Universidade de Aveiro
2016

Departamento de Eletrónica,
Telecomunicações e Informática

Bernardo José Santos Marques

Veracity - Low cost physiology assessment tool using Virtual Reality.

Veracity - Ferramenta de baixo custo para avaliação fisiológica utilizando Realidade Virtual.

Universidade de Aveiro
2016

Departamento de Eletrónica,
Telecomunicações e Informática

Bernardo José Santos Marques

Veracity - Low cost physiology assessment tool using Virtual Reality.

Veracity - Ferramenta de baixo custo para avaliação fisiológica utilizando Realidade Virtual.

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia de Computadores e Telemática, realizada sob a orientação científica do Professor Doutor José Maria Amaral Fernandes, Professor auxiliar do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro e da Doutora Susana Manuela Martinho dos Santos Baía Brás, Investigadora do IEETA, Departamento de Eletrónica Telecomunicações e Informática da Universidade de Aveiro.

o júri / the jury

presidente / president	Prof. Doutor Joaquim João Estrela Ribeiro Silvestre Madeira Professor Auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro
vogais / examiners committee	Prof. Doutor Miguel Tavares Coimbra Professor Auxiliar do Departamento de Ciências de Computadores da Faculdade de Ciências da Universidade do Porto
	Prof. Doutor José Maria Amaral Fernandes Professor Auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro

acknowledgements

During the development process of this dissertation, various people were involved directly and indirectly. To all, I express my sincere gratitude. Nevertheless I would like to give some special thanks.

First, to my mentors, for providing me the opportunity to accomplish this dissertation, for all the means regarding the development process, as well as working space and amazing environment in IEETA, for the proof-reading of the entire work and finally for all the concern and motivation to help me achieve a better work every day. To Professor José Maria Fernandes, for his splendid personality, constant availability, and for all the scientific and technical exemplary guidance shown over time in overcoming all the obstacles along the way. To Doctor Susana Brás, for her human characteristics, combined with her constant support and the tremendous help provided along this work, for all the knowledge transmitted, and of course, for all the patience.

Next, to Professor Beatriz Sousa Santos and Professor Paulo Dias from DETI/IEETA, for all the lessons learned, for the possibility of combining my dissertation to one of their practical classes and finally their advices and words of support.

To all participants involved in the case study, thanks for taking a few minutes to provide the essential data to achieve important conclusions and for the relevant feedback. Especially to Raquel Sebastião, thanks for the extra effort to fight her spider phobia (it wasn't that hard right?) and in addiction to Professor Ilídio Oliveira for not only being two of my case study participants, but for always being open to provide helpful advices and support to my work.

To Sandra Soares from the Department of Education, for providing relevant help and feedback regarding the objectives of a monitoring solution in ambulatory scenarios.

To my lab partners, for all the helpful exchanged experiences, for all the important and silly talks that helped creating a good working environment.

To João Bernardo, for all our talks, mutual support, and of course for behaving like a crazy person every time he tried the system. If the system survived you, it will resist anything or any one.

In addition, to all the virtual spiders that suffered in the hands of some cruel individuals, I salute you.

To my parents, who I will never be able to repay for all the effort, dedication and hard work put into my education both in terms off academic level and as a person with strong values. For always being there when I needed them the most, for all their inexhaustible affection, words of tenderness, strength, for believing in my success and for the constant reminder in the rewards that come for trying to be better every day. Thanks for being a constant example and for making me see what is really important in life. I love you both very much.

To Diana, you become an amazing friend really quick, for your awesome personality, your sincerity, for having a place in your couch just for me and of course for putting up all the craziness and immature moments I share with your stupid and childish husband. Last, but not least in any way, to that guy I mentioned before, my dear and everlasting friend Michael. Thanks for the person you are every single day, for always being with me celebrating the amazing moments and overcoming the worst, no matter what or how far we are apart from one another. For your constant dedication, concern, moments of pure stupidity and laughter. For those big hugs and for all the confidence that you fill me with. You and I, are more than just friends, I'm really lucky to have you. Without you, nothing would be the same. You will always be like a brother to me.

It was a great pleasure to meet and work together with all of you. Thanks.

P.S. To all those who didn't believe in me, thanks for the constant reminder of who I am and what I wanted to achieve!

palavras-chave

Realidade Virtual; Realidade Aumentada; Sistema de Monitorização Portável; Fisiologia; Fobia de Aranhas; ECG; Baixo Custo; Unity; Leap Motion.

resumo

Distúrbios de ansiedade afetam muitos indivíduos, condicionando as suas rotinas. Um exemplo é o caso da fobia específica, um medo irracional em relação a um objeto ou situação. Indivíduos fóbicos sentem uma realidade distorcida, e geralmente, tentam evitar o elemento fóbico, o que intensifica o problema.

A evolução da tecnologia não só permite o desenvolvimento de soluções portáteis para a avaliação fisiológica e comportamental, criando novas possibilidades para imitar o mundo real utilizando Realidade Virtual (VR) fora do ambiente controlado de laboratório. Estudos recentes, descrevem a exposição a VR como sendo eficaz quando comparada com a exposição *in vivo*, sendo menos agressiva para o individuo.

Nesta dissertação, propomos o *Veracity*, um sistema portátil e economicamente acessível, para apresentação de estímulos virtuais a indivíduos fóbicos e interação com esse ambiente através do reconhecimento da mão e gestos enquanto a sua resposta fisiológica e comportamental é monitorizada. O principal caso de estudo do nosso sistema é a fobia de aranhas. O sistema é rápido de configurar, permite a recolha de dados fora do ambiente de laboratório e a exposição a estímulos, que permitem reações mais naturais. Simultaneamente, a reação do indivíduo é adquirida (ECG, HR, RR, VIDEO, Imagens, 3D *tracking*, etc.), utilizando recursos externos e duas aplicações para dispositivos móveis. *Veracity* suporta ainda a gestão dos dados recolhidos, para pós-processamento integrado com a *cloud*. A sua aproximação baseada em jogos e a sua capacidade de personalizar os estímulos virtuais, proporciona um nível de versatilidadeque, que promove a sua utilidade na prática clínica como uma solução para provocar reações naturais e monitorizarem individuos com fobias específicas.

keywords

Virtual Reality; Augmented Reality; Portable Monitoring systems; Physiology; Spider Phobia; ECG; HR; Low Cost; Unity; Leap Motion.

abstract

Anxiety disorders affect many individuals, conditioning their daily life routines. Specific phobia is one example of an anxiety disorder, which is an irrational fear towards an object, or situation. Phobics felt a distorted reality, and usually try to avoid the phobic element, which will only intensify the problem.

The evolution of technology and the miniaturization brought to the foreground not only allow the development of portable solutions for the assessment of psychological and behavior but also new possibility to mimic the real world likes Virtual Reality (VR) outside of the laboratory setting. Recent studies, describe Virtual Reality exposure as effective, when compared to in vivo exposure, with the benefit of being less aggressive to the phobic individual.

In this dissertation, we propose Veracity, an affordable and portable system, which relies on VR to present more ecological and virtual stimuli to phobic individuals while monitoring their physiological and behaviour response. We used spider phobias as the main case study of our system. While presenting the VR stimuli, using a game divided in a set of increasing difficulty levels, Veracity allows the interaction with the virtual environment through hand gesture. Simultaneously the individual's reaction is acquired (ECG, HR, RR, VIDEO, Screenshots, 3D objects tracking, etc.) using external resources and two smartphone applications. Veracity also supports data management for post processing integrated with the cloud. The gamification approach and its ability to customize the virtual stimuli provides enough versatility to foster its usefulness in clinical practice as a solution to monitor and elicit natural reactions from individuals with specific phobias.

I. Contents

II. List of figures

III. List of tables

IV. List of Acronyms

API – Application Programming Interface

AR – Augmented Reality

ECG – Electrocardiography

ET – Exposure Therapy

HDR – High Dynamic Range

HR – Heart Rate

IP – Internet Protocol address

MR – Mixed Reality

OS – Operating System

PC – Personal Computer

RR – Respiratory Rate

SDK – Software Development Kit

TTS – Text to Speech

USB – Universal Serial Bus

VE – Virtual Environment

VJ – Vital Jacket

VR – Virtual Reality

VRT – Virtual Reality Therapy

VRET – Virtual Reality Exposure Therapy

Wi-Fi – Wireless Fidelity, Wireless Internet

1 Introduction

Anxiety disorders affect more than 450 million sufferers worldwide [1]. One of the most common anxiety disorders is the phobia, which affects the daily lives of a large number of individuals [2], [3]. Phobia is the medical term associated to an irrational, persistent and intense fear towards a specific object, activity or situation [4]. Furthermore, the individuals suffering from this phobia recognize the fear as excessive and irrational, acknowledging that it strongly affects their daily life and social activity. Usually, phobic individuals avoid the phobic element or any circumstance or place where it can be present, which in turn will negatively reinforce the fear and perpetuates the phobia. To break the cycle, psychology therapy is advisable in order to learn how to face, and deal with the phobic element.

Exposure Therapy (ET) is a therapy where participants are encouraged to repeatedly approach the phobic element and ultimately results in the extinction of fear through inhibitory learning mechanisms (Figure 1) [5]. The basic idea behind exposure therapy is the exposure to the phobic element, which will trigger memory, sensation, thoughts, feelings, etc., in order to develop coping strategies, allowing a gradual decrease of anxiety. However, it is reported that although effective this therapy may be distressing [6]. Considering this, and in order to make the therapy less aggressive, there are different approaches, like imagining the phobic element, multimedia presentation, virtual reality, augmented reality, among others.

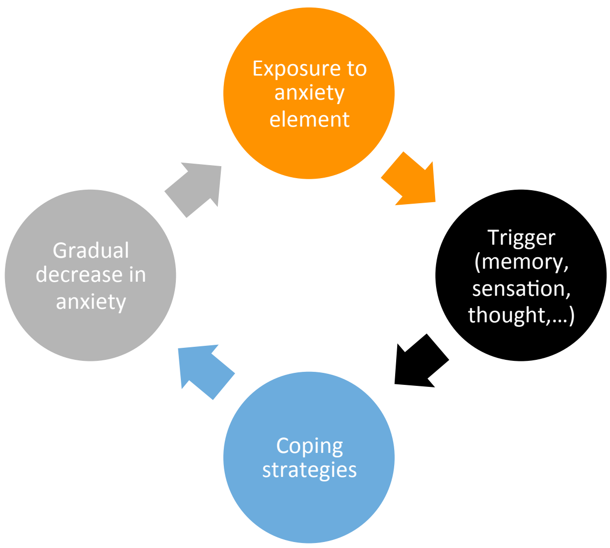

Figure 1 - Exposure Therapy cycle - The exposure to anxiety elemnets triggers memory, sensations, feelings and thoughts, allowing the sufferer to learn coping strategies, which will allow a gradual decrease in anxiety.

These therapies are usually performed in laboratory, under highly controlled settings, completely unfamiliar to the phobic individual, loosing the context relevance of the daily life environment in the studied phenomena [7]. The resulting benefits are undeniable, nevertheless this kind of approach is likely to miss important aspects associated to life outside the lab, that cannot be reproduced. The in vivo exposure is proven to be the most effective of this therapies, however, at the same time it's also too distressing [6], which will force the use of other ways of exposure, in order to better "prepare" the phobic individual to deal with direct contact to the specific phobia.

In order to capture the phobic responses in real life settings, there is an urge to develop and implement more ecological monitoring solutions, less intrusive, and at the same time, that allow the exposure to more realistic stimulus. This contrasts with typical laboratory settings that, although providing valuable assessments, imply not only highly controlled, often expensive that are non-ecologically valid i.e. unrelated to patient's daily life scenario not presenting the favourable condition to capture the natural reactions of the individuals. In this context, finding more realistic and ecological solutions supporting ambulatory scenarios could be an option to support more natural and reliable assessment, which could be easily integrated in the individual's daily life routine, better mimicking individual's' behaviour and physiological reactions.

In recent years, the evolution of technology and the miniaturization of devices like laptops, smartphones and biomedical systems emerged as a window of opportunity to explore and develop portable solutions for the assessment of physiological variables, which is an improvement when considering that most studies still rely on self-reported measures and are, as such, dependent on the individual's perception [8], [9].

Simultaneously virtual reality has been proven to be as effective as in vivo on anxiety disorders and avoidance [10], [11] among the multiple assessment and treatment choices available for Exposure Therapy. However, nowadays, the VR proposed solutions are still too expensive and do not explore the more recent advances in VR frameworks and current devices hardware characteristics, that make VR more affordable and practical outside the laboratory. Exploring these options opens an opportunity, which could help reaching a solution that shortens the gap between the laboratory and the real life scenario without compromising its usefulness.

1.1 Goals and Contributions

In this dissertation, we propose Veracity, an affordable and portable system that relies on VR to present more ecological stimulus to phobic individuals while monitoring their physiological response. The system is a valid assessment solution that can be quickly set up and presented in a daily life setting i.e. outside a laboratory, allowing more natural reactions of these individuals.

By using VR, we can achieve interaction from the phobic individuals with the system, which is less aggressive, when compared to in vivo therapy, where they are face direct contact to the stimulus. Our aim is not to replace the laboratory environment, but act as a first contact solution, opposing the introduction of the real stimulus directly to these individuals, as a first approach, which would in turn be presented later, when the individuals are better prepared, promoting a less negative response to the overall process.

Goals:

- A portable and affordable solution based on off-the-shelf units, able to be quickly set up in clinical environment or non-conventional settings (e.g. subject living rooms). This can represent a logistic improvement when compared with typical laboratory setups, i.e., expensive and of limited access.
- Creation of a generic architectural structure, applicable to other different scenarios;
- Use Virtual Reality (VR) to present more realistic stimulus while ensuring individuals own (perceived) safety (no real offensive stimulus).
- Using a game with gradual process to present the stimulus to the individuals, while providing interaction with the virtual reality environment using hand gestures.
- Monitoring the physiology of the individual’s reactions and evaluating the recorded data.
- Put the system to the test, in order to collect data and feedback that helps in the development process.

Contributions:

- Use VR to present interaction and realistic stimulus – using Unity and the Leap Motion controller Veracity is able to provide interaction ability between the individual’s with specific phobias and the VR stimulus.
- Creation of a portable and affordable solution based on off-the-shelf units – we based our solution on existing components for physiology (BitaLino, VJ) and for behaviour (Video, logical VR entities tracking) created with Unity Personal Edition.

- Veracity supports monitoring the physiology of the individual's reactions. - Our system is able to acquire ECG, HR, RR, VIDEO, Screenshots, 3D tracking of multiple objects, etc.
- Solution for data management - Veracity supports data management for post processing, integrated currently in Parse Cloud as a cloud based solution. Also all acquired information is self-explanatory to allow third party users i.e. metadata in files.
- Tested in a concrete use case - spider phobia since if triggered, reactions are highly context specific [2] - Using a game with gradual process to present the stimulus to the individuals, while providing interaction with the virtual reality world. Furthermore was put to the test in two public events for proof of concept and acceptance purposes.
- Allowed an insight on the impact of VR in the individuals acceptance / usefulness of the system – Although further analysis must be performed it was clear that the use of the VR element in the system we developed can fill the gap between the laboratory and the daily life of individuals with spider phobia and with this, help provide a first contact to the specific phobia, before direct contact can be applied in the treatment of these individuals.

1.2 Dissertation Outline

Excluding this one, 5 chapters compose this document:

- Chapter 2, describes the state of the art associated to our system and provides a theoretical introduction to the concepts of virtual and augmented reality;
- Chapter 3, starts by describing the pilot developed augmented reality game. This chapter then goes to explain the virtual reality part of our system and justifies the choice of using VR instead of AR in our system.
- Chapter 4, describes all the details related to the implementation of the system, it's architecture and hardware components, and how all the collected data is stored. All the reasons regarding the development resources and technical details of the different parts that bind the system together are highlighted in this chapter.
- Chapter 5, defines our case studies, and the obtained results and interpretation.
- Finally, Chapter 6 summarizes the conclusions drawn from the development and testing stages, as well as a subsequent analysis of the proposed solution and the possible improvements and future research.

2 State of the Art

Accordingly to the National Institute of Mental Health (NIMH) in the U.S. an anxiety disorder is a normal part of life and it affects more than 450 million sufferers worldwide [1]. Symptoms may manifest when faced with a problem at work, before taking a test, or making an important decision. But anxiety disorders involve more than temporary worry or fear. Anxiety disorder may not go away and can even get worse over time. The feelings can interfere with daily activities such as job performance, schoolwork and relationships, among others. This reality makes anxiety disorders one of the most life quality impairment in modern society. Nevertheless, more than half of the sufferers end up not getting treatment for their mental illnesses, despite the consequences [12]. This happens due to difficulty in the access to therapy (e.g. high cost, long duration or lack of therapists or the right treatment approach), or by underestimation of the problem or simply lack of knowledge.

A national survey in the U.S., concluded that almost twenty percent of psychiatric problems are anxiety-related [5], including post-traumatic stress and specific phobia, among the most widespread illnesses [13]. There are several different types of anxiety disorders, but one of the most common anxiety disorders is the specific phobia, which affects the daily lives of a large number of individuals [2], [3], affects up to 12% of people at some point in their life [14]. Phobia is the medical term associated to an individual that recognizes extreme/intense or irrational fear or aversion regarding something (e.g. specific object, activity or situation) [4]. Phobic individuals acknowledge that it strongly affects their daily life and social activity, avoiding the phobic element or any circumstance or places were it might be presented, which in turn will negatively reinforces the fear and perpetuates the phobia.

Therefore, taking into consideration the number of individuals suffering from this, it is vital to raise the awareness on the existing treatments, and significantly important, pursue more accessible methods of diagnosis and efficient methods of therapy that present more ecological and real life like stimuli, ensuring the phobic individuals own (perceived) safety (no real offensive stimulus). To break the cycle, Exposure Therapy (ET) is advisable, being the recommended first line of treatment, since approximately four years after receiving this kind of treatment, 90% of the participants report their anxiety levels reduced and 65% no longer experience their specific phobia [15].

2.1 Exposure Therapy (ET)

Exposure therapy is used on anxiety disorders in order to help the sufferers to learn how to deal with the phobic element. The exposure to anxiety element triggers memory, sensations, feelings and thoughts, allowing these individuals to learn coping strategies, which will allow a gradual decrease in anxiety, by teaching them how to face the reason in a systematic way (Figure 2) [16].

Phobic individuals are encouraged to repeatedly approach the phobic element, which allows a direct observation and understanding of these individuals reaction to traumatic and phobic stimuli [7] which will contribute to the extinction of fear through inhibitory learning mechanisms.

Figure 2 - Exposure therapy is commonly used to treat phobias, gradually increasing anxiety-triggering stimuli. Source: goo.gl/gQjkXD.

The most frequently used exposure therapy stimuli presentation techniques are (Figure 3):

- **In-vivo exposure:** Uses direct confrontation with the associated cause to the trauma/phobia (e.g. situation, activity or object), which usually involves handling potentially dangerous objects or live animals (e.g. spiders in case of spider phobia) in uncontrollable scenarios, generating risks an incompatibility between the individual and this technique [17];
- **Systematic desensitization:** Or also known as imaginary, requires the sufferer to imagine the origin of the trauma or phobia with the help of a therapist and associate the mental image obtained with the lack of anxiety presented at that moment. Being the cheapest and easier technique to apply, it requires that the individual must be in a relaxed state. However, the therapist cannot guarantee that individual is actually forcing himself to imagine the desired scenario;
- **Multimedia presentation:** Widely accepted as an effective treatment technique, uses different kinds of media presentation (e.g. images [18], sounds [19] or

videos [20]) to force the exposure to isolated stimuli in a controllable way, while allowing to the therapist the possibility to check if the individual is focus in the presentation. The International Affective Picture System (IAPS) is one of the most frequently used sets off stimuli [4], since it contains media elements, rated according to the degree of expected attraction or aversion towards themselves.

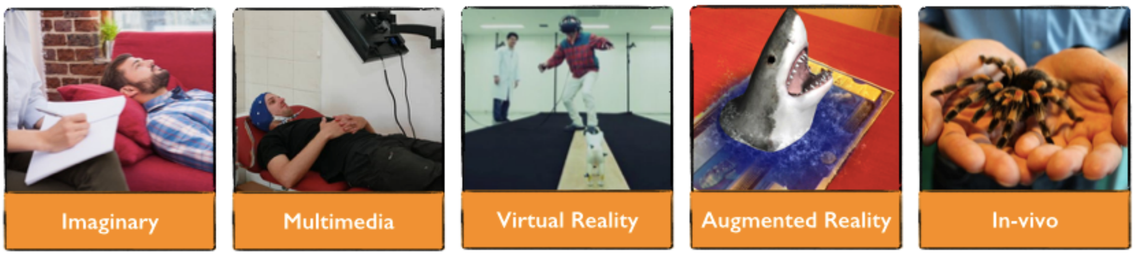

Figure 3 - Exposure Therapy treatment possibilities.

All the referenced techniques present strong points, aiming to change beliefs, behaviours and thinking's by using a progressive exposure to the stimulus that triggers anxiety, however there are also relevant downsides associated to each one and in particular, they all present the common weakness, that they are all performed under highly controlled **laboratory** environment (Figure 4), completely unfamiliar to the phobic individuals. As such, the need for ecological and non-intrusive **ambulatory** monitoring solutions becomes evident (Figure 5) [7].

Figure 4 - Example of a laboratory highly controlled environment.

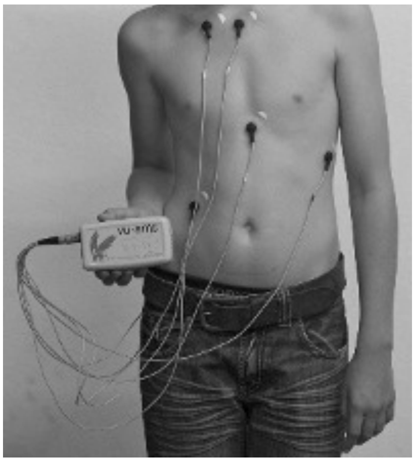

Figure 5 - Example of an ambulatory monitoring system.
Source: VU University Ambulatory Monitoring System (VU-AMS). Source: goo.gl/QlCrFo.

Although providing valuable assessments, the circumstances regarding highly controlled laboratory environment have a notable influence in the observed behavior, not valorizing the relevance of the context and environment [7]. Subsequently, these circumstances imply highly controlled, often expensive, and non-ecologically valid i.e. unrelated to normal daily life scenario of these individuals.

It is essential to reproduce the conditions of a confrontation with the phobic stimuli in a more familiar scenario, in order to be able to observe the phobic individuals natural reactions to these stimuli, thus obtaining ecologically valid and reliable results. Assuring this is currently one of the major difficulties of exposure therapy. As such, to capture the phobic responses in real life settings, there is an urge to develop and implement:

- More ecological ambulatory/portable and affordable monitoring solutions;
- Less intrusive solutions, that support ambulatory scenarios;
- Exposure to more realistic stimulus;
- Easily integrated in the phobic individual's daily life routine;
- Better mimicking the individual's' behavior and physiological reactions.

2.2 Digital realities

Technology is rapidly enhancing the way we perceive the world around us (Figure 6). Furthermore, the evolution of development tools and media devices regarding Virtual Reality (VR) and Augmented Reality (AR) in the last few years, made possible the creation of solutions that were until now, only theoretical subjects of study.

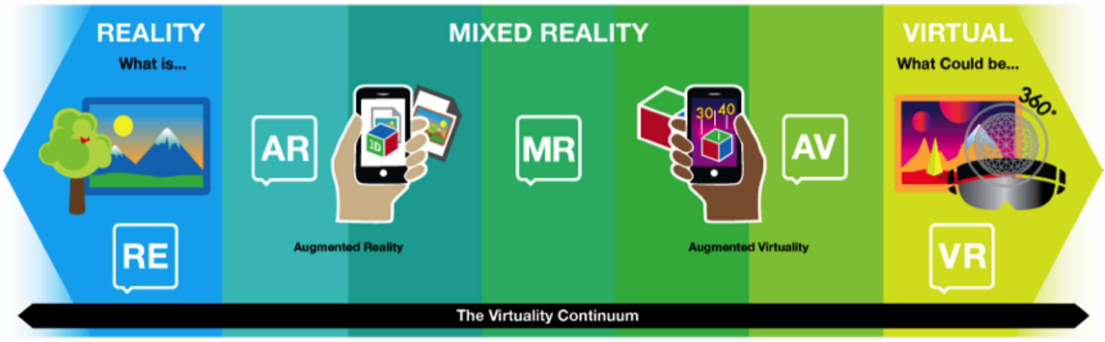

Figure 6 - Virtuality continuum: RE – Real World environment; AR – Augmented Reality; MR – Mixed Reality; AV – Augmented Virtuality; VR – Virtual Reality. Source: goo.gl/2d0XRs. Original concept: [21] [22].

The growing interest in these kinds of applications is creating new challenges for researchers in areas, not able to being explored until now, for lack of proper tools. These areas are highly interdisciplinary, combining work in diverse disciplines:

Technology oriented research

- Computer vision, computer networking & computer graphics;
- Display technology;
- Sensors;
- Signal processing.

Human centered research

- Interaction and design techniques;
- Human factors;
- Education;
- Wearable computing and mobile computing.

Our initial objective in this dissertation is to explore this tools in order to create a Virtual Environment (VE) as a solution to present real-life like stimulus combined with an ambulatory monitoring solution, taking advantage of the immersive capabilities of the current technologies [23], when compared to exposure therapies like in-vivo stimulus and non-interactive solutions namely multimedia presentations, giving a response to the previous mentioned problems regarding the highly controlled laboratory environments were this therapies are performed. The current technologies can help create new therapy procedures, which can revolutionize the way individuals, are diagnosed and treated. Even though, not all phobic disorders can benefit from these technologies, specific situations regarding particular stimulus or objects might sustain a large and positive impact in the support of phobic individuals.

As our objective is not to focus on improving and developing such stimuli, our main objective was to 1) select which of the two solution available: Virtual Reality and Augmented Reality would be more suitable for our scenario and 2) find off the shelf solutions to present virtual real-life like stimulus to phobic individuals.

2.2.1 Virtual Reality

The concept of Virtual Reality (VR) can be described as “a high-end user-computer interface that involves real-time simulation and interaction through multiple sensorial channels (vision, sound, touch, smell, taste)” [24].

The main purpose behind VR, is to create Virtual Environments (VE), that users can interact with and being stimulated by, based simulations or recreations of real life scenarios or environments, exposing users to information perceived with different senses, like visual, auditory, haptic, or other kinds of feedback [25], that share at least one attribute similar to the real world (e.g. appearance), without necessary sharing of all its physical features [21]. The development process of this VE, implies the construction of an artificial/synthetic “world”, using computer-generated systems, which should be design in such a way (goo.gl/RPRb5Y), that users would find it hard to tell the difference between what is real and what is not, exposing them to virtual sensory information, that tries to emulate real life stimuli, while providing means to navigate through and at the same time, interact with the VE elements [26].

To achieve this, the VR system should follow a set of modules (Figure 7) [24]. Using **I/O devices** like trackers, visual or sound displays it’s to possible to present the multiple stimuli of the VE and enable the interactions capabilities. The **VR Engine** provides a tool to create the VE and to use **Software and Databases** for the virtual modeling of the 3D objects (e.g. texture, geometry, etc.), the physical modeling (e.g. inertia, hardness) and the intelligent behavior associated to the objects in the VE. Finally, the **Users** and theirs **Tasks**, where the human factors would be taken into consideration.

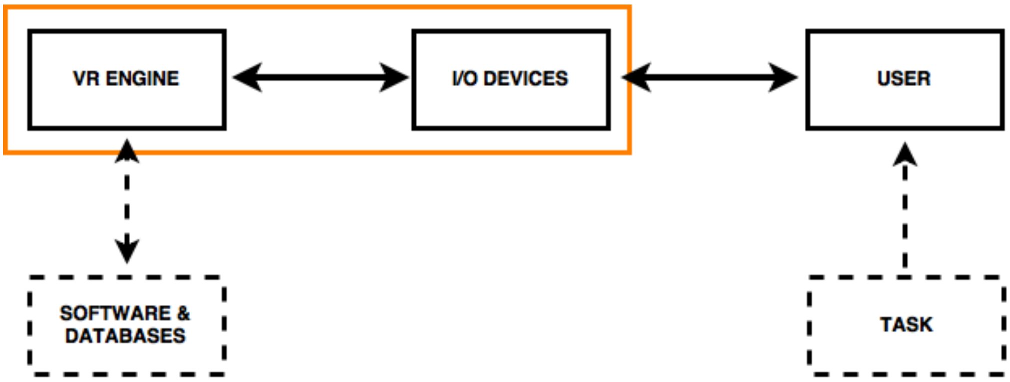

Figure 7 - Virtual Reality system modules - (Adapted from: [24]).

Categories

According to the level of immersion, it is possible to categorize VR systems. The quantity and quality of the stimuli used to stimulate the environment is closely related with the system's ability to isolate the individual from foreign real world stimuli and immerse him into the VR experience [23]. VR systems can be divided into three categories according to the following [27]:

- **Non-immersive VR**: or desktop VR, uses a conventional graphics workstation, with standard human-computer interaction devices, like a monitor a mouse or keyboard;
- **Semi-immersive VR**: uses a relatively high performance graphics computing system, combined with a large display surface or collection of displays, providing a more detailed perspective of the scenario in the virtual environment;
- **Fully Immersive VR**: probably the most widely known category, and the one that provide a better feeling of immersion and presence. The individual wears some form of head display that helps delivering the different sensory aspects of the virtual environment to him. May contain trackers or sensors to assess the individual movements and reproduce it into the virtual environment.

Applications

The number of companies developing applications regarding VR is increasing every year (Figure 8) [28], [29]. Nowadays it is possible to find applications associated to fields of interest such as medicine/healthcare (e.g. psychological therapy), media/marketing (e.g. virtual reality 3D paintings in museums), education/training (e.g. virtual classrooms), entertainment (e.g. immersive videogames), engineering/manufacturing/industry (e.g. schematic visualizers of products), military (e.g. flight simulators), among others.

Figure 8 - Rearranged sample of a total of 512 companies and startups, across 13 categories and $2.6 billion in funding, that use VR associated solutions. Source: goo.gl/H4UVvA.

In the last decade, VR systems have cause a relevant impact in the form of Virtual Reality Therapy (VRT) solutions (also known as Virtual Reality Exposure Therapy or VRET). Just like conventional Exposure Therapy (ET), VRET treatments, use the same approach, presenting the individuals to increasingly exposed to virtual stimuli related to their specific anxiety disorder, over several sessions, progressively achieving to reduce their behavioral reactions [30].

This kind of approach has been proven to be as effective as in-vivo exposure therapy, while improving the phobic individuals acceptance of the treatment [31] and ensuring they safety along the process, providing the means to create more ambulatory monitoring solutions, thus reducing the affects of the highly controlled environment circumstances of the laboratory environment.

Quoting, Xavier Palomer, co-founder of Psious[1], a Spanish startup that uses VR and AR to design phobia treatment scenarios for fear of flying, needles, crowds, heights, spiders and cockroaches: "Virtual worlds allows you to have the same or very, very similar experience you're having in the real world, but you have some control". VRET treatments provide main advantages, and more control is certainly one of those, allowing the phobic individual to experience adequate levels of anxiety, while ensuring they're safety. The field can be considered still young, but early results are positive.

At Newcastle University's Institute of Neuroscience, a program headed by Dr. Morag Maskey[2] is developing virtual reality simulations, in order to treat children with autism spectrum disorders who suffer from phobias. So far, in their first study, four out of nine children completely achieve to overcome their respective phobias. Besides, two learned to learn how to face their anxiety enough, which result in the ability to functional normally, not possible before the study.

[1] goo.gl/NBq5jY
[2] goo.gl/lPCseZ

A second larger study is being prepared by Dr. Maskey team, with the off the UK's National Health Service. Even with all the current technology, the best game engines, animators and video setting, some individuals may be apprehensive and it is possible to rise the question, that if virtual reality can be real enough to trigger anxiety in some individuals. Dr. Maskey says it is possible, but at the same time, the studies he has worked in have not encountered anyone who did not react yet.

2.2.2 Augmented Reality

Augmented Reality (AR) can be described as "a novel human machine interaction tool that overlays computer-generated information on the real world environment. The information display and image overlay are context-sensitive, which means that they depend on the observed objects" [32].

Both VR and AR have the goal of immerse the user, although the different paradigms use different approaches to accomplish this goal. While VR offers a digital recreation of a real life environment, AR, uses computer-generated technology, to blend virtual reality and real life into a new paradigm, displaying virtual elements as an overlay to the real world., which can be easily told apart, aiming to make it more meaningful through the ability to interact with it.

Mostly developed in the form of apps for mobile devices, this paradigm blends digital components into the real world, using the camera from the mobile device to detect markers and deploy an enhanced version of the real world environment. Subsequently, this creates an enhance between both, which is a subclass of VR systems, defined as Mixed Reality (MR - merge of reality and virtuality), aiming to provide a richer experience, where while still in contact with the real world, it is possible to interact with virtual elements, providing a different perception of the real world [33].

AR does not aim to fully remove the physical environment in contrast to VR, but to present virtual stimuli, while at the same time, keep the sense of presence from the individual experiencing it, trying to improve reality, instead of replacing it [34]. Depending on the context, AR takes advantages of visual clues/labels for providing additional information regarding real world specific elements (Figure 9). The concepts of mobile, and outdoors solutions, perfectly adapt to the paradigm of AR, not being confined to a single place, allowing interaction in the field, using different types of tracking (e.g. markers, sensors, GPS) and interface (e.g. handheld devices, headgear, etc.).

Figure 9 - AR example to add context-related information, using the book as a marker. Source: goo.gl/egw595.

Categories

According to the mechanism through which the solution performs the placement of the stimuli[3], its possible to divided AR systems in two categories:

- **Vision-based:** Relies on the correct detection of visual patterns (e.g. markers) or objects to know when and where to present the VE. It is currently the most used.
- **Location-based:** The placement of the VE is performed accordingly to the geographic location (e.g. using GPS coordinates) or the orientation (e.g. using dedicated movement sensors). Mostly used in specific outdoors system.

Applications

Thanks to the increasing number of augmented reality frameworks and also the decrease in hardware costs in the last decade, AR has been growing in the number of applications been used. Furthermore, the AR paradigm is creating a wider range of solutions, comparing to the VR approach, with applications in different fields: education (e.g. a real time cosmic scanner), entertainment (e.g. videogames), tourism (e.g. maps that use AR tips to show information regarding places of interest), selling's (e.g. Lego – view the final build in the mobile device screen or Rayban – it's possible to try a pair of glasses, without living the house), among others[4].

[3] goo.gl/qwnStf
[4] goo.gl/W8QXh4

3 Catch The Spiders

In this dissertation our main goal was to create a portable and affordable system that relies on VR to present more ecological and virtual stimulus to phobic individuals while monitoring their physiological and behaviour response. We selected spider phobias as our case study, as a natural follow up of previews work in this line of research such as BeMonitored developed by Ricardo Moreira [8] and Aware developed by Telmo Cruz [9], both master degree students from Computer and Telematics Engineering course in Aveiro University.

Due to spider phobia specificities it was clear that some protocol and conceptual decisions had to be made before addressing the technical and implementation aspects of the overall system.

This implied:

- Understand the specificity of spider phobia scenario;
- Select Virtual or Augmented Reality;
- Select an approach to the scenario.

We opted for a **gamification approach**, in order to allow a virtual interaction by the individuals with spider phobia and the virtual stimulus that our game would induce with the help of a spider model. The main idea behind this was to gamify the exposure therapy, in order to make easiest the interaction and initial contact with the phobic element.

This way, we can provide an experience, that allows phobic individuals to interact with impossible or dangerous situations of real life in a safe environment [36] [37], using gamified objects and goals, that promote the engagement with the phobic element, without limiting to the physics or logistics constrains of the real world. We believe that by using this approach, we can take advantage of the game objectives [35] to help phobic individuals reaching a state were they are better prepared to interact with real phobic element, (in our case – spiders) when that moment arrives.

To accomplish the proposed goals, two approaches were developed and tested, using Virtual Reality and Augmented Reality.

3.1 Unity

To create our virtual environment, all of the interactions associated to it, and also, to present the proper stimuli to phobic individuals, we decided to use the Unity game engine, even though other possibilities exist. Unity is one of the most popular and multiplatform solutions for development and deployment of Virtual Reality scenarios. Created by Unity Technologies in 2004, as a development tool for their game, GooBall, it was later launched in 2005 at Apple's Worldwide Developers Conference. Like it is referenced in Unity main website: "Today Unity is the #1 game engine on the market and in education, (...) and the fastest growing game development platform in terms of developer mindshare (…) enabling everyone to create rich interactive 3D content ".

Free and easy to use, take an important part in the choice of this game engine, since we are using Unity Personal Edition. Another valuable resource behind this choice was the good documentation that unity provides. Between the online docs, all the official forums combined with the help from the community support and the many high quality online tutorials.

One of the most impressive features is the ability to build multiple platforms projects, really easy, when in comparison with the old days, when a massive effort was required to fulfil having the same project working properly in multiple platforms. Of course there's still the need to take into consideration each platform's unique features, but Unity provides an easier way to achieve this. Currently, Unity is the only game engine on the market that brings such versatility, even in the Personal Edition version.

In the Asset Store, developers can find different virtual elements (everyday objects, buildings, etc.) to use in their projects, without having to design and create them from scratch. Combining this, with the scripting languages that the developers can use (C# or JavaScript), results in a richer environment.

3.2 The spider

For the 3D virtual spider, we used a free model that can be found in the Unity asset store (https://www.assetstore.unity3d.com/en/#!/content/22986) (Figure 10). The major goal was to deploy a model, able to mimic spiders, as best as possible, in order to give a realistic feel of the spider looks and movement. Combining this, with some scripts and the final result was a mixed of jumping, attacking and walking in random directions, that would provide the wanted stimulus to force reactions into all the individuals that experiment our game.

Figure 10 - 3D spider model used in the AR and VR games.

3.3 Mobile Augmented Reality game

Our goal was to create a game, that used markers, with the simple purpose of catching 3D virtual spiders that would be falling from a top position, with the help of a 3D box controlled by the individual fingers or a set of buttons. Augmented reality supported on mobile was our first approach as it allowed testing spider models namely in terms of credibility and test possible interactions with the virtual environment elements, encouraging people to deal with 3D virtual objects on top of the reality, by using markers as placeholders for deploying our virtual environment. As we targeted the application for people with spider phobias, spiders were an active element in the virtual environment. The development of this mobile application, open the path to the first contact with the Unity game engine, which was widely used in this dissertation.

3.3.1 The game

The game used a virtual environment consisting in a simple board, where the 3D virtual spiders would fall down from a top position and where the participant's goal would be to catch as many spiders as possible, whether by using his fingers and moving a 3D virtual box, or by using a set of buttons that would move the box left or right respectively each time the button would be pressed. We used several models in our virtual environment that can be found in Unity's Asset store, available for free to anyone (Figure 11):

- Spider;
- Donuts;
- Eight ball,
- The box.

First of all, we have the spider model, the main component of the game to provide the pretended stimulus. We also have falling donuts model that are intended to work as a reward mechanism to the individual experimenting the game, that supposedly is afraid of spiders. Furthermore, we have the eight ball model, which allows the individual to end the game whenever he wants, simply by catching it. Besides this, we also use a model for the box that the individual can move, and two more in the background, to complement the overall scenario of the game.

The rest of the game components, including the game mechanics and some model movements were developed by us from scratch, with the use of JavaScript and C# scripts, Unity tools available and Unity physics engine.

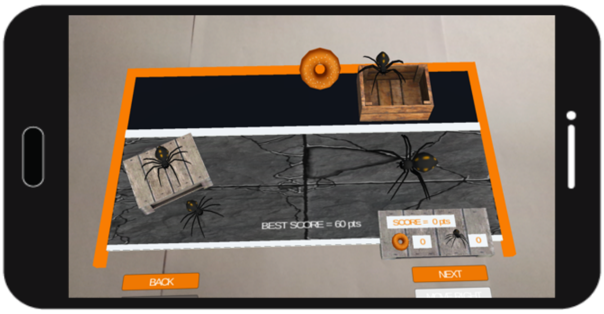

Figure 11 - Developed Virtual environment displayed in Game 1.

The game starts in the home screen (Figure 12) where it is possible to select a set of options, like choose to see the rules of the games or immediately choose which game to play. When the game is finalized (only available in Game #1), it is possible to view the number of spiders caught, take a screenshot and share that in the social networks.

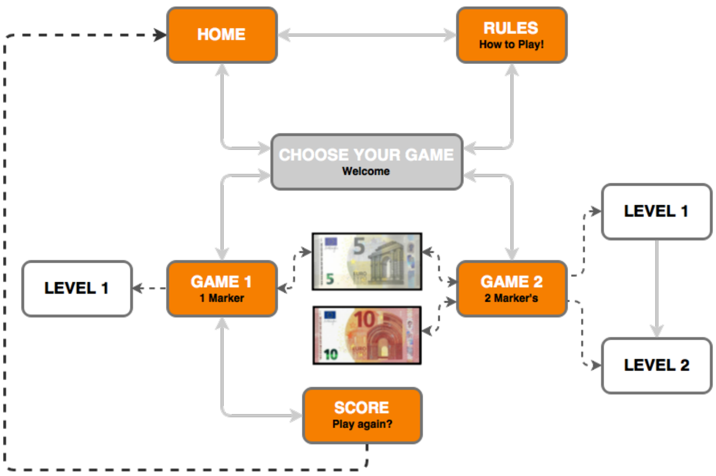

Figure 12 - Augmented Reality Game Interaction Diagram.

Game 1 uses only one marker. Game 2 uses two markers. A small video of 1 minute, showing the features of our games can be found on: https://goo.gl/TWkzWC.

Game 1

The game uses one marker for deploying the board game (5€ bill). While spiders, donuts and the eight ball fall to the ground, its possible to move the box to catch them, using the mobile device touchscreen or a set of buttons placed in strategic locations, in order to be easy to understand.

Game 2

This game uses two markers. For the board game, the 5€ bill and a second marker to represent the box, the 10€ bill. We implemented two levels, where the individual has to move the box to catch the spiders (level 1) or the object specified in the white text, donuts or spiders (level 2). This is sort of a bonus game.

Figure 13 - Mobile Device running the main game – Game 1. The device camera recognizes the marker and deploys the VR in top of it, in the respective device screen.

3.3.2 Vuforia

Besides Unity, so that we could display the virtual environment on top of the real world with the help of markers, we needed to use another tool and we decided to use the free Vuforia Library. Vuforia is a Qualcomm Technologies, Inc (https://developer.vuforia.com) platform for the development of augmented reality applications (more focus in mobile devices). This platform includes a wide variety of features, from marker and text recognition, to 3D objects and other premium functionalities.

The downside of using this library is that the markers have to be uploaded to the Vuforia portal and converted into specific files that are loaded to Unity. Later the application will be able to recognise the respective markers. The Vuforia library processes the markers previously submitted to the portal and finds as many distinct points in them as possible. It then returns to the developer a library that contains information related to the marker, which can be used in the application. Finally, when running the application, if a minimal number of points matches is found, the marker will be recognized and then the virtual environment can be displayed on top of it. Virtually any image can be used as a marker, as long as there are no cyclic patterns and the image key points are distinguishable.

3.3.3 Markers

We used a marker-based approach to allow virtual interaction with the virtual spiders and other innocuous objects within the virtual environment, using augmented reality presented on mobile device screen. By using a mobile device, running a mobile application, we wanted to explore the possibilities of using AR.

On this game we used visual markers. A marker can be described as a placeholder for the virtual environment to be displayed in top of the real world. The usage of markers, allowed us to force stimulus into the individuals playing our game only when the mobile device camera detected the marker and with this, capture more realistic reactions.

The game interaction is based in a 5€ bill marker. There’s also a bonus game, that uses the combination of this with a 10€ bill. In both games, the 5€ bill is used to mark the game board and in the bonus game, the other for the individual to interact with the AR world (10€ bill). Since our project depended on the markers, choosing the right marker was a pondered decision. First, we made some trials, until we decided to use some more specific markers (Figure 14).

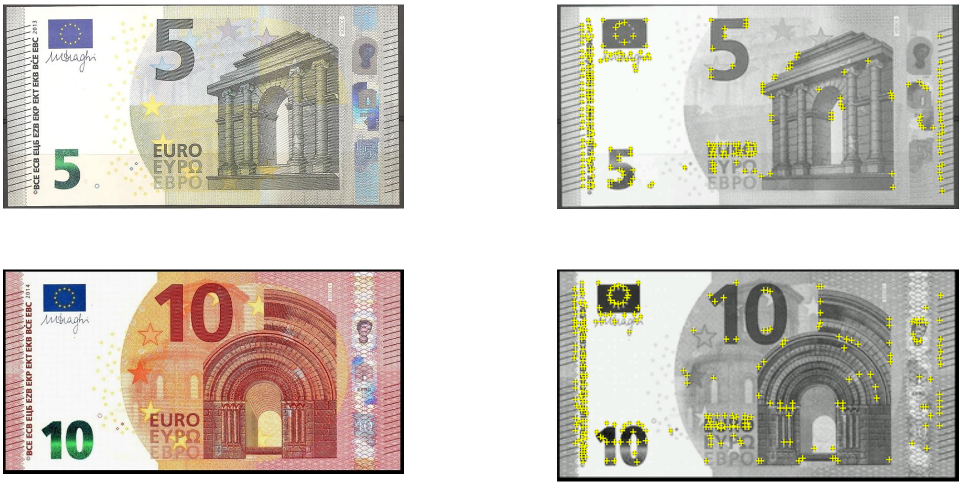

Figure 14 - Markers used in the AR game (left) and the respective interesting points used by Vuforia to recognize as a valid marker (right).

Initially, we thought about using a fifty-cent coin (Figure 15), for the player interaction with the game, because it was smaller than the bill and was also easy to find. However, we ran into a problem. We tried several coins, but all of them were too small and so Vuforia could not find enough matches. This way, the idea of the coin was no longer an option and we opted to kept the bills.

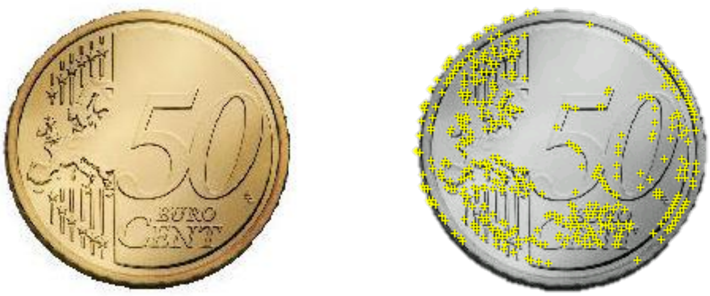

Figure 15 - Example of a 50-cent marker, tested, not used in final AR game.

After using some options for the tests, we decided that the game final markers would be: a five euros bill for the main game and a ten euros bill for the bonus game, combined with the five euros bill marker. We chose these because usually people have them in their pockets and there is no need to print anything.

3.4 Why Virtual Reality and not Augmented Reality

The knowledge obtained with the previous described AR game allowed us to understand that even though some features were quite interesting, others would compromise the human reactions. Holding the mobile device while pointing it to the respective markers and maintaining the mobile device stable after some time, becomes tiring and with time a difficult to accomplish task. Subsequently, the use of markers could also affect the human reactions, since markers are not natural and they have to be hidden from the human view in order not to steal the attention from the key aspects we want the focus to be. Furthermore, since we wanted to interact with the virtual environment, there was no easy way to accomplish this, since the mobile device camera capabilities are limited, when we want to make a real time tracking of the human hands and in top of that, introduce interaction in the virtual environment.

As such, our system needed to have a way to allow interaction, without compromising the key goals. Instead, we decided to use a Virtual Reality solution, this time in a Personal Computer (PC). This would introduce a new perspective for the participant, having a bigger and higher quality display, and would also take care of the problems mentioned before, while at the same time, giving more processing power to the virtual environment, which we expect to translate into a richer environment, and in turn more realistic reactions.

3.5 Interaction using Leap Motion

Among several options, we decided to use a standard Leap Motion controller (Leap Motion, Inc, USA, https://www.leapmotion.com) Developed by Leap Motion, Inc., an American company that manufactures and markets the computer hardware sensor. This selection was supported in both the availability of the device, the previous experience using it and the easy integration with Unity.

First it provided an easy integration with Unity that allowed, the participant hands to be converted into a 3D model that could be used to interact with the objects and scenarios, reinforcing the idea of immersion, by the part of the participants with the VR environment. The leap Motion supports hand and finger motions as input, analogous to a mouse, but requires no hand contact or touching.

The Leap Motion controller has a lot of potential. While it is not cut out to replace a touchscreen or mouse as a primary input device, it provides a new means for computational control, best served as a means for entertainment.

The Leap's capabilities allowed a motion-controlled interactive experience combined with the virtual environment (Figure 16). The Unity game engine makes it easy to develop 3D apps with seamless Leap Motion interaction for VR. With the Leap Motion + Unity, it's possible to bring the user hands into the game.

Figure 16 - Leap Motion Controller Interaction.

However, as Leap Motion controller is a device that is not standard in daily life, we decided to include it in our system in the form of two adaptation levels, with the goal to give the participant the opportunity to interact with the Leap Motion and learn how to work with it. From earlier experiments we considered this a reasonable trade off considering that the other interaction alternatives considered were traditional mouse or keyboards.

3.6 Catch The Spiders: Virtual Reality game

We selected Virtual Reality applied to spider phobia as the main scenario for the system we wanted to create. Therefore, and in order to deal with the constraints associated to this therapy, our approach was based on a game perspective (Figure 17) with progressive protocol organized in levels (increasing the intensity of the stimulus). The scenario was based on a Semi-immersive VR room, where several 3D objects would be placed. The participant could interact with several different objects (phobic and non-phobic), using a pair of 3D virtual hands. According to each level, different objects and game goals would be presented.

Figure 17 - Catch the Spiders logo - Virtual Reality Game.

3.6.1 The 8-Ball

Besides the spiders, we decided to add another 3D model, an 8-ball (a free model in the Unity asset store (https://www.assetstore.unity3d.com/en/#!/content/24730)) (Figure 18). The idea was to end the game if the individual is tired, or what to experience the next level and also end the game if the content is comprehended as being aggressive/ distressing by the phobic individual. When the ball is captured and placed inside the box, it acts as an end switch. The 8-ball allows moving from the current level to the next. Another option to skip level is by pressing the “ENTER” key in the computer. In the final level, this was mandatory, since there wasn’t any box or 8-ball.

Figure 18 - 8-Ball model used in both the AR and VR games.

3.6.2 The virtual hand

The hand model (Figure 19) was provided directly by the use of the Leap Motion Controller SDK for Unity. From the multiple choices that were presented, we decided to use the shorter hand models, which could interact easily with the remaining objects in our virtual environment, showing a good accuracy and at the same time not compromising the visual display.

Figure 19 - Virtual hand model used in the VR game.

3.6.3 Game Levels

The game's idea is to catch virtual spiders, and place them in a 3D box. The game was divided in multiple levels (Figure 20), six, to be exact, in were the difficulty increases by introducing a number of different objects (we selected boxes of different sizes and shapes) that would grow in number according to each level. Also, the number and size of spiders was adapted to the level, in accordance to the desired stimulus intensity. In the final level, we reversed the role and, instead of catching spiders, the spiders would (try to catch) follow the human hands.

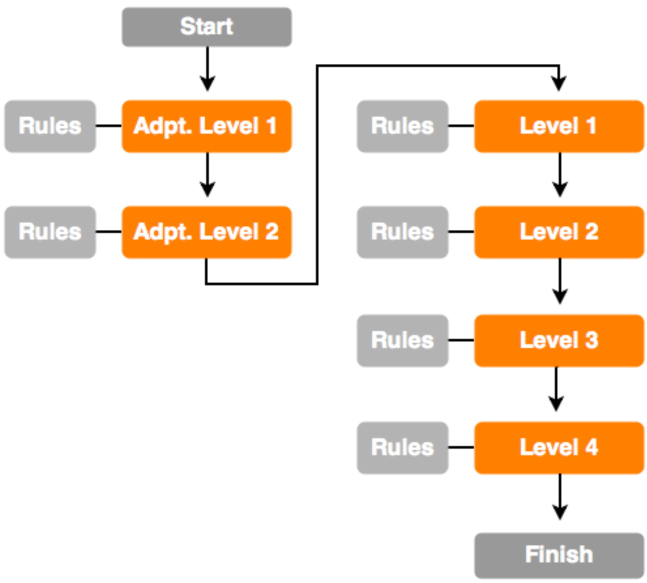

Figure 20 - Catch the Spiders game interaction diagram.

Between each level, a 10 seconds transition period was inserted. At the start of each level, an image of all the rules and objectives was presented (Figure 21), while at the same time a reading voice would narrate what was being seen (the narrative content can be found in the annex chapter). To create this, we used the Mac OS X, standard (TTS) text to speech feature. After all was understood, this image would disappear, giving place to the virtual room previously mentioned accompanied by background music.

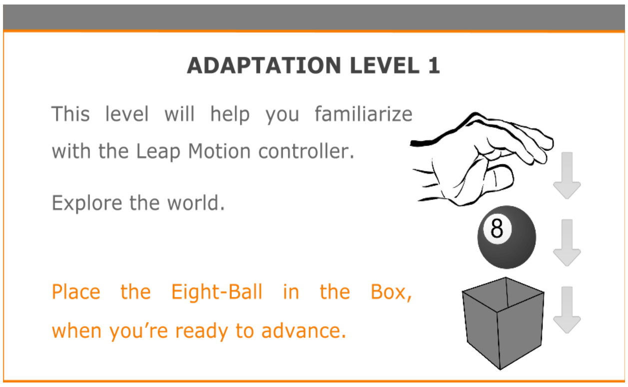

Figure 21 - Catch the Spiders example of the Rules presented to the individual experimenting the game.

Our virtual environment, more precisely the common room to every levels, were all the interactions would occur (Figure 22) was developed using a simple and intuitive scenario, built in such a way, to maintain the attention of participants in the stimulus itself, since the objective was to interact, capture and place spiders in a box.

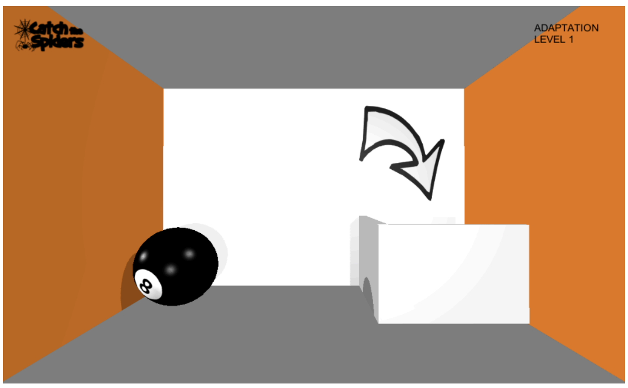

Figure 22 - Catch the Spiders Virtual Environment (VE) common room to every level.

The two first levels (Adaptation Level 1 and 2 (Figure 23)), were created to provide some basic training, regarding the interaction with the virtual environment and at the same time get acquainted and improve the skills over the Leap Motion controller, based on simple tips, it is possible to explore the possibilities, like waving, throw and catch objects. As such, in these first two levels, no spiders were presented.

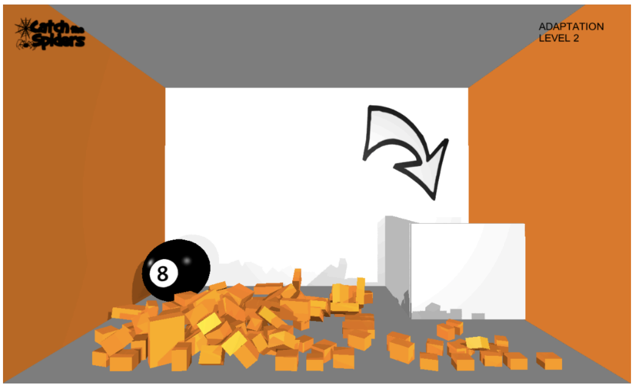

Figure 23 - Catch the Spiders Adaptation Level 2.

From this point forward the game begins. In the following levels, several objects with the shape and random movement of spiders are introduced (Figure 24). The task is simple, catching and place as many spiders as possible in the box. This also implies the direct interaction with the virtual environment remaining objects, put there to increase each level difficulty. In order to maintaining the stimulus present in all game levels, every time a spider is caught, another one is spawn.

Figure 24 - Catch the Spiders Level 2.

In the final level (Figure 25), we decided to change the objective. Since we were using a 3D virtual model of the human hands, we decided to take advantage of that fact, and instead of the main purpose, the spiders would follow the human hands. This would be a good way to see what the reactions are, whether if pushing them away, lift and throw or even try to squeeze them. In this final level we also added a new feature, the sound stimulus, using a sound that tries, as good as possible, to mimic the spider movement when walking around.

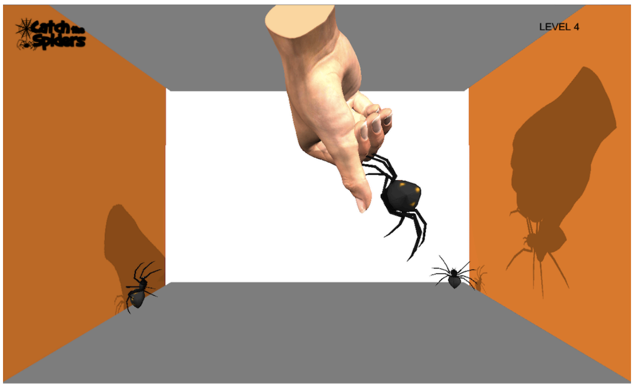

Figure 25 - Catch the Spiders Level 4.

No timer or countdown clock was presented during the multiple levels, in order to avoid any time related pressure to complete the game, this was our way to implement a “file safe” mechanism, easy to understand and at the same time, that would not corrupt the main purpose of the game (interact with the phobic elements).

4 Veracity: The System

In this section we describe the architecture, hardware and main implementation options of the Veracity system combined with the “catch the spiders” game to give response to the need to force specific stimulus, in our case, regarding the spider phobia case study.

Veracity can be quickly set up and presented in a daily life environment i.e. outside the laboratory, allowing more natural reactions from the phobic individuals. Its design allows adaptation to other scenarios as soon as clear scenario protocol is well defined i.e. stimulus, interaction paradigm and experimental protocol.

4.1 The architecture

Veracity is a combination of several modules, centered in a laptop solution, plus two mobile applications working hand to hand on a mobile device (Figure 26).

The main components are:

- Virtual Reality Environment
- User Interaction Device
- Media Recorder
- ECG/Heart Rate Measuring
- Data Manager

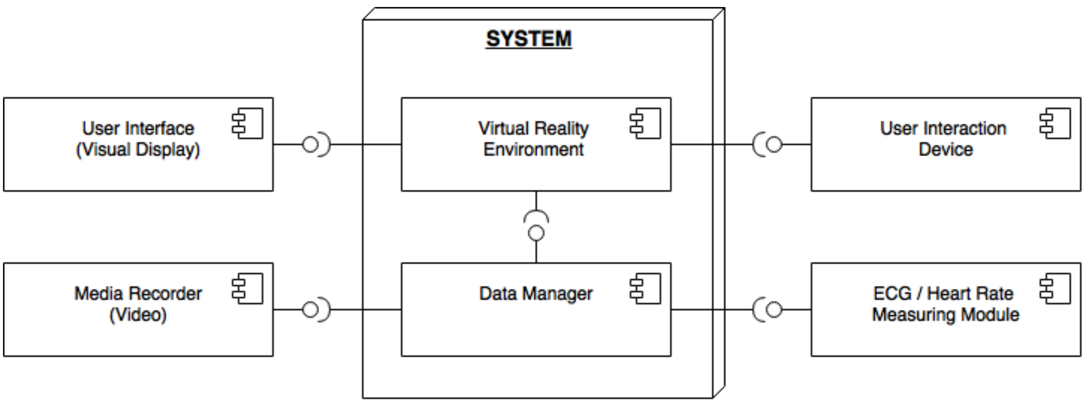

Figure 26 - Veracity system internal architecture.

Virtual Reality Environment

Central to our architecture is the “Virtual Reality Environment” as it has many roles: 1) provide a visual representation of the virtual environment, 2) support external interactions with it and 3) allow the tracking of some objects positions along the experiments, capture screenshots and save the number of spiders caught.

After some research surrounding the game engines possibilities, we concluded that Unity was and still is the best choice for the purpose behind this dissertation. Using C# and JavaScript we were able to develop of the virtual reality part of our system, which, thanks to Unity is able to run in multi-platform devices, like Microsoft Windows and MAC operating systems and can be easily adapted to be displayed in other VR devices, supported by Unity (e.g. Oculus Rift) and use different interaction devices (e.g. Razer Hydra, Leap Motion, etc.).

User Interaction Device

The “User Interaction Device” module captures the user hands and communicates with the “VR Environment” in order to create a 3D module that can accompany the user movements and enable the interaction with the remaining objects in the VR environment.

Our current implementation was conceived having Leap Motion in mind given the good integration with Unity and being a more realistic option when compared with traditional mouse and keyboard.

Media Recorder

For monitoring the individual's physiology, the system relies on the “Media Recorder” module, that acquires in-game screenshots every second and stores them to specific folders associated to the VR scenario and also uses a video recording camera to store the full study scenario.

ECG/Heart Rate Measuring

The “ECG/Heart Rate Measuring” module guarantees the physiological monitoring, which captures the ECG, HR and RR data. Currently they are acquired at 500 Hz using Vital Jacket (wearable biomedical device by Biodevices SA). It communicates the information to one of the mobile applications in the Android smartphone using Bluetooth, which must be previously paired. This information is shared with the other mobile application, which in turn sends it to the laptop, using Wi-Fi. The acquired information can be later related with the experiment events (protocol phases and VR interactions and stimulus). It is also possible to use the Bitalino biomedical device, but not with integration to the Server-Client mechanism.

Data Manager

The “Data Manager” module, allows all the acquired data to be stored locally into specific folders, using text-based format, in order to be easy to process later by external applications. In the screenshots case, an exception is made, since they are stored in Portable Network Graphics (PNG) format.

4.2 The current system Hardware

The current system (Figure 27) was developed and deployed in a MacBook Air, 13-inch, 1,4 GHz Intel Core i5, 8GB DDR3, Intel HD Graphics 5000, running OS X Yosemite 10.10.3 (1), a Samsung S3 GT-I9300, running Android 4.3 (3) and an action sport camera like Sony HDR AS30V, which besides providing a wide field of view, also allow to acquire the video from 25 Hz at 1080p to 120 Hz and 720p.

The current system is composed by:

- One laptop (1)
- One leap motion (2)
- One mobile (3)
- A ECG monitoring solution (4), initially Bitalino (version 1), currently VJ (version 2)
- A video camera (5)

Figure 27 - Veracity current system deployment.

Veracity generic deployment comprises 5 key elements. One laptop (1) providing the means to the Unity runtime and at the same time playing the role of the central node, presenting the projection and interaction with the VR environment. Currently the visualization is mainly limited by logistics and protocol, nevertheless it can use any standard visualization solution (e.g. laptop screen, external screen, projector).

We also take advantages of an android smartphone (3) that acted as a data aggregator from external sensors. Using custom or provided applications that acquire the incoming sensor readings from the biomedical device using Bluetooth and sending this information to the PC using Wi-Fi, via a Server-Client solution.

Two versions were implemented with two different ECG monitoring solution (4) – both described in detail in following sections:

- **Version 1** using Bitalino ;
- **Version 2** using VJ.

Finally we used a video recording camera (5), which would provide a wide field of view from the setup, including the scenario and all the individuals' reactions.

4.3 Overall Workflow

The basic workflow of the system is presented in Figure 28. In the PC, the Server must be started, plus the fields related to the Participants information must be filed. In the mobile device running a mobile application, the connection to the VJ Biomedical Device can be established (ensuring that Bluetooth is enabled and that the devices are previously paired) and the physiological acquisition can start. Using a different mobile application, while the first one is still running, the connection to the Server can be established and the game can be started (ensuring that Wi-Fi is enabled and both the PC and the Mobile Device are connected to the same network and that this network allows the use of static IP address).

Having all the basic connections established, the system is ready to go. When the game is started, a dedicated main folder to store all the collected data from the PC and the mobile device is created in the PC desktop using the Participant name and the timestamp. The Media Recording to save the entire scenario regarding the Participant interaction with the system is also started at this point, accompanied by the tracking of several context specific events in each level. Following the unroll of the game, all the data associated to each level is stored to this main folder. While the level of the game is inferior to level 4, the game will be in a loop, advancing to the next level. Reaching level 4, the game can finish running and the stored data can be uploaded to the Cloud.

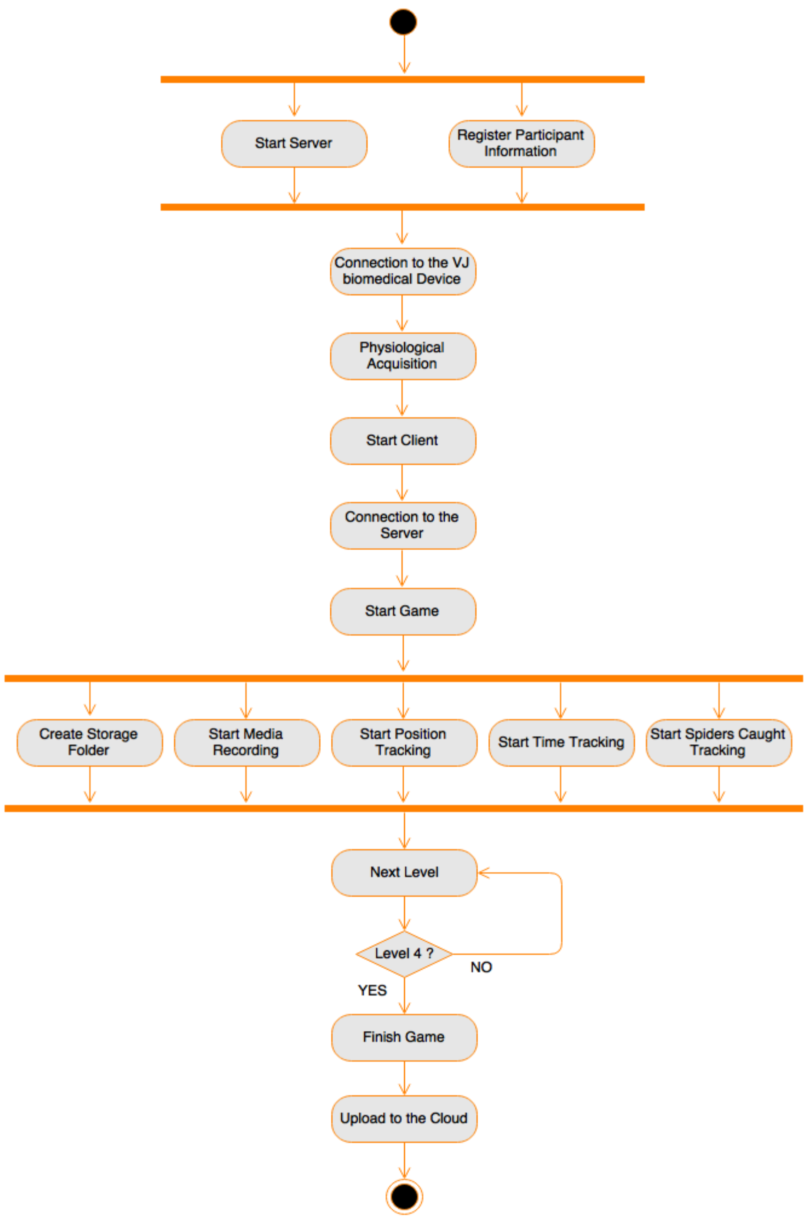

Figure 28 - Veracity workflow as an activity diagram.

4.4 The Bitalino version (version 1)

Our first option to perform ECG, HR and RR data acquisition, was to use the Bitalino board Kit (Plux, PT, http://www.bitalino.com) (Figure 29). In order to collect all this data, we tried several approaches in different platforms, namely, Windows (7 and 10) and MAC (OS X) Unity API's using Bluetooth to connect to the board kit. This proved not to be a reliable option, since the connection wasn't stable, and in the MAC, was not even possible to establish. It is important to take into consideration, that the particular board kit used by us, was a new version, still in development, which may justify some of the problems that we encountered.

We finally decided to use a mobile device running the mobile application Bitadroid (available in http://www.bitalino.com/index.php/software) to communicate with the Bitalino board kit, after it proved to be reliable in establishing the connection and in collection all the required data (Figure 30). The recorded data would be stored in the mobile device and later sent to the PC.

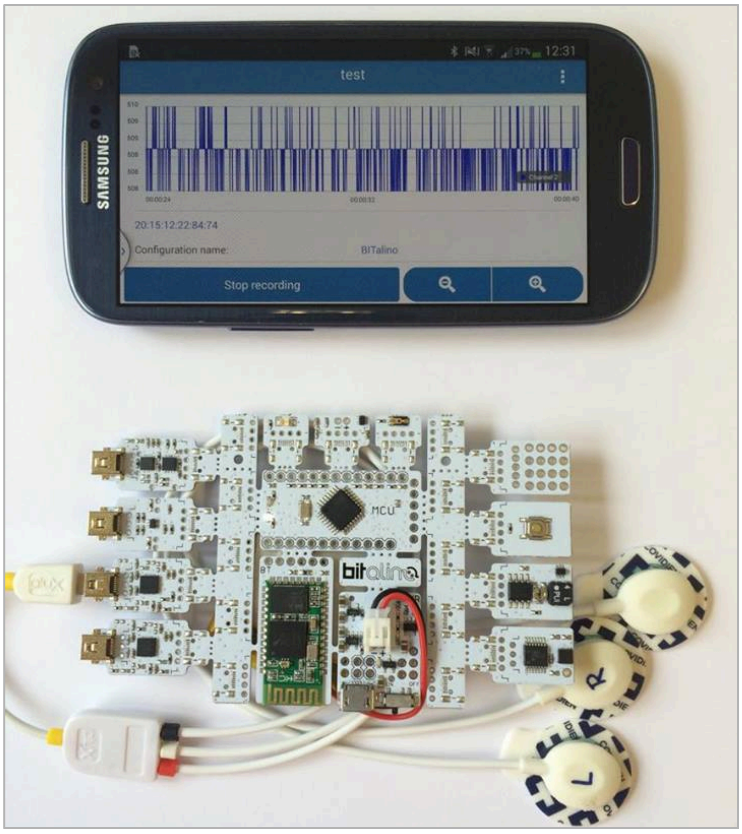

Figure 29 - Veracity version 1, based on the mobile device mobile app connected to the Bitalino Board Kit.

To close the system loop, we used Sony video recording camera that would allow recording the full scenario of our future case studies and would also provide a synchronization solution to the collected data in the mobile device and in the PC.

The resulting system was put to the test in a case study in order to evaluate the participant's acceptance of our system and how it would behave in a “large” scale test.

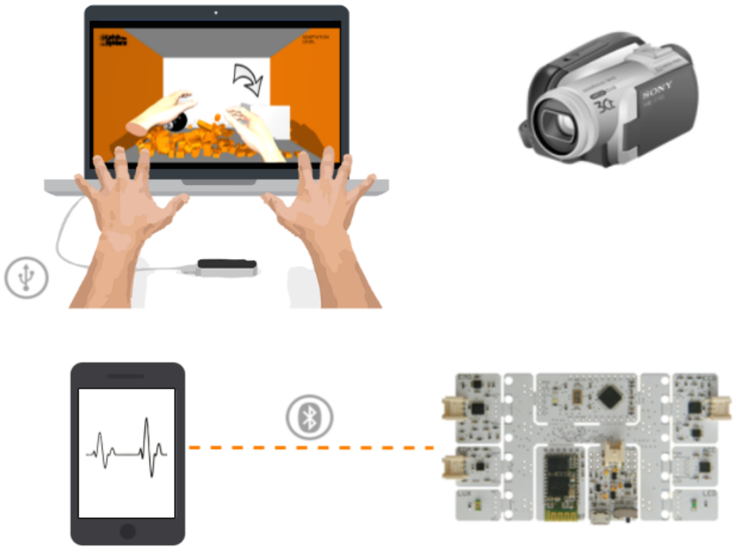

Figure 30 - Veracity version 1 based on the Bitalino implementation and respective Hardware components.

4.5 The VJ version (version 2)

In the VJ version, the main changes in comparison with the Bitalino version were:

- Online synchronous acquisition of ECG and VR events, following a Client-Server approach, between a PC and a mobile device;
- Remote monitoring and control of the acquisition session, using a a mobile device;
- Replaced the Bitalino by the VJ and used 500 Hz instead of 1000 Hz for ECG acquisition;
- Used internal HR online calculation from VJ instead of offline calculation using Pan and Tompkins method [10];
- Improved the sampling frequency in tracking interesting objects;
- Upload the relevant information to the Cloud.

The first two changes, given their relevance are described in more detail in specific section.

In this version we replaced the previous biomedical device, by the Vital Jacket (VJ) module (Biodevices, PT, http://www.vitaljacket.com) to collect the ECG, and ECG derived data (HR, RR) from each individual. We integrated the VJ in our system using freely available Vital Jacket standard SDK, (available in http://www.sdk.vitaljacket.com/?page_id=8), plus some new features.

This evolution came from the integration of the game and ECG acquisition under the same system. Although Bitalino allowed an offline data integration and joint storage solution – it relied on a mobile application BitaDroid, which implied separated interaction during the acquisition session and manual migration of the resulting data.

During some tests with version 1, a small bug was found, related to the spawning and capturing ability associated to the spiders in Level 3. As such, a new approach was adopted, where a new spider is spawn every time one is caught, instead of spawning one every five seconds.

Another relevant change was the adjustment of the event-sampling recording. We changed the time interval of the screenshots and tracking from two seconds to one second so that a more useful tracking on objects was possible. The initial sampling of the spider (biggest) and the 8-ball positions (every 10 seconds) was considered not suitable (under sampling) given the game dynamic interval. In version 2, the sampling was adjusted to one second – higher sampling induced performance issues on the game playing. Equally important, we decided to redone all the configurations between the new wearable biomedical device and the smartphone mobile application.

In version 1 we collected with success individual's ECG at 1000 Hz. The R-peak detection was based on the Pan and Tompkins method [38] calculated offline, which allowed to RR interval (duration in milliseconds between two consecutive R-peaks) calculation and therefore to extract the heart rate (HR). Thanks to the VJ SDK mobile application, in version 2, we could automatically store this value, and no offline calculus was required. In VJ version the full recording of ECG related information was added within the system, which implied some changes in data management, as was also an opportunity to evolve/correct some system characteristics.

Figure 31 - Veracity version 2 basend on the VJ biomedical device and smartphone running Unity mobile application.

4.6 The synchronization messages and the game remote controller

One major concern of the system is that all data acquired must be synchronized i.e. the game events, object position or physiological measurements – this is mandatory to allow multi modal time coherent analysis of the gathered data.

Based on the assumption that local communications latencies (e.g. Mobile and the PC) were negligible and stable we used the wireless communications such as Bluetooth and Wi-Fi to transmit time events / triggers between components. Under this assumption and to ensure a system wide synchronization we decided to use a centralized approach using a mobile application as a system time clock that sends system wide time markers (triggers) as synchronization tokens. We incorporated the system clock / synchronization functionality in a game remote controller mobile application responsible to propagate time information through the several components of the system.

As such, we created a game remote controller mobile application responsible to maintain the game clock and propagate information through the several components of the system. This also allowed using this device as an operational tool to managed, control and monitor remotely the evolution of the game / monitoring sessions.

Our goal, was to have a simple “Start & Stop” solution, that would allow us to collect the ECG, HR and RR values, at the same time as the game is started. This way, the Mobile Device would initiate the synchronization process, giving a ‘Start signal’ to the PC. Following the same process, a ‘Stop signal’ from the Mobile Device would finish the recording process in the PC, when the User finish all the levels. The ‘Start signal’ between the Mobile and the PC, even though it can contain a small delay, that can be considered negligible, will help to establish the starting point/time in all recorded data and with that, allow creating a timeline for all the events.

Messages Used between the PC and the mobile device communication:

- Connect to the Server - Establish the initial connection to the Server running in the PC;
- Start message - Moves from the server window in the PC and enables the start of the game - Adaptation Level 1;
- Stop message - Moves the game workflow to the last screen;
- Skip the rules - Enables the possibility of skipping the rules in the PC at the start of a new level;
- Next level - Moves the game workflow to the next level;
- Interesting Event - Enables the coordinator responsible for supervising the phobic individual experimenting the game to mark a time stamp associated with ra elevant behaviour in this individual reactions to the game;
- Upload to the cloud – Allows to upload the relevant information stored in the PC to the cloud in the last screen;
- Logout - Disconnect from the server. Added mainly for debug purposes.

4.6.1 Remote controller technical decisions and implementation

Ours first approach was to maintain a Bluetooth solution similarly to the existing one between the Biomedical Device and the Mobile communication in version 1. While using a tested approached it would avoid introducing further dependencies on the system. However Bluetooth integration with Unity is not available in the free version. For this reason, we excluded this option, although technically sound as it is mandatory to be able to communicated between the Unity and the game controller (the system clock).

The next step was to focus on Unity free supported options besides Bluetooth. Given the network support in Unity we considered using an extra component acting as a gateway between acting as a middleman between the PC and the VJ SDK mobile application that could manage both Bluetooth and Wi-Fi connections – acting as a client server mechanism.

Standard sockets were initially considered but were dropped, in favour of Unity own solution to connect multiple applications, whether they are desktop or mobile versions – the Unity Networking Class. The Unit Networking Class allows to set up a server or connect to an existing one, while providing a set of helper functions[5].

Some time after, we were able to mount a small solution, able to run a Server on the Unity PC version and the Client on the Unity Mobile version that could exchange simple messages. By having the guarantee that this simple, yet core solution worked, we could start adapting it into our system. The result of the integrated work in the PC, where the Server is running is easy to understand and to use, has a simple interface, dedicated to the person that will be responsible for the case studies and who will fill the Participant information in the right side of the figure. This information will be stored as previous mentioned before when the game starts.

The Server (Figure 32) is deployed using the PC IP address, with a default value for the Port (we used an high value (2500) to guarantee that no collisions problems could occur), common to both the Desktop and Mobile versions. For debugging, a small window displays some messages, related to the state of the server connections, which gives a clue that the Server has established a connection with a Client and is ready to start the game. However, for most of the time, the Server is working on background, not being displayed any information. Furthermore, the Server will be listening for pre default configured messages, and when one is received, will act according to the respective messages. The server supports a set of predefined messages that, besides allowing starting and stopping the system, also allow skipping to the next level/screen and mark a time stamp of an interesting event.

Since we had figured out how to send and receive messages with success, there was no reason to be limited for the simple "Start & Stop" messages. Subsequently, we added 5 messages, which would allow controlling multiple events. Besides the Start and Stop, we also added the possibility to skip the rules, advance to the next level and mark a time stamp of an interesting event. This would be marked by the coordinator responsible for the case studies. It's also possible to upload the relevant information to the cloud in the last level and disconnect from the server or quit the game at any time. This messages are sent to the Server when the accordingly button is pressed in the smartphone.

[5] http://docs.unity3d.com/Manual/UNetOverview.html

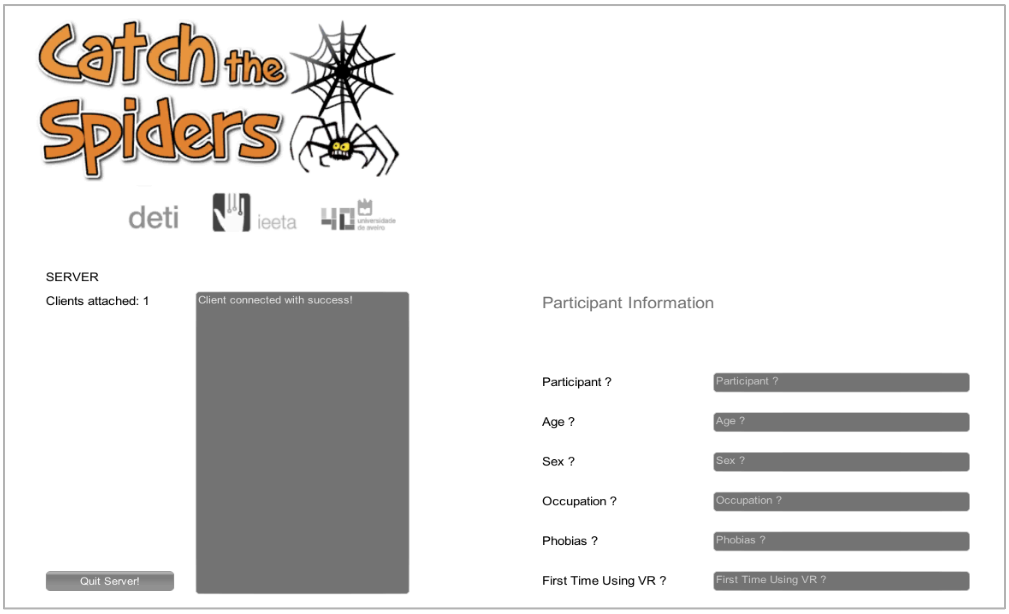

Figure 32 – Veracity server console mechanism running on the PC with one Client connected.

4.7 Game controller and Biosignal management

Besides the synchronization mechanism other main concern was to acquire and store the biomedical devices information – in this case VJ information including ECG, HR and RR values.

We needed to have an android app (developed in Java) communicating with an android unity application (developed in C#). To accomplish this, we started by using the provided Vital Jacket SDK mobile application, and using the Android Studio IDE, change it to our needs.

Taking into consideration that Unity is able to support Android plugins, we decided to implement a set of two services (One for the ECG data and the other one for the HR and RR data), common to both the VJ SDK mobile application and the one we developed with the help of Unity. A service, is nothing more than a simple way to send data from a standard app to another app. Basically, is “a piece of code” inside an app that is able to broadcast data to any other app, which should be ready/configured to listen to it.

In the particular case of our system, the broadcast service would be in the VJ SDK mobile application, which would be sending the ECG, HR and RR data. Having the connection to the VJ biomedical device already set up, thanks to the SDK, we needed to create two classes, that would extend the Service standard android class coming from android.app.Service. Besides that, add some code in the Android manifest file that let the Android know this app has two services in it, otherwise it won’t work. The final piece was to, make the Service running inside our app. To do so, we decided to start the service when the app is started.

Of course this means that the android unity application would be the broadcast receiver, which would be waiting to receive the collected data from the biomedical device. Even though this application is created using unity, the plugin required to receive the collected data is build using the Android Studio, where an android app is created, without any activity. Moreover, two classes are added, which extend android.content.BroadcastReceiver, following the same as previously described, one for the ECG, and other for the HR and RR. Since Unity is able to use external libraries, the final step was to export the app as a jar to a hierarchy of folders, using the default Asset folder: Assets/Plugins/Android/.

Subsequently in Unity, there was needed to change the Android manifest, making Unity know that a receiver exists, and what it's waiting to receive. When this information is received, it will appear in the screen, this way, the person responsible for the case study can know the information is being retrieved with success. With this, we are able to share data from one mobile app, to another in real time.

Finally, when the game is started, a string, that specifies the respective type of data: ECG, or HR and RR is added to the collected data that will be send to the Server using Wi-Fi. In turn, the Server will be listening for this strings, and will send the respective data to different files. The information regarding the biomedical device is also stored in the mobile device with an unique name that can be added before the data is collected.

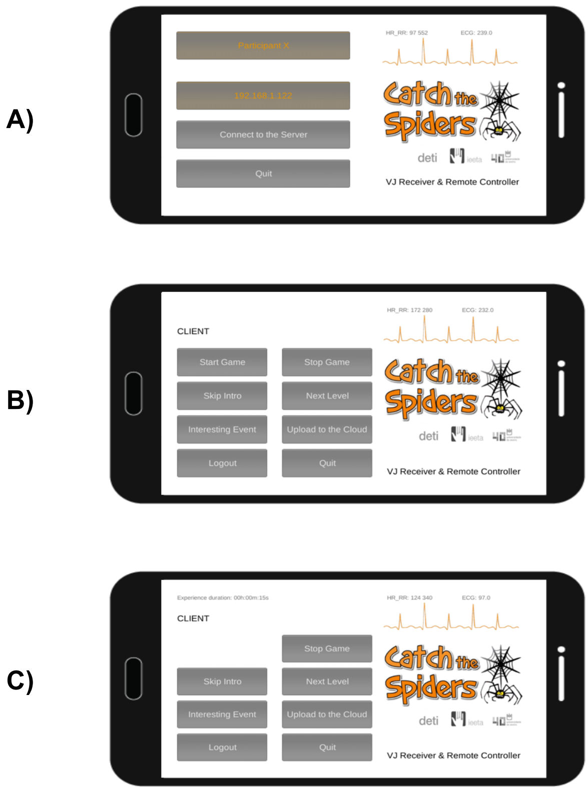

Figure 33 - Mobile remote controller application (Client): A – Initial Screen; B – Options Screen before the game is started; C – Options Screen after the game is started.

4.8 Game related information

During the game, we tracked and stored the 8-ball and the biggest spider positions of each level (excluding the spider position in the adaptations levels) during the game.

In Level 1, 2 and 3 we also recorded the number of spiders caught in the respective level and the associated timestamp, as well as the overall amount until that point.

During the development process of the system version 1, we also developed a script able to capture a screenshot of the user, using the computer webcam every 2s. However, when testing this feature, we concluded that it cause a significative slowdown in the visual display. Therefore we choose not to discard this information as other information such as the stimulus related was more relevant and could not be compromised by not crucial data like the user screen shot..

Another element that we considered important was the position of the 3D hand models. Combined with the 8-ball and biggest spider, would allow to keep tracking of each individual object in time and space. Nevertheless, this was not possible to achieve, the visual display (Figure 34) would show a sequence of were the hand would be, since the game started, until the current moment, affecting the VE. Identifying the cause of such problem is still an open issue.

Figure 34 - Hand tracking issues trying to record the position of the 3D hand models for a high sampling rate.

4.9 Data management

The data collection and management relied on the Unity game engine possibilities, using it to store relevant information into text files format. This information included, besides game related information, the biomedical information, and other participant demographics related information like age, sex, occupation, if it was the first time using VR.

The data i.e. text files were organized in folder were we also stored in-game screenshots, every 2s. Inside each level folder, we also added a text file, where the duration of each level, and when that level started would be stored. By doing this, it was possible to have a recording of what happened during each level, and of course, for the overall game. As default, the game folder is placed the desktop folder, using a folder hierarchical structure, since it is easy to find and can be a generic location, if we take into consideration different operating systems.

Since Unity enables the creation of executable for different operating systems, we develop a script that has a generic path, which works for all operating systems. When the game is started, creates the main folder and all the respective folders associated to each participant (Figure 35).

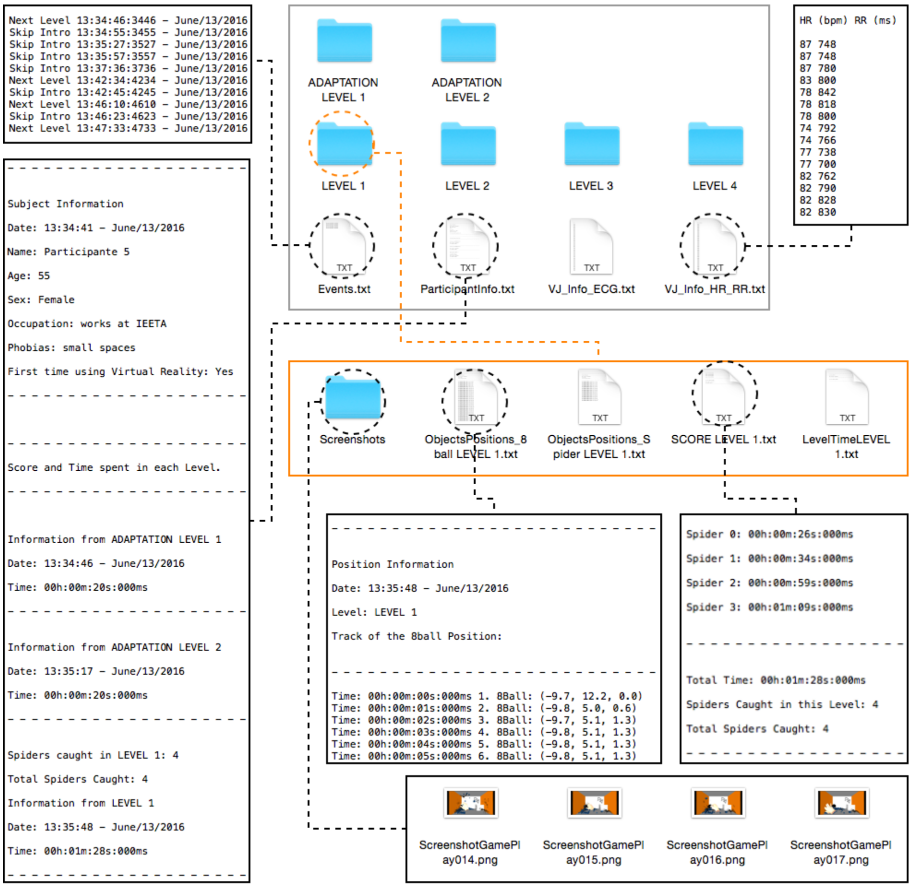

Figure 35 - Example of the different Participant collected data, including the PC and mobile device.

Having the biosignal data regarding the ECG and HR, combined with the information of the duration of each level in the game stored, it is possible to use Matlab® software to build a quick preview of the collected data like it is illustrated in Figure 36.

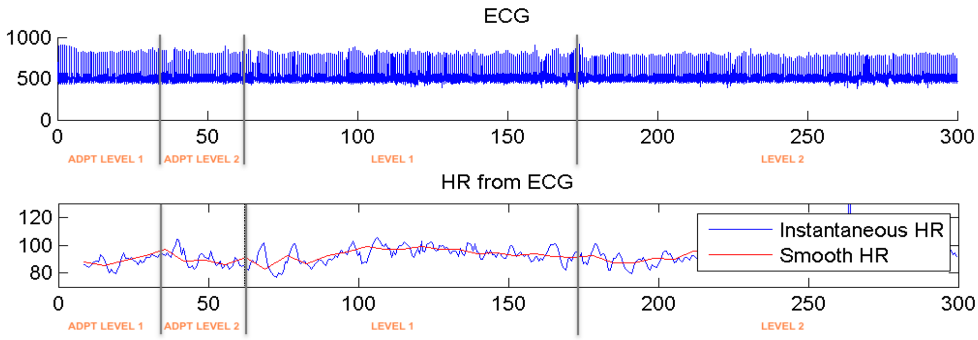

Figure 36 - Sample collection: the synchronous acquisition of the several data modalities. The level transitions (vertical lines) are mapped into both ECG and corresponding HR.

Besides saving the collected data, we also added the ability to upload text files (which contain the most relevant information) into the cloud. Since Unity does not support the most obvious choices like Dropbox or Google Drive, we decided to use Parse Cloud. Some previous work was made with this tool, in a mobile context, but after some research, we discovered that Unity also supported it. Giving this, we developed a script that allows these features, but with the restriction of only being available after all the levels were experienced. As such, in the game final level, whether by pressing the "SPACE" key on the laptop keyboard, or by clicking the "Upload to the Cloud" button in the mobile application/remote controller, the information within the text files would be send to the cloud (Figure 37).

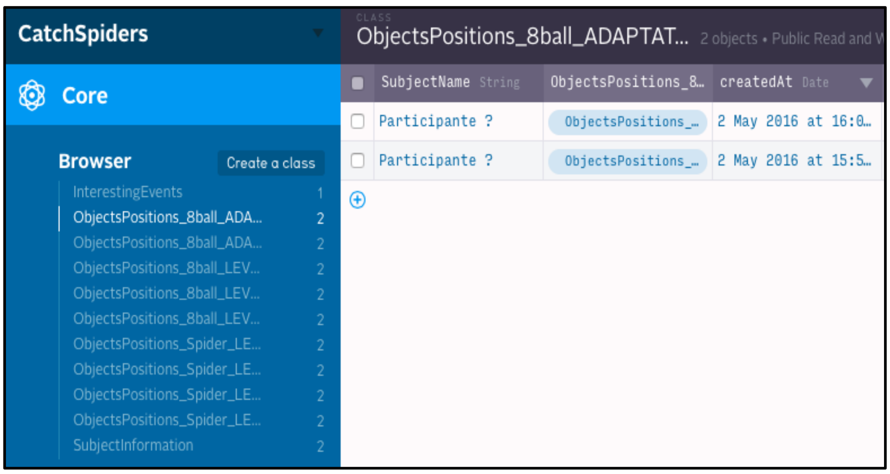

Figure 37 - Parse Cloud Dashboard with some uploaded data.

5 Case Study

Aiming to test the proper functioning of the multiple modules of our system, how it would behave in a real data-collecting scenario with multiple individuals for a long period and also to prove the initial hypothesis of having an affordable system, quick to deploy that could help shorten the gap between the laboratory and the real life scenario, we recruited 22 participants (10 females) to take part in our case study (with an average age of 31 years old).

The participants were selected from different areas of the academic community at the University of Aveiro, and were asked to fill out the Fear of Spiders Questionnaire [39] with the goal to identify possible spider phobics (the provided questionnaire can be found in here: https://goo.gl/GpQ8oB). Based on the questionnaires scores the probable phobics (individuals with scores above the 75^{th} percentile) and the non-phobics (scoring below 25^{th} percentile) were selected. However, no formal diagnosis of fear was performed.

The participants gave their written consent (document can be found in here: https://goo.gl/xOHGtx) and were informed about the possibility of being able to withdraw from the study at any time and the fact that all the data would be private and only used for this dissertation. The recruitment processes, and the data collection took place between March and June 2016, and were conducted under the guidelines of the Declaration of Helsinki and standards of the American Psychological Association.

At the beginning of the study, all the participants answered a questionnaire about their demographic and other relevant information to the study (Age, Sex, Occupation, any kind of Phobia, First time using VR) (Table 1). After each participant experience all the levels and finished the game, we ask them to answer a second questionnaire survey, related to the acceptance of our system (survey can be found in here: https://goo.gl/DzZHXV).

The data collected include two phases, the first using Bitalino (17 subjects) and the second using our improved system with the VJ (5 subject, two probable phobics and three non-phobics). The transition between these phases allowed us to assess and identify some issues that were corrected for the VJ version (in a sense, the Bitalino phase was a pilot experiment).

	Age	Sex	Phobias	First time using VR
Participant 1	38	Female	Spiders	Yes
Participant 2	20	Male	None	No
Participant 3	23	Female	None	No
Participant 4	25	Female	None	No
Participant 5	41	Male	None	No
Participant 6	23	Female	None	No
Participant 7	21	Male	None	No
Participant 8	21	Male	None	No
Participant 9	28	Male	None	No
Participant 10	51	Male	None	No
Participant 11	22	Male	None	No
Participant 12	21	Female	Spiders	Yes
Participant 13	53	Male	None	No
Participant 14	24	Male	None	No
Participant 15	23	Male	None	No
Participant 16	22	Male	None	No
Participant 17	27	Male	None	No
Participant 18	36	Female	Spiders	No
Participant 19	33	Female	Cockroaches	No
Participant 20	51	Female	Snakes	Yes
Participant 21	25	Female	None	No
Participant 22	55	Female	Spiders	Yes

Table 1 - Demographic information of the case study participants.

5.1 Experimental Setup

The experimental setup consists on a laptop, a video projector, a leap motion, a mobile device and a table (Figure 38).

In the table, we could find a laptop, which played the middleman, providing the means to properly visualize the virtual reality environment, and also at the same time record all the data. Also in the table, a video projector was placed at a distance of 1,2 meters to the wall. This way, all the participants experienced the VR environment in a 1.20 x 0.68 meters perspective (the equivalent to a 55" TV screen). The Leap Motion was placed in front of the participant, sending the input associated to the hands gestures to the laptop, and in turn to the video projector.

The participants were equipped with a set of ECG electrodes, which were placed accordingly to Bitalino (version 1) or VJ (version 2) guidelines for proper data collection (ECG, HR and RR).

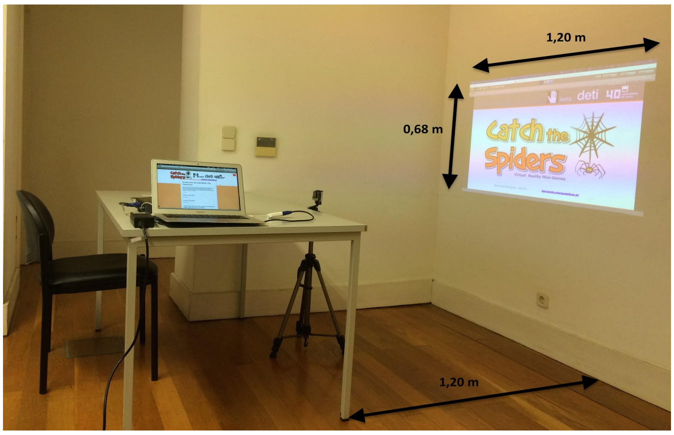

Figure 38 - Case study scenario

Two video recording cameras were used in simultaneous (Figure 39 - Front view of the participant using his hands to interact with the system.Figure 39 and Figure 40).

One, front facing the participant, with the main objective of capturing the face and the upper torso. To accomplish this we relied on a GoPro Hero 3+ Camera, which acquired the video at 100 Hz. A second camera was used to capture a bird's eye view of the experiment, including the participant and the projection of the VR environment. For this second camera, we used a Sony HDR AS30V Camera, which acquired video at 25 Hz. The sound captured in both video recordings was used to later synchronize the collected data. The video recordings provide an independent observation of the participant behaviour in "key" moments besides contextualizing the observed interaction throughout the game.

Figure 39 - Front view of the participant using his hands to interact with the system.

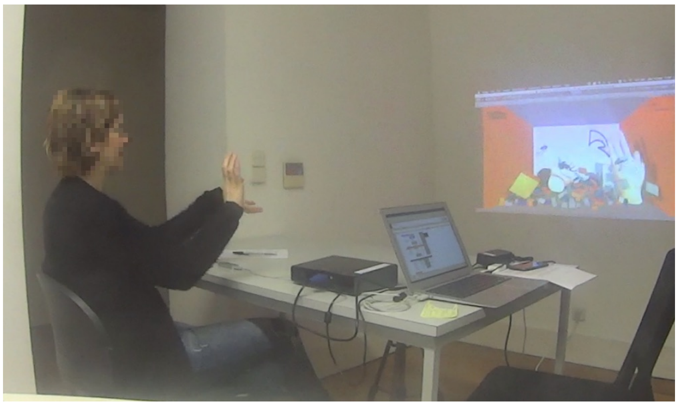

Figure 40 - Back view of the overall scenario with the game being displayed on the wall by the projector and participant using his hands to interact with the system.

5.2 User acceptance assessment

We performed a user acceptance assessment with the objective of collecting feedback from the participants and use it to improve our system. This assessment was performed through a survey presented to the participants at the end of the game. Based on the survey results from the user acceptance, we can state that the participant’s response to our solution was positive.

Eighteen of twenty-two (18/22) participants agreed that even though an adaptation period is required when using the Leap Motion controller, once you get familiarized, it is easy to use and to accomplish the required objectives from each level (Figure 42). Complementary, 19/22 participant’s state that they were able to fulfil the objectives associated to each respective level in our game and that no error occurred during the overall duration of the interaction with our virtual reality game. The remaining three participants pointed some irregularities, which sometimes occurred with the hand models. However, since the Leap Motion framework provided the hand models to us, the reported problems were out of our control.

The animation of the spiders was another consensual point. Even though we are using an animated model, 20/22 agrees that the animations used were close to reality.

Regarding the participant's choice for the preferred level (Figure 43), 9/22 selected Level 4 as the favourite (the level where the objective was not to catch spiders, but to interact with them). The second most selected level was Level 2 (with 6/22), where even though a lot of objects exist, participants enjoy that fact, combined with the spawn of a new spider, every time one was caught.

Furthermore, when asked to comment the overall system (Figure 41), regarding 4 specific topics: appearance, easy to use, clarity of the information and general satisfaction, selecting one from 5 possible options (bad, mediocre, average, good and excellent), participants feedback was substantially positive, oscillating the vast majority between the good and excellent options.

During the case study duration, none of the participants withdrew. Also, when asked to comment the duration of the study, it was unanimous that the use of a time period that the participant themselves could control was the right choice. Finally, when asked if they would be willing to play our game again, not taking into consideration the phobic factor, 19/22 said yes, which was a good indicator of the system potential and allowed to infer that the participants enjoy interacting with our system.

The overall acceptance from the participants shows positive results, while also providing us with relevant feedback to take into consideration in the future.

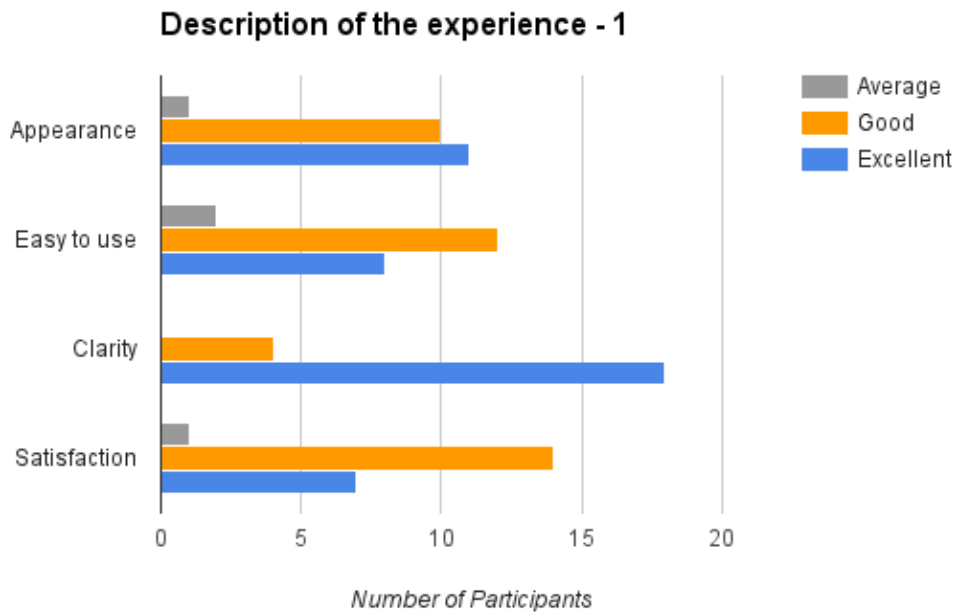

Figure 41 - Results of the survey, related to the appearance, easy to use, clarity of information ands overall satisfaction regarding the experienced game.

Figure 42 - Results of the survey, related to the acceptance of the system.

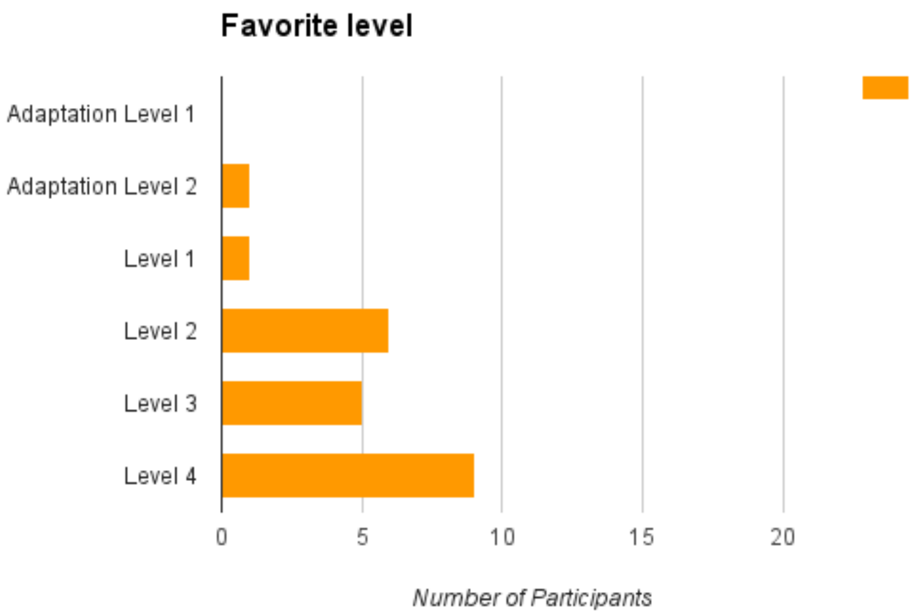

Figure 43 - Results of the survey, participant's favourite level.

5.3 Data Analysis

From the 22 participants that fulfilled the Fear of Spiders Questionnaire, 5 were selected to experiment the system final version. The idea was to evaluate the stimulus influence on cardiovascular response. Therefore, using the collected HR, a paired statistical analysis was performed. Our hypothesis is based on the assumption that there will be differences between adaptation and active levels.

For data analysis the Matlab® software was used, for HR median comparison between levels a Wilcoxon signed rank test was performed. The data dispersion was also important to infer the impact of the stimulus in the participant, in that case a Two-sample F-test was implemented, testing the alternative hypothesis that the population variance of x is lower than that of y. Both approaches evaluate multiple comparisons, in order to evaluate differences between game levels considering an alpha of 0.05. Therefore, and in order to accomplishes type I errors a post hoc correction should be performed, in that case we selected the Bonferroni correction. Figure 44, illustrates the obtained results, according to every level in the game, for each respective participant.

As such, it is possible to infer that participant 1, can be considered the “perfect subject” in this study, taking into consideration that there is an increase on the median values, over the previous levels values, ($p<0.003$). In the Adaptation Level 1 and 2, the HR values start lower, but, when the spider stimulus is introduced in Level 1, and so on, there is a considerable increase in the HR values. Furthermore, it is also possible to verify that there is an increase in the HR dispersion values in the levels with the spider stimulus, when compared with the adaptation levels, which was again statistically verify ($p<0.003$).

In the case of participant 2, the variance hypothesis, when comparing the adaptation level 1 and adaptation level 2, was rejected. This could be caused by the participant current state, showing signs of cough, which induces noise on the ECG and consequently HR.

Participant 3, verify that the variance value was higher in the levels with spiders, when compared with the adaptation levels. This fact was also verified for level 2, when compared to level 1. The exception was level 4, when compared to the adaptation level 2 (level were the spiders follow the participant hands).

For participant 4, this test shows that all levels have an increase variance value when compared to the adaptation level 1. Also levels 2 and 3 have an increase variance value when compared to level 1.

Following participant 1 results, participant 5 also shows to have a higher median value in the levels were the spider stimulus is introduced (Figure 44). Also, a statistical evidence ($p<0.003$) between median values was observed in this participant for all levels, except between level 2 and level 4. Considering the data dispersion, it indicates higher values regarding active levels (presence of spiders) ($p<0.003$). During the case study, when experiencing the two last levels, the participant complains about being tired of using the arms.

Overall, the statistical analysis proved that there is an increase in the variance values of the participants HR values, regarding the levels with the spider stimulus, when compared with the adaptation levels