interaction on HoloLens, a study was conducted with children as the data from the adults already existed.

The second scenario was based on EEG data. As the gaming community improves from time to time, and more users are interested on playing games, it is important to learn more about the interaction and the emotional state of the users. We made a research on what EEG is and decided to use Emotiv EPOC+ to capture the emotional state of the users while playing a sandbox game, MineTest.

Finally, for every study that was conducted, the methodology and results were descripted fully, followed with a plethora of figures.

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Chapter 1

Introduction

1.1 Problem Statement

My thesis is divided in to three parts, as we wanted to create an application and research users' interaction with two different tools.

The web application that I created, aims to help the data analysis of the log file that has been extracted from HoloLens. It divides the log file into tables with a specific format and the researcher can extract the tables in a ".csv" format or just view the data from the web application.

The scope of the first study was to compare, adults' interaction with HoloLens, with children's interaction with HoloLens. Having that in mind, we conducted a study on children, using HoloLens and compared our data with the data of a previous study, that was conducted with adults.

The scope of the second study was to find correlations between the emotional state of the user and the action that the user did in MineTest. The study that was conducted used Emotiv EPOC+, to capture the emotions of the user and the user were asked to build anything in MineTest.

1.2 Hypothesis and Research Questions

On the first study we set a hypothesis that we wanted to research:

H0: There are no differences between adults and children towards the i) time spent, ii) number of unsuccessful taps, iii) objects viewed, iv) number of times the target item viewed before selected, for achieving each target object.

On the second study we set a question that we wanted to answer with our study:

Is it possible to find correlations between the emotions of the user and the actions?

1.3 Proposed Approach

To create the website, we used HTML and CSS for the front end. For the back end we used PHP for the creation and connection with the database, and JavaScript for the connection of the frontend with the backend.

To test our hypothesis in the first study we used MS HoloLens. MS HoloLens was previously used in a study with adults, which data are going to be compared with our data. In the study, participated twenty children from the age eight to fifteen. The participants had to learn the gestures using the default application on HoloLens "Learn Gestures" and then they had to complete some tasks in "Galaxy Explorer" application on HoloLens." Galaxy Explorer" extracts a log file that contains user's interaction which was analyzed to make the comparison.

To answer our question in the second study we used a sandbox game "MineTest" that extracts a log file with user's interaction. To capture the emotional state of the user we used Emotiv EPOC+.

1.4 Summary of all Chapters

After slightly describing our scope and proposed approach in this Chapter, the thesis continues with the Literature Review in the second chapter. The literature review talks about the definitions and applications of the AR and EEG.

Subsequently, in Chapter 3 the two tools that are going to be used in both of our studies are fully explained. Starting from MS HoloLens, Chapter 3 contains the way a common user and a developer can interact with it and it citates a plethora of research papers that use HoloLens. For EEG, it is used a tool called Emotiv EPOC+ which is fully explained in that chapter. Also, in chapter 3 the data files that were extracted from Emotiv EPOC+ are described in detail.

In addition, Chapter 4 presents the development of the data analysis web application. It explains how the logfile from HoloLens is structured and how it was divided in the database. Equally significant is the fact that it is explained how a researcher can interact with the web application and what kind of files can be extracted from it.

Furthermore, Chapter 5 is a very important chapter, as it explains the methodology of the first study (with HoloLens), describes the user study and analyses the data.

Chapter 6 has a very similar structure with chapter 5, but it describes the second study that was conducted with Emotiv EPOC+ and a sandbox game. It explains the way the study was conducted and analyses the data.

Finally, Chapter 7 finishes the thesis with giving the conclusions on both of the studies.

Chapter 2

Literature Review

2.1 Introduction

The following Chapter talks about Augmented Reality and the research that took place to take a full understanding on the application of AR in our lives. The first functional AR systems that provided immersive mixed reality was invented in the early 90s and from that moment on, a variety of researchers became more interested. Having that in mind there is a plethora of papers that are related with AR that proves its effectiveness and usability issues.

Furthermore, equally significant is EEG in our research. In the second part of the chapter is going to be descripted EEG and how it can be used. Finally, the chapter is going to present the research and uses on EEG.

2.2 Augmented Reality Literature

2.2.1 What is AR

Augmented reality is an experience, where real-world environments are improved with superimposed computer-generated images, sounds and touch feedback. In other words, is the enhancement of one's current perception of reality. AR can be found on a common mobile device but also on an advanced headset that provides a more immersive experience.

2.2.2 How AR is used

Augmented reality combines real and computer-based scenes and images to deliver a unified but enhanced view of the world and that is why it is now used in a plethora of ways. The most well-known place to find AR is gaming. An augmented reality game often connects a procreated environment on top of user's real environment. A simple AR game can create images in the screen which are immerged with the current world. An advanced AR game transforms the environment and connects with a huge success the virtual world with the real world, to make sure that the experience is as immersive as it can be. A very famous example of a simple AR game is Pokémon GO. Pokémon GO is a game on mobile device and by using the user's location it presents on the screen the Pokémon that is currently located in the place. This makes the experience accessible to anyone who has a mobile phone and more immersive because the users have to catch the Pokémon in their location.

In addition, AR is nowadays starting to be used for medical uses. Medical students can practice surgery or view and understand complex medical conditions. AR can be combined with MRI or X-ray systems to help the surgeon have a better understanding of the condition. Furthermore, navigation applications are the most common augmented reality operations, as they are used every day by millions of people. The most known example is Google Maps that throughout the year they are making the experience more immersive by adding different functionalities. A very spectacular use of AR is its application in museums and landmarks. There is a plethora of applications that follows the tourists around and helps them learn more about the landmark their camera or location is showing. Making the experience accessible to anyone and helps the learning process. A very significant event happened on 2017 at Tankfest where Wargaming with the use of HoloLens and Tango help the viewers learn more about the tangs that they were looking at. The experience was equally beautiful with HoloLens as with a mobile device. The gadgets were presenting parts and information of the tang while the users were walking around the festival.

Figure 2.1 - Tankfest 2017 Wargaming

2.2.3 Studies in AR

From the moment AR was created and released into the world there have been a variety of researches discussing the usability aspects of Augmented Reality and the impact it is going to have in our lives. For example, HoloMol [1], which is a platform on HoloLens that helps the memorization of information and established questions regarding: i) The way users are going to use HoloMol to structure information in AR environment; ii) How the method the researches have designed is going to help the users recall the information.

In addition, a very important study [2] was conducted comparing three environments for a basic 3D visualization exploration. The study happened on a desktop (keyboard and mouse), on a tablet (with markers) and on Microsoft HoloLens (with markers). The participants were asked to press a key as soon as they knew the answer or found the 3D visualization so that the timer can be stopped. They also measured the amount of errors found in the participant’s interaction. Several hypotheses were made for the different interaction with the three environments. Very significant inference from the user study, was the fact that users performed broadly well on desktop, in comparison with the other two environments, however AR (Microsoft HoloLens) was observed to be the best in exceedingly interactive tasks and users could be almost as precise as on desktop. Furthermore, immersive AR was found to surpass the other two environments for tasks that needed manipulation.

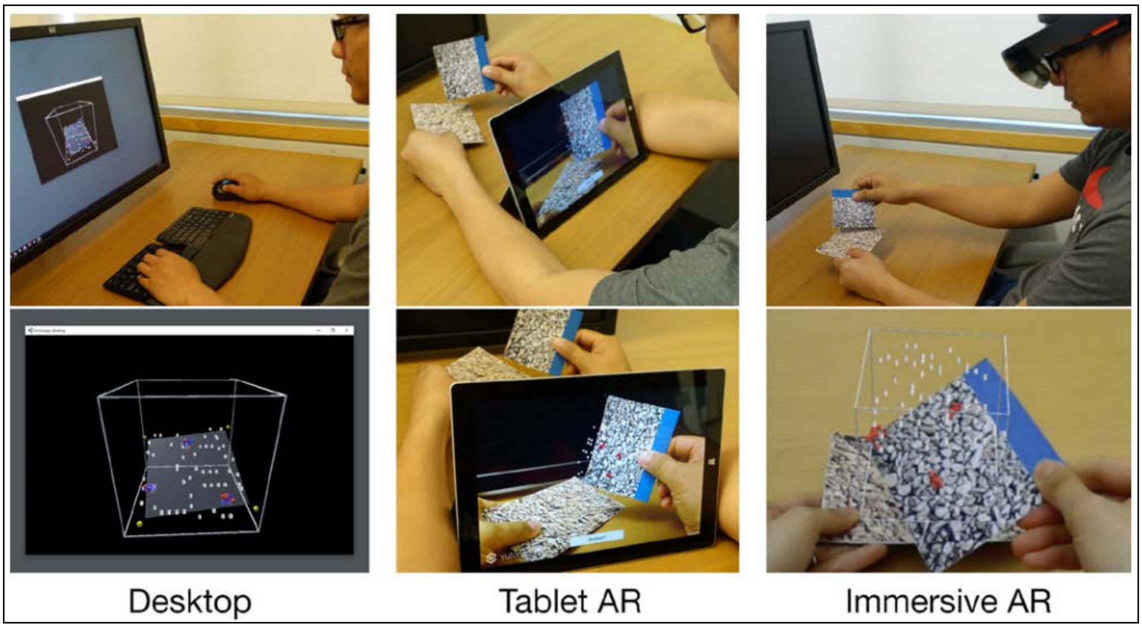


Figure 2.2 - Environment structure and user prospective.

2.2.4 Research with adults on HoloLens

To have a better understanding of the usability aspects of HoloLens and AR in general a detailed research [3] on a related study had to be done. The study happened with third-one adults, seventeen men and fourteen women on the age of twenty to twenty-nine. The participants had to complete a GEFT (Group Embedded Figures Test) test to set their differences in visual information processing by defining them to FD (Field Dependence) or FI (Field Independence) [4]. Eleven participants were FD and twenty were FI. The biggest difference between FD and FI is the way they understand a visual information. FD seems to have a difficulty with complex images and create a holistic view of the visual information. In contrast, FI analyze the visual information easily and they can detect details in a very complex image.

The participants had to interact with HoloLens, trained in an AR environment so they could feel comfortable enough and then complete a few tasks. The training phase took ten to fifteen minutes and the users had to open an application called “Holograms” and place a variety of holographic objects in their real environment. The researchers made sure that the user became comfortable with every gesture that could be detected from HoloLens (Tap, Tap and Hold, Grab, Zoom, Bloom).

At the main phase the participants had to open the application “Galaxy Explorer” and complete some tasks, in a galactic world. The tasks were separated in three difficulty levels. To find planet “Uranus” was the hard task, to find “Sagittarius A*” was the easy and finally, to find planet “Earth” was a medium difficulty task. Those three tasks were spread in a group of fifteen tasks. To extract the data from the user interaction with HoloLens a logger was implemented. The log file contains the actions the user made in “Galaxy Explorer”. The actions are gaze, gesture and voice. Every action is paired with a specific time and object. (Go to Chapter 4.3 to learn more)

After the data were analyzed the differences between the two cognitive teams were more obvious. In the medium and easy task, the FDs did not show any significant differences from FIs. However, in the hard task FDs needed more time to find “Uranus” than FIs. Equally significant is the fact that while the difficulty level of the tasks was increasing, the differences between the two cognitive teams were more obvious as the FDs observe more objects before completing a task, than FIs.

Figure 2.3 - Users interacting with HoloLens

For the qualitative data analysis, they used the answers from the questionnaire, the observations the researcher had while the users were interacting with HoloLens and the video captures from HoloLens' camera. It was observed that while the FIs find it easier to interact with a mixed reality gadget, the FDs needed more time to get used to the new environment and feel comfortable enough to be able to interact with it. In terms of the tasks, it was observed that FDs find it hard to find "Uranus" and they expressed their despair tries to find it, although FIs find it hard to find "Earth" as they said that to find "Uranus" was easy. A more general observation was that FDs were more talkative while trying to find "Uranus" and on the other hand FIs were more silent and effective, as they rarely asked questions about the way they could interact with HoloLens. FIs followed a more analytic way to complete the tasks and this help them not looking around before completing the task. However, FDs followed a more holistic approach and they were looking around, item by item until they found the item to complete the task.

2.2.5 Open Issues

Augmented Reality was the main tool for a variety of researches and applications. Thus, it has been the hot topic in the technology world for the last few years. Although there is a plethora of papers and user studies, that analyze the usability aspects of AR and MR, there are not enough on children. MR products can create visualized products in the real world and it was revealed that people can be more accurate on Mixed Reality than on a desktop [4]. On the usability aspects on AR and MR applications there are plenty of studies that descript them as more effective and accurate than desktop's [4,2]. Adults are very excited and motivated to interact with new and more immersive technologies, as they find the interaction not extremely complex. As there are not enough contexts on the children interaction, we do not really know for a fact that children can have the same impressions while interacting with AR and MR applications, as adults do. There are studies that revealed that AR memory applications help with education [5] without making a conclusion on the usability issues or comparing with adults.

2.3 Research on studies with children

Technology is evolving through time, making changes in our life every day. The evolution of technology does not only affect us, but most importantly it affects the children. They way children interact with technology creates fascinating questions of what the future is going to show us in terms of new technological discoveries. For that reason, education of technology and education with technology is a must in our generation. More specific,[5] Mixed Reality on education may help the student improve their skills, by letting them perform a variety of tasks. In addition, MR can help children improve their communication skills by helping them interact with a plethora of stories and phases, especially children with disabilities that it is easier and clearer to them to interact with images rather than reading words. In general, MR can help children with disabilities improve and discover their skill, for instance children with low motor skills can learn geometrical and mathematical concepts by having them projected to them as interactive images. Another significant example is to help children with Down syndrome to learn words.

Children tend to use digital games more than adults, having that in mind a research [6] was made to state observations of children's interaction with augmented reality. [6,7] It was observed that younger children faced different difficulties than older children and they required more assistance. Furthermore, even though older children seem to enjoy the game, they dislike walking. Lastly, it was observed that older children bend their back more than younger. [7] Having that in mind, in order to create beneficial environment for children, the AR environments must be appropriately designed.

2.4 <u>Research on user creative process in a Sandbox game</u>

To have a better understanding on the creativity pattern the users experience while playing a game, a research was conducted on a user study that describes the creative process of the user while interacting with a sandbox game.

The study[8] happened with twenty-eight participants, sixteen men and twelve women, in the age of twenty-two to twenty-four. It was given to the participants an instruction file that descripted how to download and set MineTest on the computer, the main actions and settings that can be used for the experiment. Every user had to complete five hours of playtime in two weeks and record the interaction. Through those five hours the users had to create whatever they wanted in the virtual environment. When the log file and recorded video form each user, were returned to the researcher, there were three phases remained. The determination of the data, formalization of the data and the discovery of the creative phase.

The data that was extracted from MineTest is a log file with all the actions the user made in the five hours session (Go to Chapter 6.2.2 to learn more about the log file). The data were imported in an application that analyzed them and exported the creativity phases. The algorithm that was used was created based on the four phases that were determined from Wallas.

Wallas' phases were:

1. Phase1: Recording scattered user activity in different locations or segregated behavior. At this stage the user is probably trying to determine the scope, to identify the problem-problematic areas.

2. Phase2: The user moves away from problematic, ubiquitously defined areas in a different space and begins to revise and relax restrictions that show activity in an area away from the problem.

3. Phase3: It remains in an area for more time, where the user starts creating or exhibiting activity that stabilizes and develops.

4. Phase4: Returns to previous activity from Phase1 and / or Phase2 and links previous constructions.

Furthermore, after the experiment, a focus group happened to help the researchers communicate the participants and identify the important parts of the study and have a better understanding on the interaction with MineTest. The focus group helped on the determination of the phases that were created based on Wallas' phases and also the creation of the pseudocode of the algorithms.

Phases of the creativity models:

1. Phase 1: At this point the user probably tries to define the purpose of the game, to identify problem-problem areas.

2. Phase 2: Removal from problematic areas. He begins to re-examine and relax in another area.

3. Phase 3: It remains in an area for most of the time. It begins to create and present a constant activity that is being developed.

4. Phase 4: Link to past problematic areas (possibly the first phase).

Every log file that was extracted from MineTest was then imported in the application and with the help of the algorithms, the four above phases were identified, if they existed.

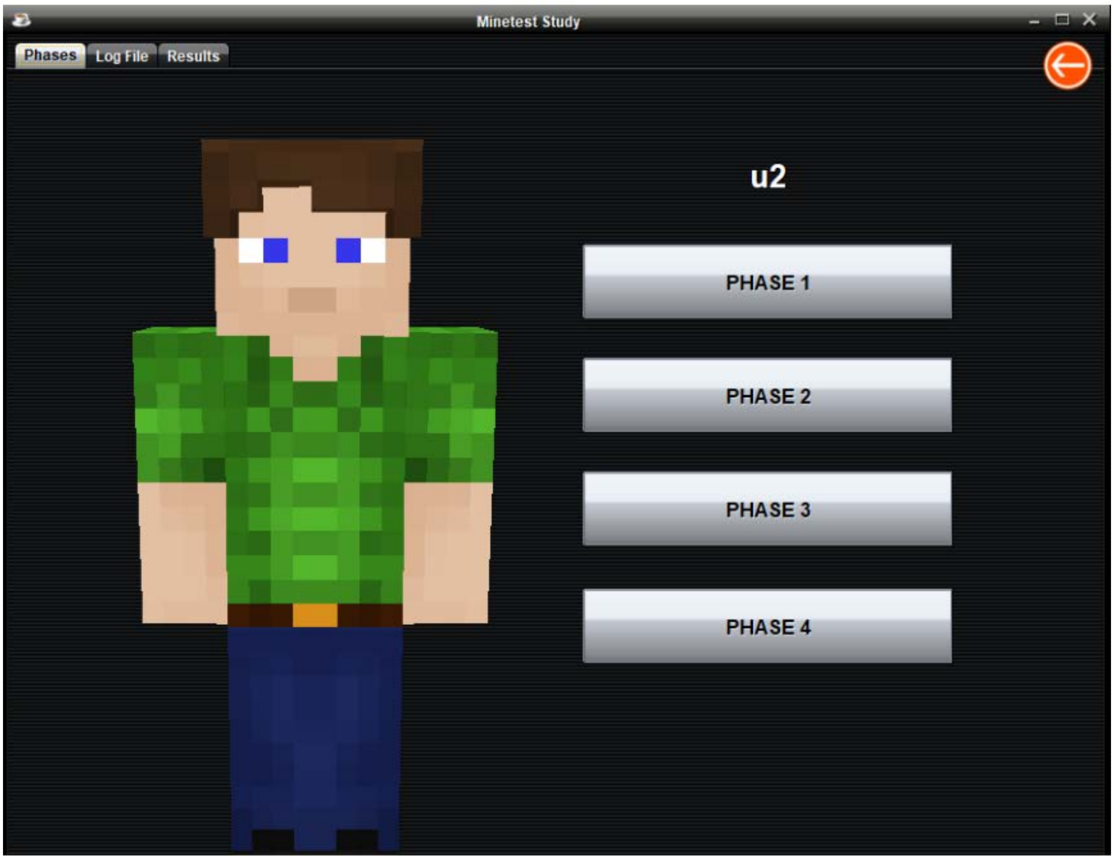


Figure 2.4 – Snap shot of the app's interface

2.5 EEG Literature

2.5.1 What is EEG

EEG means Electroencephalography and it is a physiological method to record the electrical activity that is generated from the brain via electrodes that are placed on the surface of the scalp.

2.5.2 How EEG is used

EEG was at first used to diagnose conditions such as seizures, epilepsy, head injuries etc. and study the physical state of the mind while sleeping. Although, the last decade EEG is used to understand how the brain works in different situations and especially while interacting with technology. The psychological state of a user is difficult to be detected as every person has different facial expressions and way of expressing their feelings. Having that in mind, EEG became the main element in a plethora of user studies.

To get the EEG data, the electrodes that detect the electrical activity of the brain, are placed to the head with a headset or an elastic cap. The electrodes are placed in specific positions set from the 10-20 system. The 10-20 system [9] is an international method of positioning the electrodes and it is called like that, due to the fact that the distances between the contiguous electrodes are 10% or 20% of the total front-back or right-left distance of the skull.

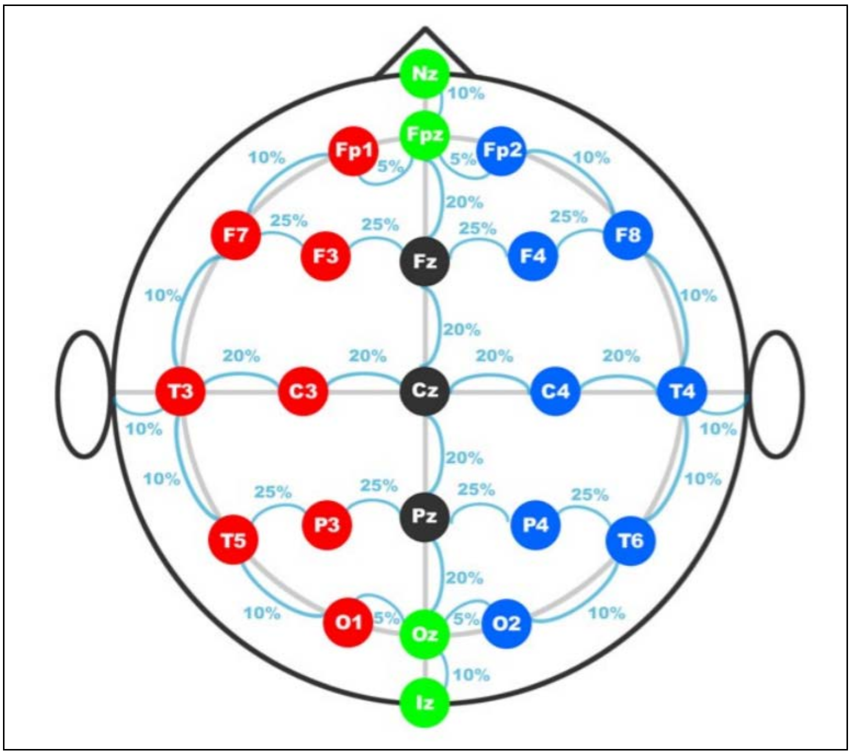


Figure 2.5 - 10/20 System Electrode Distance

As it is shown in “Figure 2.4” every site has a letter that identifies the lobe and number to set the hemisphere location.

1. Frontal cortex (F): The Frontal part of the brain is responsible for the cognitive control of behavior.

2. Temporal cortex (T): The Temporal part of the brain is responsible for the language processing and speech production.

3. Central cortex (C): The Central lobe does not exist and it is only used to help for the identification and the placement process.

4. Parietal cortex (P): The Parietal part of the brain is responsible for the motor skills.

5. Occipital cortex (O): The Occipital part of the brain is responsible for processing visual information.

The “z” means zero, the even numbers (2,4,6,8) mean the electrode’s position is in the right hemisphere and odd numbers (1,3,5,7) mean the electrode’s position is in the left hemisphere.

2.5.3 Studies with EEG

EEG headsets are starting to make a tremendous change in the research area, as the researchers now can measure and have as an output specific data, that they can analysis and compare with their actions. For instance, a research [10] was conducted using Bralnquiry EEG PET device, to answer a plethora of questions that are referring to the use of EEG, accuracy and features that can be extracted from EEG records.

In addition, there is a variety of studies that describes the user experience while playing a game, and psychophysiological studies can provide objectives and results in real time. EEG provides data about the brain’s electrical activity, that can relate to emotional reactions of a user while playing a video game [11]. EEG data are sensitive enough to pick reactions and responses that the human eye cannot pick. The psychophysiological studies can provide the researcher with a plethora of details about the emotional state of the participants, however the drawbacks of using an EEG device are very important. The devices that are used are expensive and they need time to be fully trained and effective. Also, a big issue is the amount of time that the devices need to be set up. The headset must be in a specific position so every sensor should be able to detect the brain waves.

2.5.4 Open Issues

EEG gives the ability to researchers, to have a better understanding of the emotional state of the user. Especially while playing, users have mixed feelings as they go through different types of situations. There is a plethora of papers that review psychophysiological methods in games [12], however they do not discuss if a user’s emotions can correlate with the actions that occurred in the game and if there is a pattern that connects a user's emotions with their actions. In addition, while the gaming industry is improving, a variety of researches were conducted that discuss the users' interactions within the games, however they are not usually correlated with their emotions.

Chapter 3

Microsoft HoloLens and Emotiv Epoc+

3.1 Introduction

In Chapter three is going to be explained the two main tools that were used in the studies. The first study is structured with HoloLens. The chapter contains the way a Mixed Reality gadget (Microsoft HoloLens) works and how the user can interact with it. Also, it explains the way a developer can connect HoloLens with the computer.

The second study is based on Emotiv EPOC +. The chapter explains how Emotiv EPOC + works and how it is used in researches and in everyday life. This tool is an advanced tool that has a significant way of connecting with the computer, and in the chapter the way it can be connected is explained, and way the headset had to be worn and how the researcher can extract the data. The data that are extracted from Emotiv EPOC + are advanced so every file had to be explained.

3.2 What is HoloLens

Microsoft HoloLens is a Mixed Reality headset that presents visual objects within the real environment of the user [1]. HoloLens presents 3D holograms and the user does not need any particular skills to interact with them.

3.2.1 What is MR

Mixed Reality is a mixture of Augmented Reality and Virtual Reality within the real world [11].

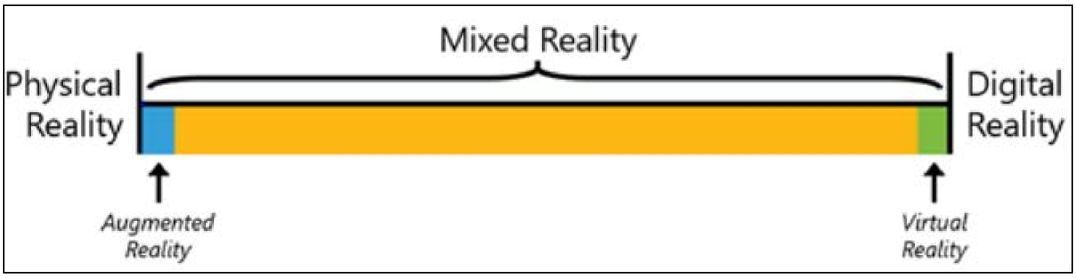


Figure 3.1 - Mixed Reality Spectrum

Augmented reality is the experience that previews visual elements on videos of the real world and virtual reality is the experience that change your view into a digital. MR previews virtual elements in the real world of the user and waits for the user to add an action and interact with the virtual elements without erasing the real elements in the environment of the user. It combines three elements, computer processing, human input and environmental input, to create a new experience that is going to help the user interact with a digital world [12]. In addition, in MR it is important to present elements to the users without confusing them that the whole environment has changed and only that the elements are added in their world.

Having that in mind, HoloLens is a Mixed Reality headset that maintains the environment of the user and presents holograms that can be selected by the user. HoloLens' experience could easily be confused as AR, because of the variety of visual effects and virtual videos that are presented in the view point of the user. However, it can be instructed from the user in several ways to make changes in the interface, and that makes the experience Mixed Reality.

3.2.2 How HoloLens works

Microsoft HoloLens is a very complex headset that maintains the real environment, presents holograms, detects the had gestures of the user, listens to the vocal instructions of the users and extracts sounds to create a more immersive experience.

Figure 3.2 - HoloLens Headset

First and foremost,[13] to present holograms and maintain the real environment HoloLens uses two translucent screens and projects light in the user's eyes. To make the image look as immersive as possible, in collaboration with the front cameras, the visual objects are presented in the right place as 3D holograms [14]. The cameras have a one-hundred-twenty degrees gaze that is used, not only to set the environment and collect as much data as they could, but also to detect user's hand gestures.

Furthermore, to help the holograms follow the user's view point, HoloLens watches the user's gaze and the position of the head. To do that, it contains an accelerometer to measure the speed of the head, a gyroscope for the tilt of the head and a magnetometer as a compass [13]. To take vocal instructions HoloLens has microphones and speakers that are above your ears to make the user thing that the sounds come from the real environment. The speakers are placed above the ears and not in the user's ears to make sure that no sound from the environment is blocked.

3.3 How HoloLens is used

3.3.1 User's interaction

HoloLens is used in different ways. From the moment HoloLens was released it drove the attention of a lot of researchers that were interested in the way users can interact with Mixed Reality and its benefits. However, the audience of HoloLens was also younger people that wanted to entertain themselves with a games or videos. Having that in mind, the interaction had to be usable enough to help the occasional users and simple enough for the advanced users.

In general HoloLens goggles have a very similar exterior with VR headsets. To wear them, the users have to rotate the headband and slide it back. Place the googles on their nose and then adjust the tightness of the headset around their head, by turning the adjustment wheel on the back of the headband. However, HoloLens has a massive difference from VR headset, users can see and interact with their real environment. HoloLens projects a transparent screen which has to be in the middle of user's point of view. What makes the setup of HoloLens complicate is the fact that to set the screen in the middle users have to experiment with the placement of the headset, move the goggles around until they get the best view. HoloLens also comes with a strap that helps the headset stay stable and increases the weight of the gadget on the users' nose. Moreover, if the users feel that HoloLens does not fit right around their nose, an extra nose pad is also provided. Finally, to take off the headset, users have to loosen the headband from the adjustment wheel and lift the whole headset.

To interact with HoloLens there are three interaction types, gaze, gestures and voice.

1. Gaze: The sensors that are imported on the inside of the HoloLens are able to detect where the user is looking at. Users can look around not only by moving their eyes but also their whole head. HoloLens creates a dot that works as a cursor and is presented where the user's head is pointing at. This helps the software to know with which object the interaction is about to happen.

2. <u>Gestures:</u> The front cameras in the headset create a conceptual framework to detect only the gestures that occurred in it. Users cannot see the framework, but they are aware of the cameras and can guess their view point. The main hand gesture is Air Tab [15]. Users have to place whichever hand they want, in front of HoloLens and lift and drop only their index finger, as shown in Figure 3.3.

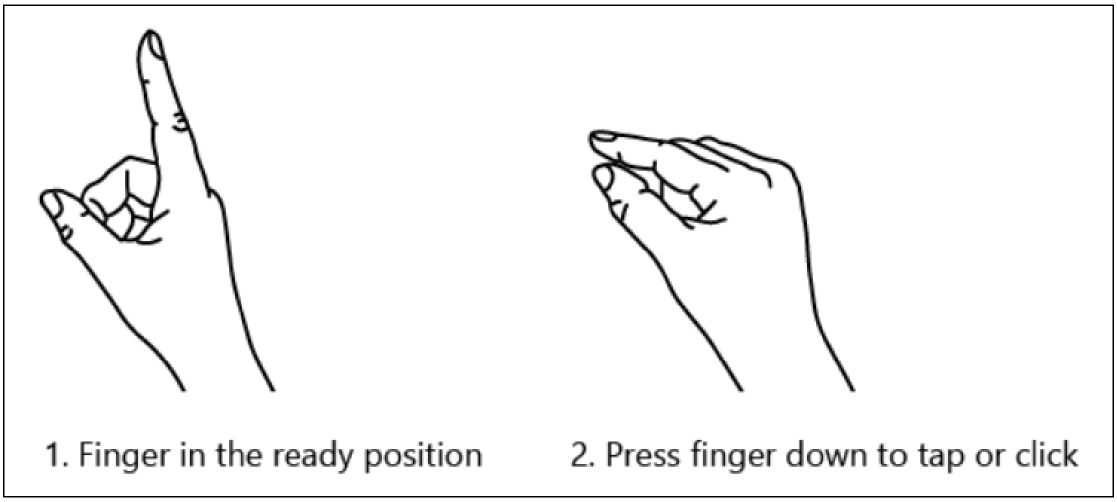


Figure 3.3 - Air tab Gesture

Users can also Tap and Hold. Tab and Hold is the same gesture as air tap with the difference that when the users drop their index finger, they keep it down and move around their whole arm depending on the action they want to make. To grab an object, they have to Tap and Hold for a little more than a second, release their index finger and move around their head to move the object. To zoom in or zoom out an object, they Tap and Hold and while keeping their index finger down they move their arm on the right to zoom in and on the left to zoom out. To tilt an object, users do the same thing they did with zoom but instead of moving their arm on the right and left, they move it upwards and downwards. Lastly, to close an application or open the menu window users have to do the Bloom gesture. They place their hand in front of the camera with their fingers closed together, looking upwards and they opened them at the same time as shown in Figure 3.4.

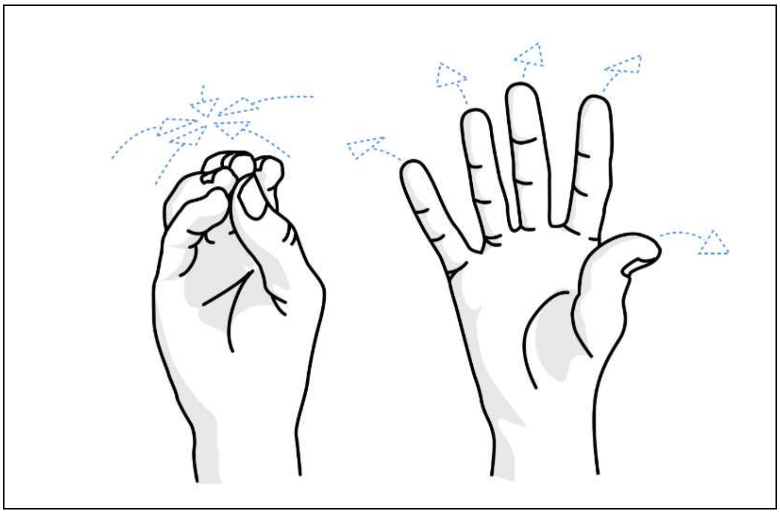


Figure 3.4 - Bloom Gesture

3. Voice: In some cases, users can instruct HoloLens with their voice. HoloLens has a variety of keywords/ key phases that can help users interact with the holograms easier. (start tutorial/ begin tutorial, stop tutorial/ end tutorial, reset/ reset view, grab, zoom/ zoom tool, rotate/ rotate tool, tilt/ tilt tool, back/ go back, controls, about, etc.)

3.3.2 Connection with the computer

To connect HoloLens with the computer, you have to make sure that the HoloLens is connected with the WIFI. The first step is to “bloom” to open the menu, from the menu you have to tap “Settings”. On the Settings window find “Network & Internet” and tap it so you can connect HoloLens with the WIFI (The WIFI that HoloLens is going to be connected has to be the same with the WIFI that the computer is already connected)

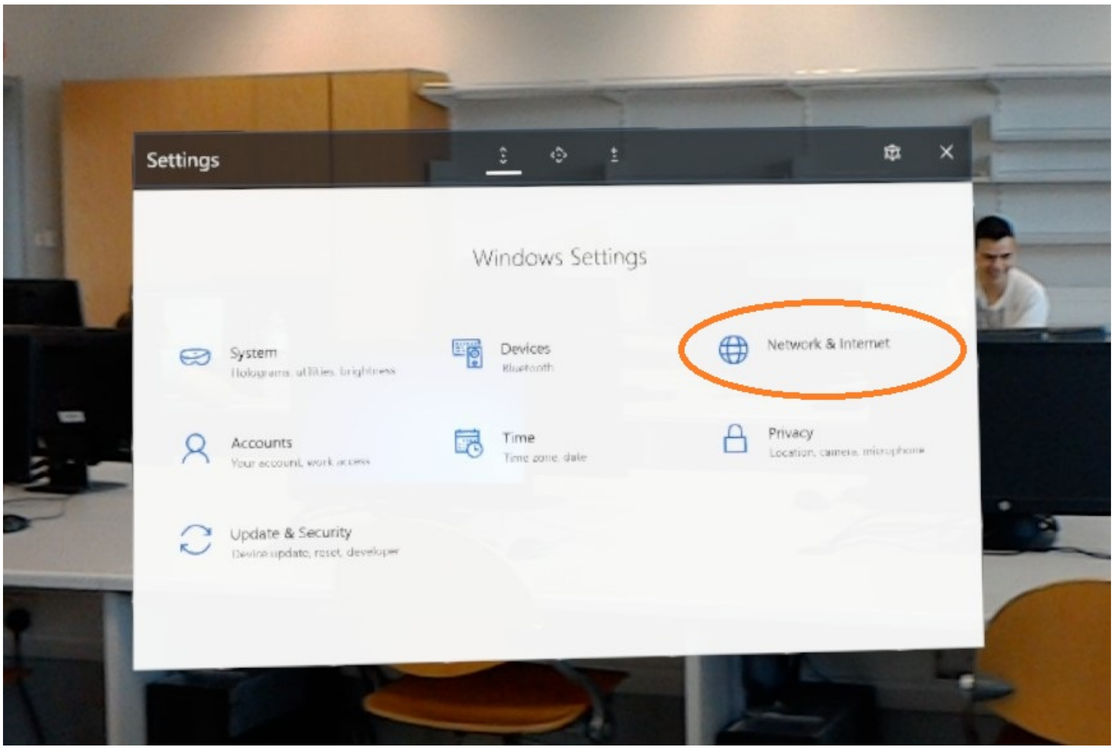


Figure 3.5 - Select Network & Internet

After the connection with the WIFI, press “Advanced options”, as shown in Figure 3.6 to open the option of the specific WIFI.

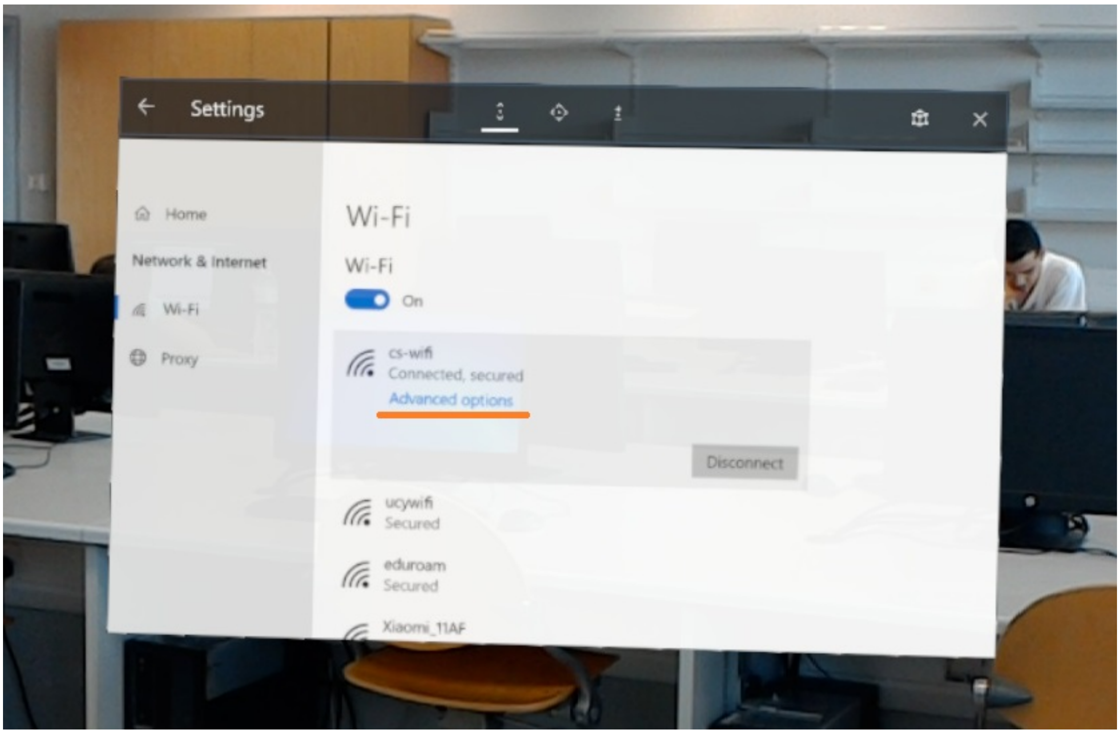


Figure 3.6 - Select Advanced options

When the “Advanced options” opens, scroll down until you find “IPv4 address” and write the address in the address bar oy your browser on the computer. If the content of the website that is presented is the same with Figure 3.7, press the button “Advanced” to continue.

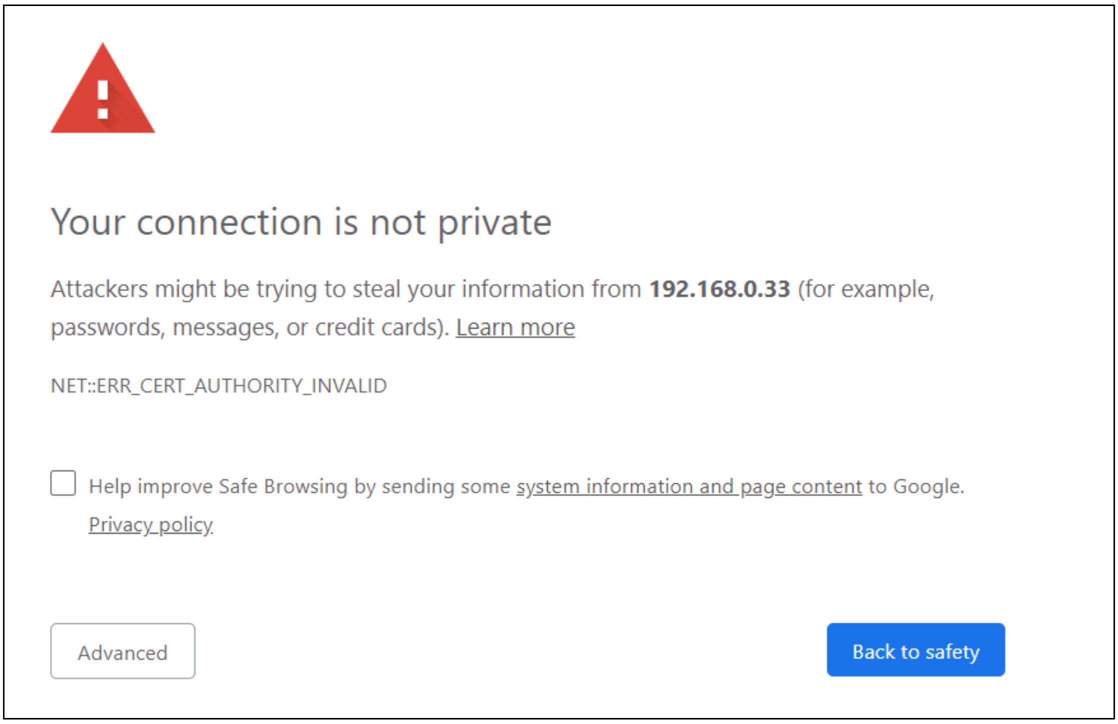


Figure 3.7 - Press Advanced

In addition, by pressing "Advanced" the content of the page is going to expanded and you now have to press "Proceed to" the IPv4 address that you have previously imported "(unsafe)". At that point a pop-up is going to ask you to insert your HoloLens account and password and once you do that it opens up a HoloLens page.

3.4 Research on HoloLens

HoloLens is a very revolutionary gadget that attracted the eyes of researchers for years. There is a plethora of research papers that use HoloLens as an MR device that could be compared with the 2D interaction type gadgets. [4] A study specifically separates the participants based on the type of visual information processing, and then compares HoloLens' experience with desktops. In general, it appeared that, despite the cognition type and the small difficulties FDs faced, HoloLens was more effective and accurate. In addition, another study that wanted to research more on the differences on the interaction between the two cognitive types used HoloLens [3]. The differences were huge as FDs had more difficulties than the FIs in all the possible ways of interaction (Go to Chapter 2.2.4 to learn more about the study). Moreover, HoloLens opened the doors to different application ideas that brings a revolutionary improvement to technology and everything that can be associated with it. For instance, recently a paper has been published, that presents the development of an AR system that tests an early onset of Alzheimer's disease, using MS HoloLens [16]. As the security of our privacy becomes more important, a variety of authentications system have been researched and tested. A recent study on HoloLens, describes the implementation as well as the evaluation of a Recall-based Graphical Password Authentication, named HoloPass. In terms of security no significant difference was found in comparison with the desktop version of the application, however in terms of user preference related to authentication type HoloLens, it appeared to be more usable [17].

3.5 What is Emotiv EPOC +

Emotiv EPOC+ is a multi-channel EEG system that offers several applications such as neurotherapy, biofeedback and brain computer interface. It includes fourteen channels that are based the 10-20 system (Go to Chapter 2.4 to learn more about how EEG works), which are AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4. It does not contain all the channels from the 10-20 system and that is why it cannot support a full BCI experience.

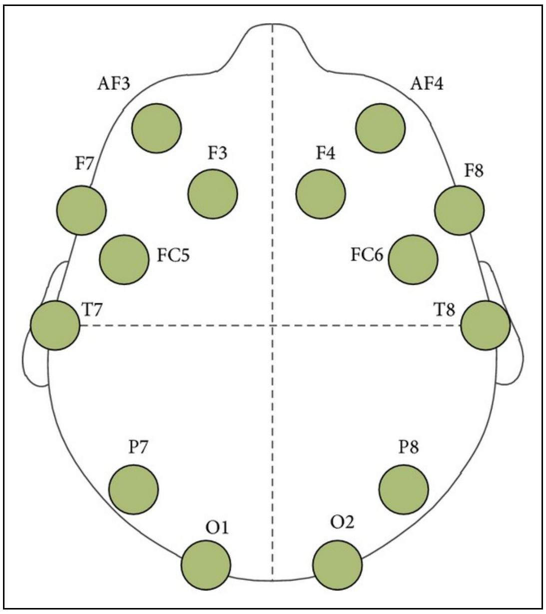


Figure 3.8 - Emotiv EPOC+ channels' placement

Emotiv EPOC + has three different detection software, Expressiv, Affectiv and Cognitiv suites [18]. The Expressiv suite is used to illustrate the user's facial expressions. The Affectiv suite tracks the emotional states of the user. Finally, the Cognitiv suite performs a BCI control, which helps the user make an external activity on a computer, by using the brain signals that are detected form a device [19].

3.6 How to use Emotiv EPOC +

3.6.1 How to wear Emotiv EPOC +

Emotiv EPOC+ is meant to be used in research. It is a cheap headset, so it could be easily purchased from universities or companies that want to analyze the human brain or try the BCI feature. There is a plethora of people that are interested on Emotiv EPOC+ and that does not only contain researchers, that are going to have some time interacting and get to know its features before using it. In addition, a common user can train the BCI system to control the computer with commands from the user's mind.

However, it is quite complex to adjust the headset properly. Emotiv EPOC+ contains a headset, pack of fourteen sensors, a bottle of distilled water, a charger and a USB.

The headset had to be fully charged before using it. It usually takes 4 hours to be fully charged and it has to be on the “off” position. When the headset is fully charged the users have to hydrate every sensor while they are in their pack, using the distiller water. When each and every one of the sensors are fully hydrated, they can be installed in the black plastic headset arms, by turning them clockwise. The sensors have to be fully hydrated on the headset.

The users have to turn on the headset and insert the USB in their computer or connect it with Bluetooth. To wear the headset, users have to slide it down from the top of their head without stretching it. Each side has two basic sensors that were initially on the headset, these sensors have to touch the bone behind each ear lobe. The two front sensors should be approximately three fingers above the eyebrows or on the hairline.

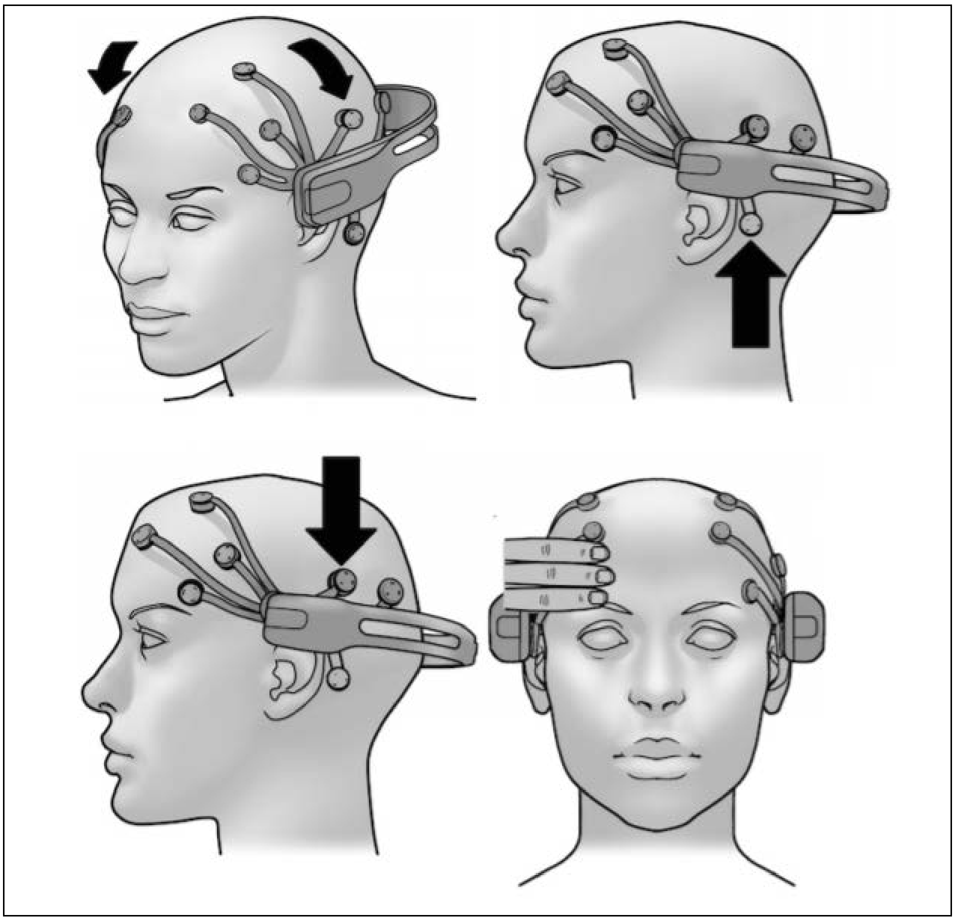


Figure 3.9 - How to wear Emotiv EPOC+

In the screen of the computer users can see the sensors' placement and make sure that every sensor has a green color. The sensors can have four different colors, each of them means a different thing.

- If a sensor is black, it means that it cannot be detected.
- If it is red, it means that is not properly attached to the head.
- If it is yellow, it means that the measurements are not going to be that accurate.
- If it is green, the sensor is fully adjusted and in the right position.

After making sure that every sensor has a green color, the users have to press down the two basic sensors for twenty seconds.

3.6.2 Connection with Computer

While wearing Emotiv EPOC+ it has to be connected with the computer. The users can connect it with USB or with Bluetooth. To use the headset the users have to download an application from their official website (https://www.emotiv.com/product-category/applications/). In their website they have a plethora of applications and licenses that can be purchases from anyone that owns the headset.

Their free application is called EmotivBCI. EmotivBCI provides the users the basic features of Emotiv EPOC+. Users can train the commands and control machines, view in real-time their emotional state, view their facial expressions and they can see the motion sensor data streams from their headset. EmotivBCI is a very useful tool if users only want to view their data, train the BCI system and get used to the headset. However, the data cannot be downloaded so the application cannot be useful to a researcher that wants to analyze the data.

The website provides a variety of license that provide different functionalities. More fitted in our situation was “PRO License”. “PRO License” contains everything that EmotivBCI does but it adds some more functionalities. It is created for researchers because it provides the ability to export Raw EEG data, Performance Metrics data, Motion sensor data and FFT/Band power data in real time. After downloading the “PRO License” users insert their Emotiv account and whenever the headset is connected with the computer, they can access the application and select the feature they want.

3.6.3 Performance Metrics Data

The “Performance Metrics” feature presents a graph with the emotional state of the user. The y axis starts for zero to one hundred and the x axis it represents the time every ten seconds.

“Performance Metrics” contains six emotions that the user might feel:

- Stress (FRU): It represent the comfort the user feels while doing a certain task. High stress level means that the user is probably feeling devastated or the task is difficult. Low or medium stress level means that the productivity is improving.

- Engagement (ENG): It represents the level of immersion in the moment and it connects with the attention and concentration the user has while doing the task. High engagement level means greater attention, focus and workload.

- Interest (VAL): It represents the attraction the user feels in the environment or task. High interest level means high sympathy feelings. Medium interest level means that the user neither like nor dislikes the task. Low interest level means that the user has a strong antipathy of the task.

- Excitement (EXC): It represents a feeling of a physiological enthusiasm, that results on different responses. For example, pupil dilation, eye widening, sweat gland stimulation, heart rate and muscle tension. Higher excitement range means higher physiological enthusiasm. It provides short-term changes in the user's excitement over time.

- Focus (FOC): It represents a fixed attention on a task or a specific element. High focus level of task switching means poor focus and distraction.

- Relaxation (MED): It represents the user's ability to recover from deep concentration. High score of relaxations means that the user can easily relax.

Every time users want to save their data, they have to start a recording by pressing the red dot in the left corner. After the interaction is over from the same spot the recording can be stopped. In the side menu the "Recordings" section, has every recording that the users have already saved. From there they can Export their data in a csv format.

They are exported three files. The name of each file is almost the same, first it is the name of the recording then, the date of the recording and then the timestamp the recording started. Each of the above are separated with a "_".

test1_2019.02.13_15.44.46	2/13/2019 4:58 PM	Microsoft Excel Comma Separated Values File
test1_2019.02.13_15.44.46.pm	2/13/2019 5:39 PM	Microsoft Excel Comma Separated Values File
test1_2019.02.13_15.44.46_marker	2/13/2019 3:51 PM	JSON File

Figure 3.10 - Test1 file example

Each file has a different use and format:

1. recordingName_date_timestamp: This file is the biggest of the three of them and it is called EDF file. This file is compatible with a plethora of EEG analysis programs. The first line of the file has a couple of information about the recording. The "title:" contains the title that was given to the recording by the users. The "recorded:" contains the local date and time when the recording was started to the nearest second and it is presented in the format "[Month]-[Day] [Hours].[Minutes].[Seconds]". The "timestamp started:" contains the

time the session was started to the nearest millisecond and it is presented in the format "[Year]-[Month]-[Day]T[Hours]:[Minutes]:[Seconds]+[hours from GMT]". The session starts when the headset connects to the application. The "sampling:" represents the sampling rate per seconds. The "subject:" it is the name of the subject that was given by the users when the recording started. The "labels:" contains the name of each column. To make the file readable the content of the "labels:" be arranged on each column. The "chan:" represents the total number of columns in the file. The "units:" contains the measurement units.

After arranging the content of the "label:" cell every column in the file now has a name. The "COUNTER" column can have the value 0 to 128 and it represents the packet counter. The "INTERPOLATED" column is a flag which has the value 1 if a packet was dropped and the value 0 if the sample was good. The follow fourteen columns that have the names "AF3", "F7", "F3", "FC5", "T7", "P7", "O1", "O2", "P8", "T8", "FC6", "F4", "F8", "AF4" represents every sensor on the headset and they contain the voltage fluctuations over time. The column "RAW_CQ" represents the eight bottom bits of the uncompressed EEG signal and it is used to get the contact quality of the indicators in the application. The following two columns "GYROX" and "GYROY" represents the horizontal and vertical difference readings since the previous sample. The "MARKER:" is the actual value of the market that has been inserted. When the value is 0 it means that there was not marker trigger detected. If the marker trigger was detected the value is the associated number. The "MARKER_HARDWARE:" is the index of the device that has been used to trigger the marker. The first device has value 1 and the second the value 2. The "TIME_STAMP_s" and "TIME_STAMP_ms" are the number of seconds (s) and millisecond (ms) that were passed after the headset was connected to the application. The following fourteen columns that have the names "CQ_AF3", "CQ_F7", "CQ_F3", "CQ_FC5", "CQ_T7", "CQ_P7", "CQ_O1", "CQ_O2", "CQ_P8", "CQ_T8", "CQ_FC6", "CQ_F4", "CQ_F8", "CQ_AF4" represents the color of the CQ map indicators, if the value is 0 it means black, if it is 1 it means red, if it is 2 is orange, if it is 3 is yellow and finally if the value is 4 it means green. The last two columns have the names “CQ_CMS”, “CQ_DRL” and they show the contact of the headset. Red is represented with 1 and green is represented with 4.

2. recordingName_date_timestamp.pm: This file is the most important file, as it contains the “Performance Metrics” of the recording. This file is in a CSV format. The column “Timestamp” contains the timestamp of the sample seconds after the headset connected. To transfer the timestamp in the real time, we set the cell’s format on “Time” and we created an excel format that has as a result the real local time.

   Real local time= (Timestamp+("1/1/1970"-"1/1/1900"+1)*86400)/86400 +TIME(2,0,0)

   The file analyses six emotional states that were explained early in this subchapter. Every emotion has a “nickname” _ENG= Engagement, _VAL= Interest, _MED= Relaxation, _FRU= Stress, _FOC= Focus, _EXC= Excitement. There are five columns for each emotion:

   a) SCA= Is the raw data that can be a number from 0 to 1. Scaling is based on a successive approximation of the mean and difference for each recording and it is calculated as the session progresses.

   b) RAW= The raw values can be a negative single digit number to a positive single digit number. These numbers are meaningful only when looked at relatively.

   c) MIN & MAX= These columns are calculated from the scaled data and are set based on the population data.

   d) ACT= Is a flag that has the value 1 when the Performance Metrics is active and 9 when it is not.

The column “SCA_LEX” represents long term excitement and it is a better measurement of the overall mood, rather than intense changes in mental arousal. The last fourteen columns that have the names “CQ_AF3”, “CQ_F7”, “CQ_F3”, “CQ_FC5”, “CQ_T7”, “CQ_P7”, “CQ_O1”, “CQ_O2”, “CQ_P8”, “CQ_T8”, “CQ_FC6”, “CQ_F4”, “CQ_F8”, “CQ_AF4” represents the color of the CQ map indicators, if the value is 0 it means black, if it is 1 it means red, if it is 2 is orange, if it is 3 is yellow and finally if the value is 4 it means green.

TimeStamp	SCA_ENG	RAW_ENG	MIN_ENG	MAX_ENG	ACT_ENG	SCA_VAL	RAW_VAL	MIN_VAL	MAX_VAL	ACT_VAL	SCA_MED	RAW_MED	MIN_MED	MAX_MED	ACT_MED	SCA_FRU	R
1550065496	0.676628	-0.1636	-1.36924	0.490316	1	0.543752	4.44076	-8.11334	15.287	1	0.267258	0.117551	0.042466	0.296101	1	0.347503	
1550065506	0.686673	-0.16741	-1.3637	0.490037	1	0.465893	2.65292	-8.13256	15.2617	1	0.174551	0.089869	0.042688	0.294583	1	0.279492	
1550065516	0.647444	-0.30529	-1.35778	0.488774	1	0.464575	2.89658	-8.21079	15.253	1	0.154387	0.082429	0.042488	0.293004	1	0.313093	
1550065526	0.491785	-0.5725	-1.3526	0.484835	1	0.457119	2.61222	-8.27635	15.2401	1	0.210725	0.101218	0.042516	0.291489	1	0.270783	
1550065536	0.49919	-0.22828	-1.35033	0.479887	1	0.486978	3.3547	-8.34695	15.2292	1	0.274304	0.117042	0.042782	0.290064	1	0.275296	
1550065546	0.618819	-0.333	-1.34515	0.476503	1	0.605595	5.5514	-8.3581	15.2153	1	0.359755	0.137658	0.043487	0.289081	1	0.372564	
1550065557	0.636883	-0.16532	-1.33908	0.473042	1	0.492956	3.3812	-8.38675	15.2002	1	0.241751	0.10989	0.043968	0.287878	1	0.314189	
1550065567	0.642718	-0.233	-1.33341	0.471222	1	0.52817	3.9927	-8.4056	15.1723	1	0.320119	0.128801	0.044447	0.286697	1	0.351358	
1550065577	0.674886	-0.21515	-1.32796	0.469785	1	0.472022	2.59938	-8.4297	15.1478	1	0.240956	0.109043	0.044955	0.285584	1	0.285916	
1550065587	0.606971	-0.24359	-1.32241	0.467272	1	0.471167	2.84827	-8.49342	15.1358	1	0.200673	0.098269	0.045068	0.284257	1	0.253401	
1550065597	0.728611	-0.02161	-1.31808	0.467114	1	0.5983	5.21889	-8.49523	15.1105	1	0.352674	0.134975	0.045464	0.283146	1	0.251698	
1550065607	0.664355	-0.33278	-1.31446	0.46868	1	0.488422	3.08369	-8.5078	15.0851	1	0.268198	0.116603	0.046028	0.28218	1	0.245244	
1550065617	0.630811	-0.10009	-1.30909	0.466082	1	0.499918	3.31681	-8.53564	15.0614	1	0.274667	0.117882	0.046398	0.281045	1	0.236476	
1550065627	0.68017	-0.19894	-1.30439	0.465544	1	0.502457	3.24491	-8.5549	15.0356	1	0.263218	0.115271	0.046835	0.279977	1	0.232411	
1550065637	0.663082	-0.0635	-1.29933	0.464027	1	0.591237	5.55726	-8.57065	15.0116	1	0.24369	0.110216	0.047116	0.278839	1	0.218234	
1550065647	0.671097	-0.21943	-1.2948	0.463662	1	0.486543	2.37142	-8.5794	14.9964	1	0.208797	0.10071	0.04739	0.277728	1	0.251986	

Figure 3.11– Snap shot of a small part of the CSV file

3. recordingName_date_timestamp_marker: This file is in a JSON format and it contains the description of the keystroke markers used. The baseline markers and their values are “Eyes Opened Start: 1”, “Eyes Opened End: 2”, “Eyes Closed Start: 3” and “Eyes Closed End: 4”.

3.7 Research on Emotiv EPOC +

Emotiv EPOC+ is a useful tool for researchers that want to analyze more human emotions in different situations, and to improve the BCI applications, so they can be easily accessible to people that really need them. As Emotiv EPOC+ is a commercial tool a research has been conducted describing its capabilities and pointing out its drawbacks.

[20] Emotiv EPOC+ appeared to be a little sensitive as the sensor could easily broke and after some time, they were non oxidized. In addition, a journal wanted to

examine whether Emotiv EPOC+ had a potential to be used to control a computer using facial expressions [21]. It describes Emotiv EPOC's + accuracy, on the two studies they have conducted, mentioning that after some time its accuracy started to improve. Finally, on the previous version of Emotiv EPOC+ (Emotiv EPOC), it was conducted a study that wanted to measure the cortical activity when the participants were introduced to noises [22].

Chapter 4

Data Analysis Web Application

4.1 Introduction

The data analysis is a hard and time demanding task. Considering that, a website for presenting and managing the data is required. The aim of the website is to simplify the data analysis, by presenting only the needed data with a neat and simple way to help the researcher conclude. The website is called Holo Logger since it is based on a log file that is extracted from Galaxy Explorer on Microsoft HoloLens.

4.2 Project Introduction

4.2.1 Galaxy Explorer

Galaxy Explorer is an open source application on HoloLens created by Microsoft. It aims at educating and entertaining the user by showcasing and providing auditory information for our Galaxy. With the plethora of colors and the realistic graphics it transforms the room into our galaxy and encourages the user to explore the planets. The application has an educational feel to it, since there is a tour guide for every point, that the user wants to learn about, in the universe.

Galaxy Explorer is provided by Microsoft, it is available on GitHub, and the version that is deployed on our HoloLens exports a log file with the user's interactions with the application.

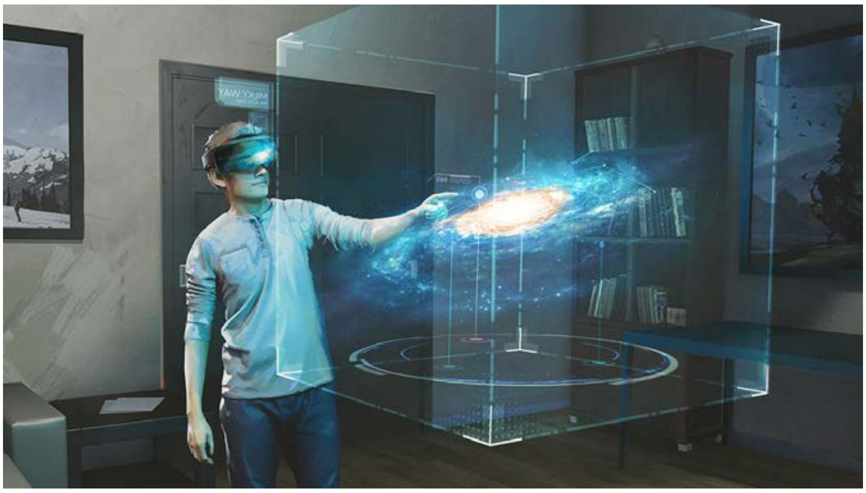


Figure 4.1 - Interaction with HoloLens

4.2.2 Project Requirements

First and foremost, an interview with the co-supervisor of my dissertation was conducted to set the requirements and define the general interface of the website. Before the website, the data analysis had to be done manually, so it is also going to be used for future studies with Galaxy Explorer.

The website had to have a clean and neat interface. The users of the application are going to operate with its features for long periods of time and the analysis that they will have to do is usually very time consuming and hard. Having that in mind, the interface had to be simple with only the important information being presented.

The primary action of the website was to upload a file. The researcher has to upload the Log File that is extracted from HoloLens. When the log file is uploaded, its data are divided in the database (the way the data are divided is explained further down in the report). The researcher can, then, view the uploaded data.

After a previous study was conducted, it was observed a specific format for the data submission. Everything had to be in tables, to help the user connect the associated information. The actions are separated per user. Firstly, the user of the applications must have the ability to add the personal information of each participant. The personal information is important for the data analysis at the end. For each participant the user wanted to view all their actions, so they can make more detailed assumptions. In addition, equally significant was the fact that it was also wanted to present the actions that referred to "Tabbing" an object and the frequency of each action per user.

Furthermore, the most important was the extraction of the excel files. The excel files are useful for the comparison of the results. It had to be in a specific format, to help the user insert the file to data analysis algorithms.

4.3 Logger

To create the Log file, we have to deploy our version of Galaxy Explorer which extracts the file. To find the right version, you must connect HoloLens with the computer, select "Views" from the site-map and then from the "Apps" tab, you have to select the Galaxy Explorer with the same description as shown in Figure 4.2

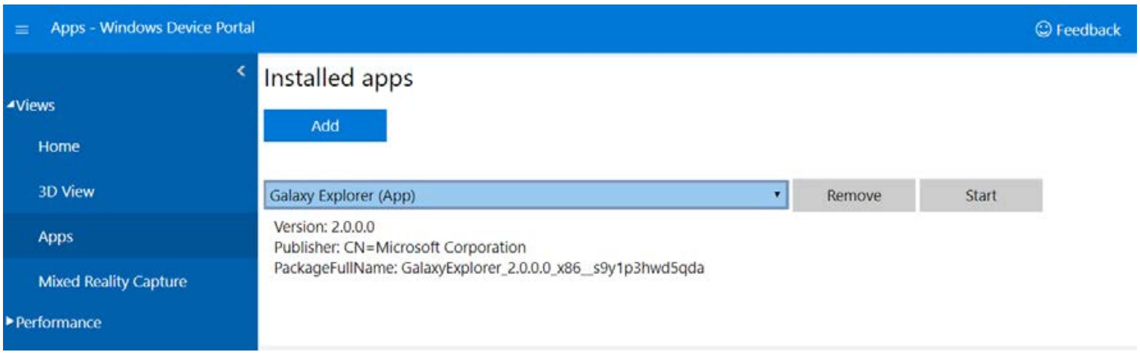


Figure 4.2 - HoloLens Website- Apps

4.3.1 Extract Log File

The interaction with the user starts to get recorded from the moment the application has opened. When the interaction with the application is over and the user exits Galaxy Explorer, the log file can be extracted from the computer, when it is connected with HoloLens. (Go to Chapter 3.3.2 to see how you can connect HoloLens with the computer)

From the HoloLens website after selecting “System” on the site menu press “File explorer” and follow the following steps.

Step 1

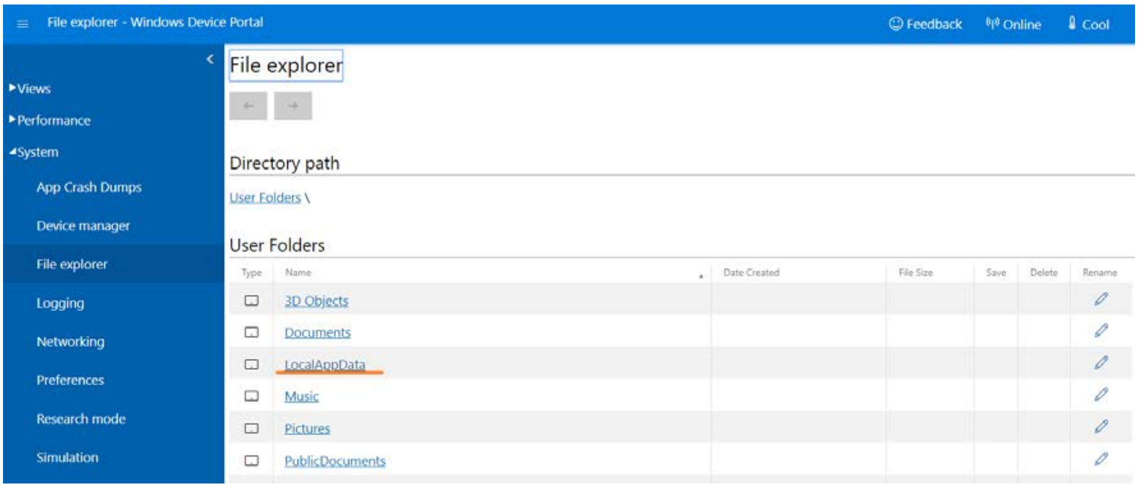


Figure 4.3- Select LocalAppData

Step 2

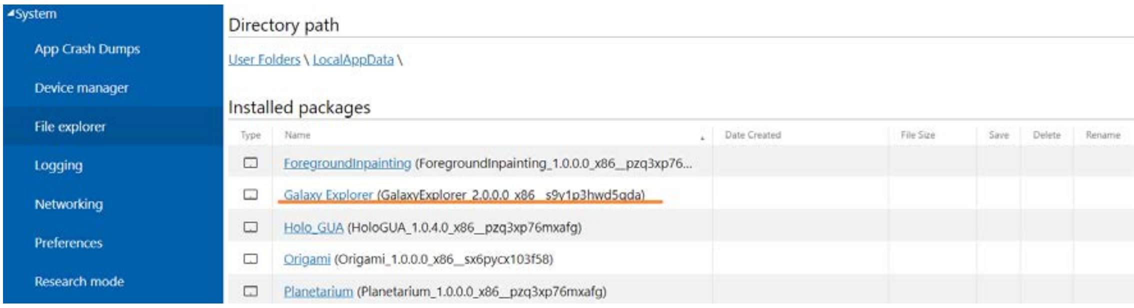


Figure 4.4 - Select Galaxy Explorer

Step 3

Figure 4.5 - Select LocalState

Step 4

Figure 4.6 - Select save icon in row MyLogFile.txt

4.3.2 Log File Format

The Log File has every action the user has made from the moment Galaxy Explorer opened. If you do not delete the log file after a user has completed their tasks, the actions of the next user are added at the end of the file.

The name of the file is "MyLogFile.txt" and the lines have a specific format. As it is shown in Figure 4.7 after every word there is a [space]. The first string of each line is always the time, which is presented in a simple format “H:MM:SS”. In addition, the most frequently displayed lines have the format “desiredTarget [object]”, which represent the specific time the user gazed at an object. Furthermore, there are lines that have the format “Hand Hand[action]” or “Hand TapPressed”. At the first format, [action] can either be “Enter” or “Exit” and it represents the movement of the hand in front of HoloLens’ camera. The second format is recorded when the user air-taps but this action does not specify the object the user is trying to air-tap. Lastly, an action very rarely displayed is “TriggerSpeechCommand [word]” which is recorded when the users use their voice to make an action and the word is a specific keyword which is set from the application’s developers.

```
0:01:19 desiredTarget Sun
0:01:21 desiredTarget Mercury
0:01:21 desiredTarget Sun
0:01:22 Hand TapPressed
0:01:23 Hand TapPressed
0:01:24 Hand HandExit
0:01:24 Hand HandEnter
0:01:24 Hand HandExit
0:01:28 Hand HandEnter
0:01:30 Hand HandExit
0:01:31 TriggerSpeechCommand zoom
0:01:31 Hand HandEnter
0:01:31 Hand HandEnter
0:01:31 Hand HandExit
0:01:31 Hand HandExit
```

Figure 4.7 - Snapshot from MyLogFile.txt

4.4 Website Description

4.4.1 Log File Separation

After a user study, the log file consists of a lot of data and it becomes hard to read. Therefore, the first part of the separation is to separate the actions per user. Every time a new user interacts with Galaxy Explorer, a new timer restarts from 0:00:00 and the actions are added to the end of the file. This made the user separation easier as the time resets to 00:00:00 immediately for each new user. Then every line was split and saved in a specific database.

4.4.2 Database

The creation of the website required a database to store every information that existed in the log file. The database is called “logger” and it consists of three tables. “user”, “taskObject” and “descriptionAct”.

The table “user” contains every data that is related with the user. While reading the log file the program compares the current time with the previous one and when the current line has a smaller time than the previous then it automatically creates a new user in the “user” table. The ID of the table is an auto-incremented integer and the username is “user-[number]”. The [number] is auto-incremented from the web application. In addition, when the program finds a new user, it automatically inserts the duration of the interaction of the current user, which is the time that is written in the last record of said user, and then creates a new user. Moreover, there are some empty columns for each user that interest their personal information and can be updated from the researcher who uses the web application. Those columns are “Age”, ”Sex”, “Feel” and “TestScore”. The “Age” and “Sex” columns are very important in a study as a lot of papers are consecutively commenting on the age and gender of the participants. Equally significant, are the “Feel” and “TestScore” columns as a variety of studies in Human Computer Interaction are interested in GEFT Tests and their results. Finally, a column automatically saves the creation date of each user to help the researcher keep track of the data.

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra
1	**ID**	int(11)			No	*None*		AUTO_INCREMENT
2	**Username**	varchar(128)	utf8_general_ci		No	*None*		
3	**Age**	int(11)			Yes	*NULL*		
4	**Sex**	varchar(45)	utf8_general_ci		Yes	*NULL*		
5	**Feel**	int(1)			Yes	*NULL*		
6	**TestScore**	int(11)			Yes	*NULL*		
7	**DateCreated**	varchar(45)	utf8_general_ci		No	*None*		
8	**Duration**	time			Yes	*NULL*		

Figure 4.8 - User Table in Database

The table "taskObject" collects only the name of the Objects in every action. Every object is imported in the table only one time. The program selects all the actions from the log file, except the ones that contain the word "TapPressed" and takes their last word as an object. If a new action occurs and the object of the action is not in the table, then it is going to be imported. The tapPressed actions are not selected because they have no object. Finally, the "taskObject" table's ID is an auto-incremented integer.

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra
1	**ID**	int(11)			No	*None*		AUTO_INCREMENT
2	**ObjectName**	varchar(45)	utf8_general_ci		No	*None*		

Figure 4.9 - Task Object Table in the Database

The table "descriptionAct" is the most complex table of the three, as it is connected with both the other tables and cannot hold any data without them. Its ID is also autoincremented integer. The column "Name" defines the name of the action, in our case it is the word after the time. In addition, the column "Time" is the time that the action took place. For example, the first line in Figure 4.7 has the name "desiredTarget" and the time 00:01:19. The most important fact about this table is the connection with the two others. The "descriptionAct" table has as a foreign key the ID of the user that did the action and the columnd is named "UserID". To set this foreign key, the web application keeps a variable of the name of the current user and every time a new action occurs, the Database is instantly notified. Moreover, the table is also connected with the table "taskObject". The column "objectID" is also a foreign key and it is connected with the corresponding object from the “taskObject” table. To set this column we had two types of lines, the lines with the objects already defined and the “tapPressed” lines. The already defined lines are easily connected with “objectID” because their object is mentioned as the last word. However, the “tapPressed” lines do not have an object. To define the object of those lines, the web application keeps a record of the previous object that had been “desired” (gazed at) by the user and when the action is “tapPressed” it connects it with the recorded object.

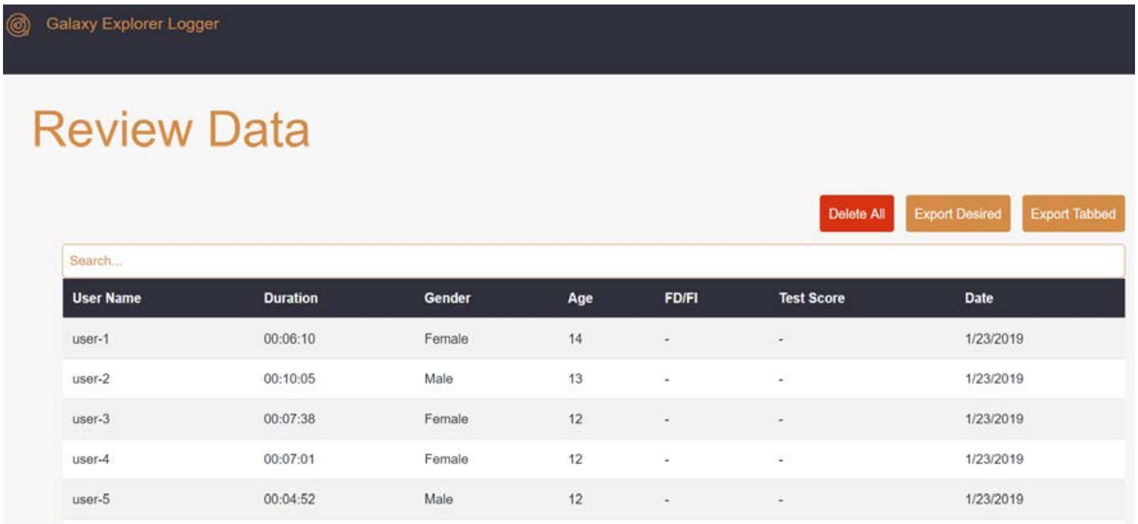
#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra
1	ID	int(11)			No	None		AUTO_INCREMENT
2	Name	varchar(1000)	utf8_general_ci		No	None		
3	Time	time			No	None		
4	UserID	int(11)			No	None		
5	ObjectID	int(11)			No	None		

Figure 4.10 - Description Act Table in the Database

4.4.3 Presentment and Edit of the Data

The web application is going to be used for Data Analysis, so it has to be simple and very clean to help the users focus on the important information and not distract them. The information the users need to see are simple and the necessary actions are very limited.

The home page is a simple interface with two buttons, giving the user the options to upload data or to review data. If the users want to upload data they can easily browse for the log file, which is a .txt file. The web application cannot interact with any other type of file. The log file must be the same format as it is exported from HoloLens. If the users want to review the data, the first page that is presented to them is a table with all the users and their personal information. The table has the User name, the Duration (the whole time they needed to finish the interaction with the Galaxy Explorer), the Date the user was created and some information that can be added in the table from the user of the web application as shown in Figure 4.12. Specifically, the Gender of the user, the Age of the user and the two variables that can be extracted after the GEFT test.



User Name	Duration	Gender	Age	FD/FI	Test Score	Date
user-1	00:06:10	Female	14	-	-	1/23/2019
user-2	00:10:05	Male	13	-	-	1/23/2019
user-3	00:07:38	Female	12	-	-	1/23/2019
user-4	00:07:01	Female	12	-	-	1/23/2019
user-5	00:04:52	Male	12	-	-	1/23/2019

Figure 4.11 - The interface of the Review Data functionality

In addition, the researcher can view a more detailed review of each user by clicking their row in the table. The new page gives the researcher three new tables that are related with the selected user. The researcher can insert or change the personal information of the selected user by using the form shown in Figure 4.12. The form does not have to be fully completed to be submitted, in our case we did not import any information that was related with the GEFT test. After pressing the “Submit Changes” button the Database is going to be updated with the new data. Moreover, the more important data of each user are presented inside the three dropdown tables. The first table with the title “All Actions” displays every action the user did from the moment Galaxy Explorer started in HoloLens. The second table which is called “Task Completion” displays every air-tap the user did in the Galaxy Explorer and also the object they tapped. The final table, called “Frequency of Actions” displays the names of all the actions the user did once and how many times they did every action.

Figure 4.12 - The interface of the Detailed Data of user-2

4.4.4 Excel Extraction

The final requirement of the website was to export the data in excel files. Every table that was described above has a button called "Export". When the button is pressed it automatically downloads the selected table in a .csv format.

On the "Review Data" page, where all the users are presented there are two buttons, "Export Desired" and "Export Tapped" (view Figure 4.11), both of them download a .csv file, with a very similar format. Every row of the file is related with one user. As shown in Figure 4.13 the first seven columns are common in both files. They are general information about the user, starting from the username, age, gender, the two variables that are extracted from the GEFT test, the duration of the user's interaction and the amount of actions. In addition, for each action the files have two types of columns. The title of the first column is the name of the action and each record, contains the amount of times the user did the mentioned action and the contents of the second column is the first time the action occurred.

	Username	Age	Gender	Feel	TestScore	Duration	NumOfActions	TapPresse	Time	TapPressedBack	Time	TapPressedEarth	Time	TapPressedEarthFocus	Time	TapP
2	user-1	14	Female	-	0	0:06:10	398	-	-	10	0:01:37	2	0:02:15	-	-	-
3	user-10	11	Male	-	0	0:08:19	580	-	-	13	0:02:16	-	-	4	0:02:51	-
4	user-11	9	Male	-	0	0:07:36	617	1	0:00:17	8	0:01:41	-	-	3	0:01:50	-
5	user-12	12	Female	-	0	0:10:06	482	-	-	8	0:02:43	-	-	1	0:02:58	-
6	user-13	10	Female	-	0	0:07:38	382	-	-	9	0:02:27	-	-	5	0:02:49	-
7	user-14	9	Male	-	0	0:09:22	685	-	-	9	0:03:14	-	-	4	0:02:28	-
8	user-15	11	Male	-	0	0:06:45	302	-	-	11	0:02:45	-	-	3	0:00:31	-
9	user-16	11	Male	-	0	0:10:01	571	-	-	12	0:04:10	-	-	3	0:04:23	
10	user-17	15	Female	-	0	0:09:05	613	2	0:00:14	9	0:02:00	2	0:02:24	2	0:08:57	-
11	user-18	10	Male	-	0	0:09:46	547	7	0:04:12	6	0:04:54	-	-	4	0:00:15	-
12	user-19	10	Female	-	0	0:09:56	495	-	-	17	0:00:18	-	-	4	0:02:16	-
13	user-2	13	Male	-	0	0:10:05	406	-	-	11	0:02:29	4	0:03:22	8	0:03:16	-
14	user-20	11	Male	-	0	0:07:40	392	-	-	8	0:02:08	2	0:02:31	1	0:07:21	-
15	user-3	12	Female	-	0	0:07:38	428	-	-	13	0:02:26	-	-	5	0:02:46	-
16	user-4	12	Female	-	0	0:07:01	332	-	-	9	0:00:54	-	-	4	0:00:16	-
17	user-5	12	Male	-	0	0:04:52	433	-	-	9	0:01:38	-	-	2	0:01:51	-

Figure 4.13 - actionPerUser.csv file format

The button “Export Desired” downloads a file called actionPerUsersDesired.csv and contains every object that has been desired from each user. The format of the file is similar with the one shown in Figure 4.13 with the difference that the action column is the action every user made, that starts with “desiredTarget”. The button “Export Tapped” downloads a file called actionPerUsers.csv and it contains every object that has been tapped by each user. In Figure 4.13 it is representation of the file with fifteen users and the action column is all the actions every user made that start with “TapPressed”.

4.5 Website Development

4.5.1 Tools

The website was built using VS Code, HTML, CSS, JavaScript and PHP. First but foremost, a throw-away prototype of the website was made, to make sure that the layout was defined and to split the information into windows. After a meeting with my co-supervisor, the prototype of the website was finished and the front-end was implemented using HTML and CSS. The front-end had to be simple. The main color had to be white to help the user concentrate on the information and to not get distracted while analyzing their data. There are three main colors in the website that were found from the image in the home page (Figure 4.14), #f7f6f6 for the background of every page, #d48b47 for the main titles and lastly #30303c which is the color of the header of the page and of each table.

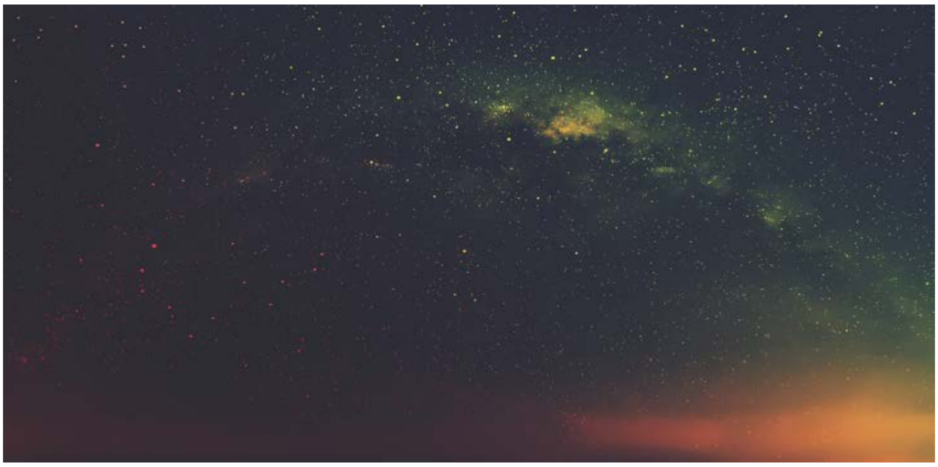


Figure 4.14 - Home page background image

The main items in the website are the tables to display the data and the buttons to extract the excel file or to delete all the data. The functionality of the website is implemented using JavaScript, the interface has its own ”.js ” file and “.php” files. The “.js” files have the functionality of the website. For instance, the reading of the Log File is implemented in a “.js” file and the connection with the database with a “.php” file.

The connection with the database was implemented using PHP. To create the database, I used XAMPP which provides a local host server with a database infrastructure. All the files are .php to make the extraction and import of data easier. The data are fetched from the database into the tables automatically every time a refresh occurs and the tables are updated with the click of the button “Submit Changes”. To fetch the data and display them in the tables a MySQL query requests the needed information from the database and with a while loop in PHP, everything is displayed in each row. The small forms were created in HTML and as a placeholder they must display the value that exists in the database for each record they represent, so php was used to display that data.

Too implement the main two buttons that extract the data in .csv files, a series of queries were implemented and the data are extracted with the help of PHP, JavaScript and Ajax.

4.5.2 Problems

To implement the website fully only a few minor problems appeared. The display of the data and the architecture of the information was important and to perfect the way they are presented, it was necessary to have extra meetings with my co-supervisor to make sure their usability. The most important feature of the website are the data. The way the data are collected was important, so the separation of the log file was a delicate procedure, to make sure that every information for the user was easily extracted and every table in the database is connected as needed with the other tables.

Another important part was the extraction of the csv file. The problems that I faced on the extraction of the file was the way to present the data as simple as possible to help the user for their analysis. The extraction had to be in a certain way and it had to include all the users together. To achieve the most useful format of the .csv file we had to take into consideration all the data of the previous research on Galaxy Explore and the way the database is structured.

Chapter 5

User Study on HoloLens

5.1 Introduction

In this chapter it is going to be described the user study with children. To describe the user study, first of all we must take into consideration the literature and the reason the study was selected. The user study is going to be compared with a previous study that was conducted with adults. In addition, the main part of this chapter is to look in the hypotheses, methodology, results of the user study with children and the comparison with the adults.

5.2 User study structure

5.2.1 Hypothesis

The study was designed based on the following hypothesis:

H0: There are no differences between adults and children towards the i) time spent, ii) number of unsuccessful taps, iii) objects viewed, iv) number of times the target item viewed before selected, for achieving each target object.

5.2.2 Training Phase

The study was performed with children, so the training phase was the most important part. HoloLens is perceived as a new gadget for children, especially in Cyprus. Having that in mind it was very important to explain to the participants the way HoloLens works and how they can interact with it. To make sure that the participants understood the way they can interact with HoloLens, we explained the different gestures and how to use them and an application about gestures was played by the participants. The application is initially on HoloLens and it is called “Learn Gesture”, It explains the gestures with different holograms, guides users to try and get used to gestures and gives them as much time as they need, so they can feel comfortable.

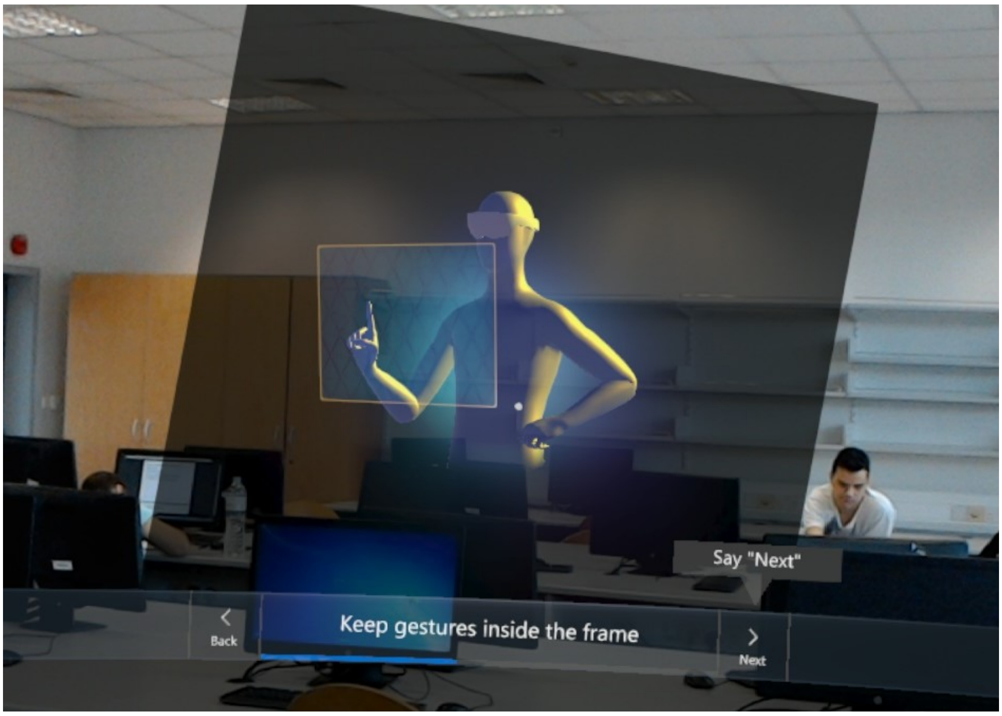


Figure 5.1 - Screenshot of Learn Gestures

5.2.3 Basic Phase

The basic phase has the same tasks as a previous study which performed with adults, to make sure that the results can be comparable. Participants had to interact with Galaxy Explorer on HoloLens and complete the tasks that they were instructed to do, so specific data can be extracted. In addition to the Log file, that is extracted from Galaxy Explorer through the logger, we collected qualitative data through observations about the way the participants reacted, the difficulties they have found, but also the comments they had during the basic phase.

The user study was in Greek but all the instructions on the applications were in English. If the participants were not comfortable with English everything had to be translated to help them interact with HoloLens. Also, to find the object of each task, if the participant did not know the translation or the way the object is written, a translation was made for them and sometimes the spelling of the word.

Tasks:

1. Find “Solar System” and select it
2. Find the “Sun” and select it
3. Using “Grab” from the toolbox move the sun wherever you want
4. Go back
5. Find “Earth” and select it
6. Using “Zoom” in the toolbox zoom in or zoom out on earth
7. Go back
8. Find “Uranus” and select it
9. Using “Tilt” in the toolbox rotate Uranus
10. Go back
11. Go back, again
12. Find “Galactic Center” and select it
13. Find “Sagittarius A*” and select it
14. Go back to find the “Earth”
15. “Bloom” to close the application

5.2.4 Questionnaire

The log file and the observations were not enough to make sure that we understood the emotional state of our participants while interacting with HoloLens, so to define usability issues on HoloLens we conducted a questionnaire. The questionnaire took place after the basic phase and every question had to be read at loud to make sure that our participants understood.

Some of the questions used the Geneva Emotion Wheel (GEW) which helps the researcher to understand the emotional state of the participants by asking them to point at their emotional state in the wheel at the Figure 5.2. The GEW we selected was only for children, as the colors were bright and main emotions were simple enough for them to know. However, we explained the emotions on the wheel, to make sure that everybody understood.

The questionnaire was translated in Greek and the participants were asked all questions out loud, while the researcher was writing down the replies, so children did not have to write anything.

<u>The Questionnaire:</u>

1. Is it your first time you are using HoloLens?
2. What did you like more about HoloLens?
3. What made you more impressed?
4. What made it harder to use HoloLens?
5. What you did not like on it's use?
6. What other electrical gadgets do you use in your everyday life?
7. From a scale of 1 to 5 how hard did you find the gestures? (scale 1-5 very hard – very easy)
8. Was there a gesture that was harder for you?
9. From a scale of 1 to 5 how hard/tiring did you find the selection of an object with your head movement and gaze? (scale 1-5 very hard – very easy) (scale 1-5 very tiring – not tiring at all)
10. From a scale of 1 to 5 how hard/tiring did you find the selection of an object with your hands? (scale 1-5 very hard – very easy) (scale 1-5 very tiring – not tiring at all)

11. Was there a moment in the study that you were trying to do something but you could not from the first try? If your answer was yes, what were you trying to do?
12. Was there a moment in the study where you were tired or bored and did not want to continue?
13. Would you want to use HoloLens again?
14. Can you think of any other use of HoloLens?

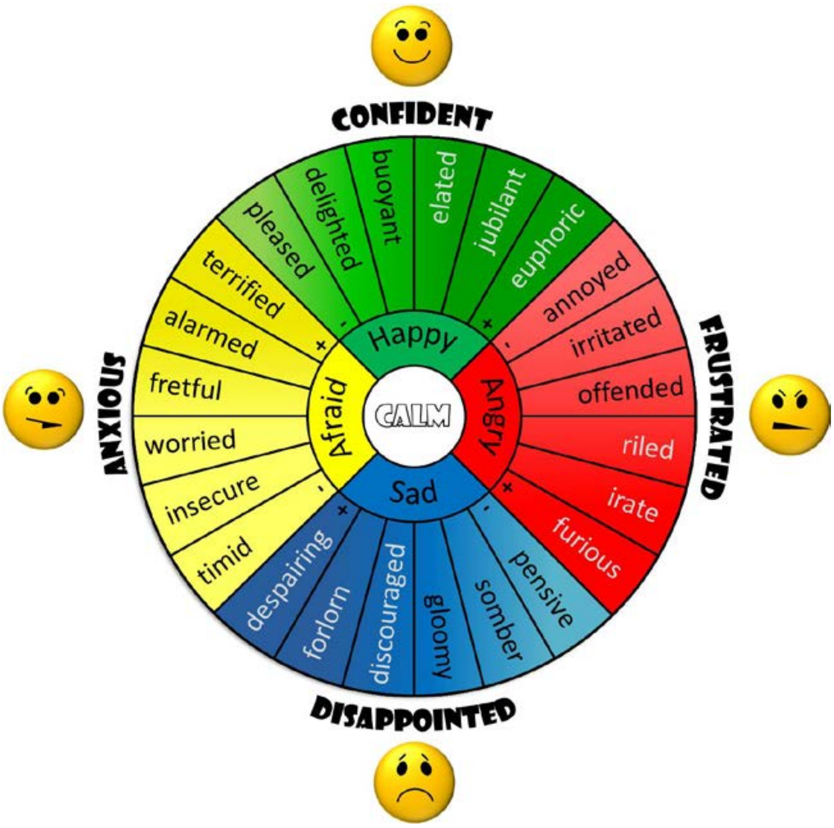


Figure 5.2 - Geneva Emotion Wheel of children

15. Using the wheel above, how would you describe your emotions while using HoloLens?
16. Using the wheel above, how would you describe your emotions while trying to do something that you find hard to do?
17. Using the wheel above, how would you describe your emotions while succeeded to do something that you found hard at first?

5.2.5 Consent Form

Since the study was with children a Consent form had to be made, to make sure that the guardians were informed about out study, the methodology we were using and the data we were going to collect from the study. The form was sent in Greek:

Dear gardeners,

I am Antrea Chrysanthou, I study Computer Science at the University of Cyprus. In context of the thesis that I have to conduct with the oversight of Dr. Styliani Kleanthous, who is a visiting lecturer on the department of Computer Science in the University of Cyprus.

<u>What is our research:</u>

In our research the children will have the opportunity to experience one of the latest technologies on mixed reality on HoloLens. The research was going to conducted with children 8 to 15 years old, using HoloLens. HoloLens is an electrical headset made with Microsoft which connect a virtual reality with the reality, using holograms. The aim of this research was to compare children's reactions with the reactions adults had in the same experiment that already happened.

The research which the users are participating in, is divided into 3 parts

1. Training Phase: To make sure that the children can feel confident with HoloLens and learn how it works.

2. Main Phase: The children are going to interact with a virtual world where it is going to be presented to them a hologram of our galaxy and solar system. In that phase children are going to be asked to recognize some planets.

3. Questionnaire: Finally. Children will have to answer to some questions about their experience with the user study.

Children’s participations is voluntary:

The children can take a break whenever they want to, but also they can stop the user study.

Information we want to collect:

The user study is anonymous. The actions the users are going to make in the course of the experiment are going to be observed and write down.

How we ensure your privacy

We may publish research papers and reports that may include you comments and actions, but your data will be anonymous. This means your name and identity will not be linked in our research reports to anything you say or do.

Your consent

Please sign this form showing that you consent to us collecting these data.

I give my consent (please tick all that apply):

- ☐ For people to observe my child during the research.
- ☐ For my child’s interaction data to be tracked.

If you want to withdraw your consent in the future, contact the persons named below who will destroy any personal data we hold about you (such as the recordings). Otherwise, we will delete your personal data after two years.

Antrea Chrysanthou (antreachrysanthou@gmail.com)

Dr. Styliani Kleanthous (stellak@cs.ucy.ac.cy)

Participant’s Name ____

Signature ____

Date ____

5.2.6 Pilot

Because the tasks of the basic phase were created for adults, a pilot test was conducted to make sure that the tasks were not too difficult for children. The pilot test happened with only one female participant. She is eleven years old and had never used HoloLens. She was asked to finish every task from the training phase and the basic phase. From the observation of the pilot, the tasks for the basic phase were understood to be simple enough for children and a few notes where made on the way the training phase had to be improved. The training phase was the most important part in the pilot, after the pilot it became clear that it had to be more emphasized to help the children understand how they can interact with the HoloLens.

After the pilot and a meeting with the co-supervisor the structure of the study was complete.

5.3 User study

5.3.1 User Study Description

The user study happened in one week. The consent forms were sent to every guardian, to read the requirements and fill the forms. After receiving the consent forms, we set a program so that every child was going to participate in the study for thirty to forty-five minutes. The study ended up having twenty participants from eight to fifteen years old. Every step that was descripted on the “User study structure” was implemented.

5.3.2 Data Analysis and Comparison with Adults

The data analysis focused on *the time* that each participant needed to achieve each target object, *the gaze behavior* they followed to locate the item, according to their gaze data within HoloLens and the *tap gesture use*. These were analyzed based on the participants' age (adult/child) and the difficulty level of each target object.

In order to test our research hypothesis, we initially run an Independent Sample T-Test between adults and children with respect to the total time in seconds they required to complete the task. Adults (M: 523.45, SD: 186.43) took more time to complete the task compared to children (M: 485.95, SD: 103.12) The results revealed no significant differences in the total time the users in the two groups required to complete the tasks ($t(49) = 0.820$, $p = .416$). Furthermore, to investigate differences in the gaze behavior of the participants (how many objects the participants viewed while searching for a target object), an Independent Sample T-Test was run. There was a statistical difference between the two groups of users in their gaze behavior before selecting a target ($t(47) = -2.32$, $p = 0.025$) Adults viewed significantly less objects before selecting a target overall (M: 19.39, SD: 17.26) compared to children (M: 39.89, SD: 43.89). The number of tap gesture use was examined similarly to above. No statistically significant results were revealed in the number of tap gestures for selecting Uranus. However, when examining the number of tap gestures performed for locating Sagittarius ($t(47) = -2.844$, $p = 0.007$) and Earth ($t(49) = 4.700$, $p = 0.000$) objects there was a significant statistical differences between adults and children, with adults using less taps for selecting Sagittarius and children using less taps for selecting the Earth.

It was interesting for us to also look whether there are any differences between genders in the two groups. Independent Sample T-Test revealed no differences between genders in adults nor children participants. Similarly, we explored the differences between younger and older children (aged 8-11 and 12-15). There were no statistical differences in their interaction behavior based on the parameters we have examined.

5.3.3 Qualitative Data Analysis

While the children were interacting with HoloLens some observations were made, to have a better understanding of their experience.

A very significant observation is that most of the children under 10 years old were more stressed than older children, and this was later confirmed from the questionnaire. However, the stress of the younger participants was not really affecting their interaction, as they were following the instructions and interacting with HoloLens as better as they could.

Equally significant was the fact that most of the children found the hand gestures hard, but it was observed that their interaction improved with time. User 17 specifically mention that *"At the beginning I could not tap but that happened because it was my first time. After the tutorial I could tap the holograms easily."* It was also observed that most of the users could not zoom from the first time, specifically one user found it that hard that they did not wish to try zooming again, and they continued the experiment with the next actions. Furthermore, nobody remembered the "bloom" gesture and when they were asked to "bloom" to close the program, most of them were looking at the toolbar in Galaxy Explorer to find a bloom icon or they asked for guidance. Very significant was the fact that most of the children could understand the way their head had to move so they can look around and interact with as many holograms as possible, although there was a very small number of participants that found it hard to move around, to understand what the dot (their gaze) is doing and how to make the dot follow what they are looking at.

Moreover, most of the participants were excited to use HoloLens for the first time and when they were asked what they liked, most of them answered with amazement on the way they could communicate and interact with HoloLens. User 6 noted *"It is like VR, but HoloLens has a camera and it can see my hands, so I can select the planets."*. Several children were also amazed about the fact that they can hear the instructions without headphones.

In terms of the tasks it was observed that the participants could easily view the items that were asked to. A small number of children prefer to watch around or listen to the voice informing them about the planets, in contrast to most of them who wanted to finish the task so they can continue. It was also noticed that only 3 participants could find Uranus without asking or getting any guidance. Also, 3 participants were able to find the earth when they were not in our Solar System, most of them panicked and asked for help because they could not see the earth in their screen.

Finally, it was noticed that HoloLens has a massive problem with the participants that could not take off their glasses. In that situation, the setup of HoloLens was very hard and time-consuming, the participants had to hold the HoloLens in one place all the time and this could affect the interaction process. Also, most of the children after approximately 30 minutes they were tired because the HoloLens started feeling heavy on their head. Most of them did not mentioned the distress they felt because they did not want to stop the experiment but when they were asked to note something, they did not like about HoloLens their comments were that it was too tight or too heavy on their head. *“It was too heavy on my nose.”* -User 19, *“It was too heavy that I wanted to sit.”* -User 18.

5.3.4 Geneva Wheel Questionnaire Answers

An interesting aspect of this study is the data collected through the questionnaire regarding the children’s emotions during their interaction with Hololens. As can be seen at the Table 5.3 for Question 1(Using the wheel above, how would you describe your emotions while using HoloLens?) most of the children participants were positive, selecting emotions in the Happy part of the wheel (90%). Only 10% (2 children) selected ‘timid’ since they were feeling anxious while interacting with Hololens. Furthermore, we asked the children who had a difficulty in pursuing the task (Using the wheel above, how would you describe your emotions while trying to do something that you find hard to do?). The children expressed their anxiety, disappointment and frustration. 35% felt anxious selecting one of the followings terrified, insecure, worried, timid. 20% were frustrated during a task that they found hard to do.

	Q1	Q2	Q3
u01	elated	worried	pleased
u02	elated	timid	-
u03	jubilant	-	-
u04	jubilant	annoyed	jubilant
u05	elated	-	-
u06	pleased	-	-
u07	euphoric	somber	jubilant
u08	euphoric	furious	elated
u09	euphoric	-	-
u10	euphoric	timid	euphoric
u11	timid	terrified	euphoric
u12	timid	annoyed	elated
u13	pleased	-	-
u14	buoyant	annoyed	buoyant
u15	elated	insecure	euphoric
u16	delighted	pensive	elated
u17	jubilant	pensive	euphoric
u18	elated	timid	euphoric
u19	euphoric	timid	euphoric
u20	euphoric	-	-

Table 5.3 - Geneva Users' Answers

5.3.5 Limitations

While doing the user study we faced some problems that could affect the data. Firstly, HoloLens appeared to be heavy for the children, at the end of the experiment most of the children ended up having red marks on their nose or forehead and some of them expressed their dissatisfaction on the weight of HoloLens while taking it off. In addition, HoloLens could not work on people that were having eyesight problems and need to wear their glasses. They could not fit their glasses in to the headset and the could not see without them. Also, even if the participants did not have eyesight problems at the end most of them complained that their eyes hurt after interacting with HoloLens.

Furthermore, while interacting with Galaxy Explorer we faced bags. For instance, sometimes the toolbar did not work right. “Back” button was missing, or the button were not clickable. On that times we stopped the interaction and started over. Fortunately, the problematic interface was detected at the beginning before the user started the main tasks.

Last but not least, the initial position of the participants was standing up and interacting with HoloLens so they can move around. However, there were children that did not want to stay standing up and requested to sit in the middle of the experiment. They could sit whenever they want but maybe the fact that they were sited could interfere with our results.

Chapter 6

User Study with Emotiv EPOC+

6.1 <u>Introduction</u>

In this chapter is going to be descripted the user study that was conducted on Emotiv EPOC+ and MineTest. The following subchapters are going to give detailed explanations on the way the study was conducted, explain the sandbox game called MineTest and its logfile and analyze the data of the study.

6.2 <u>User Study Structure</u>

6.2.1 Research Question

Before conducting the study, we set a research question that we wanted to answer:

Is there a pattern in users' emotional state?

6.2.2 Sandbox game MineTest

A sandbox is a type of a gaming style, in which the user has very little limits. Having that in mind a sandbox game lets the user interact with the environment freely without interfering in the user's decisions while playing.

Figure 6.1 - Sandbox game MineTest

MineTest is an open source sandbox game, that creates a new environment and lets the user interact with it. The environment is a simple low poly 3D world available for the user to build everything that the user wants. MineTest has a variety of modes and worlds so that the users can change the scenery. The game lets the users search for the resources that are needed to build the object that they want. MineTest is the open source version of Minecraft, with the huge difference that MineTest exports a log file that has a detailed description of the user's interaction while playing.

The log file is a ".txt" file that starts with the date and time the user joined the game and continues with the user's interaction. The user can do five different actions in the game.

1. Digs: the user uses a tool to dig or break an object in a specific position

2. Places: the user uses a tool to build or place something is a specific position

3. Crafts: the user uses a combination of tools to create new tools or elements

4. Takes: the user takes a new tool from the repository. User's repository contains every tool and object that can be provided to the user without any limit.

5. Activates: the user activates a new tool and it is ready to be used.

Every action is followed by the time it occurred and the coordinates of the action that have the format (x, y, z). Every action, coordinate and time is important cause they might reveal a pattern.

```
2019-02-23 13:51:31: ACTION[Server]: user1 [127.0.0.1] joins game.
2019-02-23 13:51:31: ACTION[Server]: user1 joins game. List of players: user1
2019-02-23 13:51:46: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,6)
2019-02-23 13:51:46: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,7)
2019-02-23 13:51:46: ACTION[Server]: user1 digs default:dirt_with_grass at (-21,11,8)
2019-02-23 13:51:46: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,8)
2019-02-23 13:51:47: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,9)
2019-02-23 13:51:47: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,10)
2019-02-23 13:51:47: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,11)
2019-02-23 13:51:47: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,12)
2019-02-23 13:51:48: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,13)
2019-02-23 13:51:48: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,14)
2019-02-23 13:51:48: ACTION[Server]: user1 digs default:dirt_with_grass at (-22,12,15)
2019-02-23 13:51:57: ACTION[Server]: user1 takes default:aspen_tree from creative inventory
2019-02-23 13:51:59: ACTION[Server]: user1 takes default:acacia_tree from creative inventory
2019-02-23 13:52:00: ACTION[Server]: user1 takes default:acacia_wood from creative inventory
2019-02-23 13:52:06: ACTION[Server]: user1 takes xpanes:bar_flat from creative inventory
2019-02-23 13:52:12: ACTION[Server]: user1 takes default:brick from creative inventory
2019-02-23 13:52:19: ACTION[Server]: user1 places node default:brick at (-7,10,24)
2019-02-23 13:52:20: ACTION[Server]: user1 places node default:brick at (-6,10,24)
```

Figure 6.2 - Snap shot from MineTest log file

6.2.3 Training Phase

The participants had to go through a small training on how to play on MineTest. However, most of the participants already knew how to play so the training phase was skipped. For the participants that did not know how to play on MineTest it was explained to them how to interact with the game and if they wanted they could read the given instructions. (Almost all the participants that did not know how to play on

MineTest did not want to read the instructions and they were okay with the instructions from the researcher.)

- Walking: You can move your player with the arrow keys on your keyboard. The up arrow moves you forward, and the down arrow moves you backward. The left and right arrows move you to the left or right. You can use the mouse to rotate the camera.

- Camera Controls: To control your camera view is important when you are building and want to have a close look of the objects. You can change the camera view by using the F7 key. You can see below the how the camera looks like when you press F7 key.

- Inventory: An inventory is primarily used to store item stacks. There are other uses, such as crafting. An inventory consists of a rectangular grid of item slots. Each item slot can be either empty or hold one item stack. Item stacks can be moved freely between slot and slot, given that the destination slot is either empty or of the same item type.

Taking: You can take items from an occupied slot if the cursor holds nothing.

- `Left click`: take entire item stack
- `Right click`: take half from the item stack (rounding up if uneven)
- `Middle click`: take 10 items from the item stack

Dropping: You can drop items onto a slot if the cursor holds 1 or more items and the slot is either empty or contains an item stack of the same item type.

- `Left click`: drop entire item stack
- `Right click`: drop 1 item of the item stack
- `Middle click`: drop 10 items of the item stack

Exchanging: You can exchange items if the cursor holds one or more items and the destination slot is occupied by a different item type.

- `Left`, `middle` and `right click`: exchange item stacks from cursor and from selected item slot

Throwing away: If you hold an item stack and click with it somewhere outside the menu, the item stack gets thrown away into the environment.

- <u>Building/Positioning:</u> Using refers to a specific activity with a block. The kind of activity depends on the block. Not all blocks can be used.

  By default, using is done by clicking with the `right mouse button` on the block that shall be used. Building, also called placing, is the activity of placing blocks next to other blocks. It is one of the most basic things you can do in MineTest.

  To build, one must wield something which can be built, point to something which can be built to and press the build key (`Right mouse button` by default). Most blocks can be built. Building is, unlike mining, always instantly done. On blocks which react on a right-click (e.g. Chest, Furnace, Sign, etc.), you have to press Sneak+`Right-click` instead.

  Use/build: Right mouse button

  If the pointed thing is usable (example: Chest), you use it, otherwise you attempt to build at this block.

There was no training phase for the Emotiv EPOC+ as the only thing users needed to know was that their emotional state was recorded.

6.2.4 Basic Phase

After the training, the Emotiv EPOC+ had to be adjusted on the participant's head. The researcher had to make sure that every sensor has a green light so that the data can be trustworthy. Then, the researcher starts the recording from EmotivPro. The users have maximum one hour to build whatever they want in a random MineTest world without any limits from the world or the experiment.

6.2.5 Questionnaire

Interaction with MineTest:

1. Have you ever played MineTest or MineCraft? Yes / No
2. Did you find any difficulties while playing MineTest? Yes / No
3. If your answer on the previous question was yes, can you note the moment that you find difficult?
4. Did you enjoyed playing MineTest? Yes / No
5. If your answer on the previous question was yes, can you note the times that you enjoyed the game most?
6. Did you manage to build everything you wanted in the 1 hour that was given? Yes / No
7. What did you build?

Interaction with Emotiv EPOC+:

1. Were you stressed because your emotional state could be tracked? Yes / No
2. Was there a time when you were feeling stressed? Yes / No
3. If your answer was yes, can you note the reasons you were feeling stressed? Can you note the time you were more interested in the game?
4. Can you note the time you were more relaxed while playing?
5. Can you note the time you were more excited while playing?
6. Is there something that bothered you with Emotiv EPOC+? Yes / No
7. If your answer was yes, can you note the reason?

6.2.6 Consent Form

What this study is about

The purpose of this study is to compare the creativity phase and the emotional state of the participants while creating something of their choice in MineTest.

Your participation in this study is voluntary

You can take a break at any time. Just tell the researcher if you need a break. You can leave at any time without giving a reason.

Information we want to collect

To capture your emotional state, a headset called Emotiv EPOC+ is going to be used and extract your feelings. In addition, to have detailed conclusions about your interaction with the game, we are going to extract a log file that contains the actions you made while playing.

How we ensure your privacy

We may publish research papers and reports that may include your comments and actions, but your data will be anonymous. This means your name and identity will not be linked in our research reports to anything you say or do.

Your consent

Please sign this form showing that you consent to us collecting these data.

I give my consent (please tick all that apply):

☐ For people to observe me during the research.

☐ For my interaction data to be tracked.

☐ For my emotional state data to be tracked.

If you want to withdraw your consent in the future, contact the persons named below who will destroy any personal data we hold about you (such as the recordings). Otherwise, we will delete your personal data after two years.

Antrea Chrysanthou (antreachrysanthou@gmail.com)

Dr. Styliani Kleanthous (stellak@cs.ucy.ac.cy)

Participant's Name ______________________________

Signature ______________________________

Date ______________________________

6.3 User Study

6.3.1 User Study Description

The study that was conducted was with fourteen participants, four women and ten men in the age range of twenty to twenty-five. The participants were connected with Emotiv EPOC + so we could collect their emotional state and they were asked to create something in MineTest for maximum one hour. If the participants finished the task earlier, they were free to stop. After their interaction with the game they were asked some questions about their interaction, their emotional state, their creation and their experience with Emotiv EPOC+. For each user we extracted the two files from EmotivPRO and the log file from MineTest.

6.3.2 Data Analysis

The data that was collected from Emotiv EPOC+ and MineTest was very detailed and general, so they had to be divided and saved in a specific format. From the data that was extracted from Emotiv EPOC+ we only used the file named "recordingName_date_timestamp.pm" (Go to Chapter 3.6.3 to read more about the file). From the file we collected the columns that started with "SCA_".

Thus, in order to analyze the overall users' emotional response while interacting with MineTest we calculated the mean of each emotion for each user. The results can be seen in Figure 6.4 and in Figure 6.5 we transformed the data to a chart.

	SCA_ENGMean	SCA_VALMean	SCA_MEDMean	SCA_FRUMean	SCA_FOCMean	SCA_EXCMean	SCA_LEXMean
User1	0.601394391	0.581309526	0.321157638	0.581809872	0.47962797	0.316532573	0.318738227
User2	0.620969022	0.664296454	0.39041013	0.999447	0.839019495	0.95694	0.964918924
User3	0.494135617	0.804558435	0.693894173	0.854289403	0.477735972	0.448255653	0.449479411
User4	0.736223298	0.766165498	0.286072903	0.994340169	0.556017542	0.27794815	0.281027674
User5	0.664962794	0.592074504	0.302941	0.551116475	0.429115936	0.217503963	0.226038979
User6	0.661861547	0.583655022	0.351717726	0.551276283	0.33626284	0.12508805	0.130562155
User7	0.4758584	0.565569219	0.269957006	0.479397402	0.553680876	0.442429135	0.443940133
User8	0.609438754	0.55673433	0.302941	0	0.590169588	0.482264106	0.484288304
User9	0.649900486	0.767846838	0.302941	0	0.802224559	0.829705243	0.836131486
User10	0.598617669	0.658716599	0.303162828	0.128872263	0.915218788	1	1.00833
User11	0.65706619	0.597289692	0.24662889	0.488092032	0.383224261	0.157450087	0.163582196
User12	0.655319899	0.557152195	0.265855828	0.341594408	0.43816971	0.357681314	0.354968639
User13	0.732930286	0.64596933	0.354329271	0.530505862	0.421939015	0.290802912	0.295709905
User14	0.594875697	0.595425214	0.280659505	0.338218725	0.401880128	0.227001849	0.229451715

Figure 6.3 - Snapshot of the data mean table

There were no significant similarities based on the emotional response of each user while interacting with the game as shown in Figure 6.4. Overall, each user appears to have a different emotional experience than the rest. Although, some similarities can be seen when observing each emotion independently. For example, very significant is the fact that SCA_EXCMean and SCA_LEXMean have almost the same values and this appears very clearly in the chart (Figure 6.5). In addition, SCA_ENGMean and SCA_VALMean appear to have very close values on most of the users. For instance, user4 and user14 have almost the exact same values whereas in user3 the values seem to have the most difference between them. Last but not least, in SCA_LEXMean and SCA_FOCMean we can observe a similar pattern as the previous observation where the two metrics have very similar values except from user4, user5 and user6.

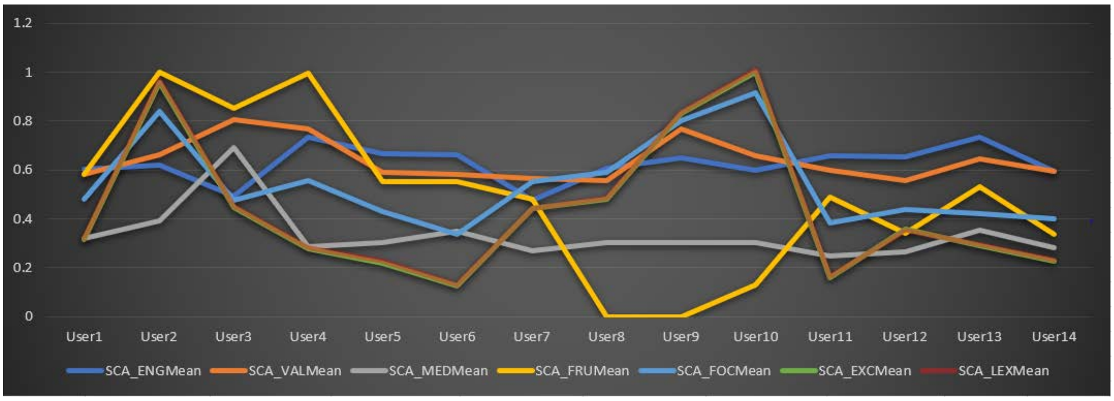


Figure 6.4 - Chart from the data mean table

In addition, the log file that was extracted from MineTest was then divided to tasks. We manually divided users' interaction with the game in different sections depending on the activity they were doing. Finally, we combined the two mentioned files in one. The file is named "username_minetest_emotive_onlySCA.csv" and it contains the title of each activity section (from MineTest's logfile) and the results from the Emotiv EPOC+, that occurred the specific time period.

Joins the game								
Timestamp	Time	SCA_ENG	SCA_VAL	SCA_MED	SCA_FRU	SCA_FOC	SCA_EXC	SCA_LEX
1.55E+09	1:51:28 PM	0.829309	0.366473	0.263396	0.469766	0.381549	0.128095	0.204403
Digs grass for 3sec (13.51.46-13.51.48)								
Timestamp	Time	SCA_ENG	SCA_VAL	SCA_MED	SCA_FRU	SCA_FOC	SCA_EXC	SCA_LEX
1.55E+09	1:52:39 PM	0.849319	0.474653	0.258168	0.547201	0.410909	0.207835	0.198172
Interacts with invetory for 15sec (13.51.57-13.52.12)								
Timestamp	Time	SCA_ENG	SCA_VAL	SCA_MED	SCA_FRU	SCA_FOC	SCA_EXC	SCA_LEX
1.55E+09	1:52:49 PM	0.855505	0.468242	0.260308	0.436709	0.364592	0.195764	0.190395
1.55E+09	1:52:59 PM	0.815411	0.438094	0.245163	0.383385	0.349416	0.166449	0.182312
1.55E+09	1:53:09 PM	0.800123	0.437255	0.254291	0.317874	0.329128	0.204017	0.185098
Places bricks, digs brigs or grass for 136 sec (13:52:19 to 13:54:35)								
Timestamp	Time	SCA_ENG	SCA_VAL	SCA_MED	SCA_FRU	SCA_FOC	SCA_EXC	SCA_LEX
1.55E+09	1:53:19 PM	0.823188	0.499381	0.289184	0.423725	0.38382	0.432784	0.232104
1.55E+09	1:53:29 PM	0.802054	0.457899	0.263594	0.529501	0.451477	0.269725	0.276248
1.55E+09	1:53:39 PM	0.741466	0.458252	0.2569	0.512321	0.443894	0.191234	0.267546
1.55E+09	1:53:49 PM	0.756966	0.496882	0.249648	0.583483	0.470281	0.279336	0.257162
1.55E+09	1:53:59 PM	0.725039	0.471764	0.265002	0.435934	0.421207	0.299568	0.273337
1.55E+09	1:54:09 PM	0.745728	0.478473	0.258831	0.446484	0.463975	0.492724	0.324101
1.55E+09	1:54:19 PM	0.717207	0.46076	0.253267	0.385538	0.440254	0.237209	0.332874
1.55E+09	1:54:30 PM	0.754	0.503426	0.258001	0.374137	0.413414	0.235395	0.300914
Selects a door and continues digging/placing brick and grass for 164 sec (13:54:46 to 13:57:30)								
Timestamp	Time	SCA_ENG	SCA_VAL	SCA_MED	SCA_FRU	SCA_FOC	SCA_EXC	SCA_LEX
1.55E+09	1:54:40 PM	0.793265	0.547198	0.287308	0.523673	0.482518	0.519367	0.330651

Figure 6.3 - Snapshot from the new file

6.3.3 Qualitative Data Analysis,

While the participants were interacting with MineTest and wearing the Emotiv EPOC+ their behavior was under observation to make sure that our data could be more complete.

From the questionnaire and the small introduction with our participants we realized that most of our participants already knew how to interact with MineTest and that is why there were no usability issues. Even the users that did not know how to play, they did not need more than three minutes to get used to the game. Having that in mind almost all the participants were excited to create something on MineTest. However, their reactions did not seem to change, and only some participants were fully expressing their excitement or disapproval when they discovered a new object in their inventory, or a different ability they could do. Specifically, User 3 said on the questionnaire "I was a bit stressed when it was night" and User 4 said "*I was very excited when I discovered that the inventory had obsidian glass doors*". In addition, only two people were bored while building on MineTest, and when one of them was asked why, he said, "*I could build all day, so I thought that it was okay to stop, as I was a bit bored*".

Finally, in terms of Emotiv EPOC+ after some time the sensors started to press the head of the user and they started having headaches. One user also requested to stop the experiment because he could not handle the pressure.

6.3.4 Limitations

While doing the user study we faced some problems that could affect the data and the user interaction. Firstly, because of the duration of the game some participants might got bored or lost interest on the game. For instance, two participants got bored and stopped playing the game a little bit earlier than the other participants.

In addition, a small problem that might interfere with our data, is the fact that most of the participants already knew how to play MineTest. This might affect us because if you are a brand-new user you are more interested on the environment and the ways you can interact with the game. Whilst if you already know what the interface looks like and how to interact with it, you are only interested on what you are going to build and not the way you interact with it. However, all the participants knew the existence of the game and its concept despite the fact they have never played.

Furthermore, there was a plethora of problems with Emotiv EPOC+ that might interfere with the user's experience. Firstly, the headset turned out to be a bit tight around the user's head. After some time wearing it, most of the users started to have a headache or just hurt their head on specific spots. Moreover, we had several issues with four of our participants. On one of the participants, while she was interacting with MineTest the Emotiv EPOC+ stopped the recognition little by little. On the following three, the data recording from EmotivPRO stopped while the user was interacting with MineTest and we have half of the data. Also, it was extremely hard to set the headset and have all the sensors on green mode and especially to find a woman that has thin hair so the indicators could stay active.

Finally, just because we are interacting and analyzing data that have to do with a human's emotional state, there are a lot of obstacles that can interfere. For example, a participant maybe is having a stressful day that might be showing in our data. This is a problem because the user's personal state does not have anything to do with the creativity state or the interacting state of the user.

Chapter 7

Conclusion and Future Work

7.1 <u>User study with HoloLens</u>

To compare adults' interaction with children's, while using HoloLens we conducted a user study. The user study had as participant twenty children from the age of eight to fifteen. Each experiment took thirty to forty-five minutes depending on child's experience. First, it was explained to the children, what is HoloLens and how they can interact with it, and then they could get started with "Learn Gestures" application. The participants were then asked to complete some tasks in "Galaxy Explorer". The tasks were based on a user study that was previously conducted with adults.

The user study took one week and the data were later analyzed and compared with the adults’. There were no significant differences between the two teams. In terms of tasks, it was observed that adults took more time to complete individual tasks. However, the total time had no significant differences. In addition, it was observed that adults view an object less times before selecting it. Lastly, in terms of the number of tabs per task, it seems that adults used “tab” less times to select "Sagittarius A * " and children used “tab” less times to select "Earth".

7.2 <u>User study with Emotiv EPOC +</u>

To find if there are any correlations between user's emotion and the actions in a game, we have conducted a user study.

To capture the emotional state of the user we used an EEG tool, called Emotiv EPOC+. The Emotiv EPOC+ collect six emotions, stress, engagement, focus, interest, excitement and relaxation. The study was conducted with fourteen participants from the age of twenty to twenty-four. It was asked from the participants to build whatever they want in a random environment in MineTest. Each participant had maximum one hour to complete the creation and interaction. After conducting the study, the data were divided, using only the columns that start with “SCA_” to wind any differences in users’ emotional response while playing.

7.3 Future Work

With this thesis we tried to cover the interaction differences between adults and children while using HoloLens. However, HoloLens is a very revolutionary tool that can help on further research on children’s MR interaction. For example, more research can be done with children which can discuss the interaction differences between 3D and 2D environments, taking into consideration not only usability issues but also the user experience.

In addition, we used Emotiv EPOC+ to capture the user’s emotional state while interacting with a sandbox game. While the gaming community is growing, a future research suggestion could be to learn more about user interactions while playing in a variety of age ranges. Our aim in the future study is to answer the research question “Is there a correlation between user’s emotional state and the actions the user performed?”. Moreover, the extracted data from Emotiv EPOC+ can also be used to make games more personalized, so user’s creativity could be enhanced while playing. Is there a correlation between user’s emotional state and the actions the user performed?

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