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AWARE: Mobile Augmented Reality Psychological Assessment Solution

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 Eletrónica, 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.

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Prof. Doutor José Maria Amaral Fernandes
Professor Auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro

agradecimentos

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palavras-chave sistemas de monitorização, computação móvel, fobias, emoções, realidade aumentada

resumo

A exposição a agressões psicológicas subsequentes do estilo de vida na sociedade atual, como o stress, trauma, ou a deslocalização constante, têm um forte impacto na condição psicológica e comportamental das pessoas, podendo mesmo conduzir a distúrbios de ansiedade. Desta forma, é imperativo que os processos de terapia recriem ambientes semelhantes aos do quotidiano do indivíduo ("contextos ecologicamente válidos"), para que este possa ser exposto aos seus receios de forma controlada. No entanto, existe alguma dificuldade em obter dados ecologicamente precisos, uma vez que as ferramentas de medição ou métodos de monitorização utilizados induzem alterações no contexto real, colocando em causa a viabilidade da execução do processo num ambiente natural para o utilizador.

Nesta dissertação, propomos o sistema AWARE, uma solução que permite avaliar as condições fisiológicas e comportamentais do(s) participante(s) de uma experiência. Este sistema permite integrar o individuo num contexto ecologicamente válido (fora de laboratório), durante a execução de terapia, recorrendo aos recursos de localização, deteção de movimento e conectividade disponíveis num *smartphone*, bem como a dispositivos dedicados de medição de sinais vitais, de uma forma não intrusiva, abstraindo o sujeito do mesmo. A existência de uma estrutura de persistência de dados suportada na *Cloud* garante também um acesso remoto a estes resultados.

Terapias associadas a distúrbios comportamentais têm usualmente como componente fundamental a exposição a estímulos que despoletam reações de ansiedade. Desta forma, e paralelamente à monitorização, o sistema proposto está preparado para a apresentação de estímulos, permitindo a avaliação da consequente reação do utilizador. Graças à implementação de tecnologias de realidade aumentada, torna-se possível apresentar modelos 3D virtuais, integrados na perspetiva do mundo real do sujeito. Esta proposta de solução constitui, assim, uma ferramenta flexível e de utilização intuitiva, com a qual podemos avaliar as alterações provocadas no comportamento em cada sujeito, quando confrontado com estímulos específicos.

O sistema AWARE foi testado em dois contextos diferentes: 1. A componente de monitorização foi utilizada em artistas aquando da representação de variados temas de música clássica; 2. As componentes de monitorização e realidade aumentada foram aplicadas em simultâneo no contexto do estudo e tratamento de fobias. No primeiro caso de estudo, verificou-se um aumento da frequência cardíaca em momentos cruciais das peças, como a subida ao palco e o início da atuação. No segundo contexto, verificou-se que o aparecimento de um estímulo despoleta alterações fisiológicas (exemplo: alterações na frequência cardíaca). Em terapias de tratamento de fobias, os indivíduos são repetidamente sujeitos ao mesmo tipo de testes/estímulos, de forma a avaliar a reação à exposição continuada aos mesmos (cuja variação irá, em teoria, sofrer uma diminuição, caso o sujeito seja fóbico). Na nossa experiência, dois voluntários não fóbicos realizaram dois testes sucessivos, não havendo um padrão de variação da frequência cardíaca do primeiro para o segundo teste. Este valor vai de encontro ao esperado, dada a caracterização não fobica dos sujeitos.

Os resultados apresentados sugerem que o sistema proposto pode revelar-se uma ferramenta útil quer na monitorização não intrusiva, quer em terapias de exposição, sendo de fácil integração num contexto real.

keywords monitoring systems, mobile computing, phobias, emotions, augmented reality

abstract

The exposure to psychologically hostile situations in today's society, like stress, trauma or constant life event changing have a strong negative influence on people's psychological condition and general behavior, possibly leading to anxiety-related disorders. Therefore, it is of extreme importance that the therapy processes are able to recreate a natural and familiar ("ecological") environment, according to the individual everyday life, allowing him/her to face his/her fear in a controlled environment. However, up to this day, there are issues related to the gathering of ecologically precise data, due to the real world variations induced by the measuring tools or the viability issues related to the therapy's execution.

In this dissertation, we propose the AWARE system, a solution that allows the assessment of a subject's physiological and behavioral condition in an ecologically valid context, using the location, movement description and connectivity resources available on a smartphone, as well as dedicated vital signal measuring devices. The whole process is executed outside of the lab, in a real ecosystem, while keeping the subject oblivious about the whole monitoring activity. The existence of a data persistence based on the Cloud assures the remote availability of this results.

Parallel to the monitoring, the proposed solution is also ready to present stimuli, providing a means of evaluating the subject's reaction. Augmented reality technologies are employed in order to present different 3D models embedded into the subject's real world perspective. Our system establishes itself as a flexible and intuitive tool, with which we can study the behavioral changes caused by the confrontation of a person with a specific set of stimuli.

AWARE was tested in two different contexts: 1. Independently, the monitoring features were used in musicians during the performance of classical plays; 2. On a different scenario, both the augmented reality and the monitoring modules were tested together in phobia analysis and treatment. In the first study case, a heart rate frequency increase was detected in crucial moments of the plays (like going to the stage, or beginning the performance). In the second study case, some physiological reactions to the presented stimuli (e.g. heart rate frequency variation) were observed. In phobia treatment therapies, subjects repeat the same series of tests multiple times, in order to evaluate the reaction to continuous exposure to the same stimuli (which will, in theory, have a progressively lower variation in phobic subjects). In our experiments, the volunteers executed two tests each, and there was not any visible heart rate standard deviation decrease, an expected result, given their non-phobic condition.

The presented results suggest that the proposed system may be a useful tool in non-intrusive monitoring, and in exposure therapies, being the system integration in real contexts of straightforward use.

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1. Introduction & Motivation

In today's fast-changing society, people are frequently exposed to psychologically hostile situations, like stress, trauma, and unexpected life changing events. These conditions are usually worsened by the lifestyle changes observed all over the world in the last few decades, defined by the pressure associated with many modern jobs and the progressively decrease in the duration of people's leisure time [1]. This exposure has a strong negative influence in our psychological condition, and if left unattended, it can lead to the appearance of various psychological and emotion-related disorders, a problem common to almost half a billion people [2]. Over time, the burden of mental illnesses (e.g. anxiety-related problems, one of the most common types of mental disease nowadays, accounting for almost twenty percent of all psychological illnesses [3]) translates into personal behavior changes that can threat the patient's life quality (e.g. sleep deprivation, panic attacks, depression, cardiovascular problems, suicidal thoughts [4]).

On behavior disorders, the exposure therapies are usually used in order to guarantee the subject habituation to the cause of the illness. In this kind of therapy, the subject is exposed to a stimulus (e.g. visual) that triggers anxiety (e.g. spider presentation in arachnophobia). This therapy aims to change beliefs, behavior and thinking, by a progressive exposure to the stimulus (either time exposure, or proximity to stimulus).

Usually, these therapies have been performed in laboratory, under highly controlled settings completely unfamiliar to the patient. These circumstances have a notable influence in the observed behavior, not valorizing the relevance of the context and environment in the studied phenomena [5]. There are relevant benefits in the results produced with this approach, however researchers are likely to miss important aspects of emotional functioning related to life outside the lab [5]. Therefore, there is a need of non-intrusively monitoring people in their daily life context (ambulatory assessment), in order to properly capture the mentioned emotional responses. Consequently, the capturing and quantification of physiology and behavior in real life conditions are vital to the development/improvement of psychological treatments [2].

The technological evolution and miniaturization that occurred in the last few years provided an opportunity to develop a viable application for the purpose of ecological ambulatory assessment. The advent of mobile devices, for both user interface and data gathering, makes it possible to adapt these new technologies to aid in the diagnosis and treatment of psychological disorders, with no necessary downsides in its effectiveness [6], when compared to conventional treatment. Considering the stimulus presentation, and the need to make it as near as possible to reality, the augmented reality (the rendering of a virtual model in a real world video) and its recent developments, provide an unprecedented means of performing therapy-related stimuli in a natural but highly controllable environment, while maintaining the subjects' sense of presence and own-body awareness. This opens an opportunity to use it as an information delivery medium when designing an exposure-based psychological assessment tool.

Objectives

AWARE is a mobile-based context-aware monitoring tool (i.e. a system that changes its operational behavior based on captured working environment surroundings [7]). With it, we aim to provide the following high-level features:

- Non-intrusive ambulatory assessment of the subject's behavioral and psycho-physiological data;
- Realistic synthetic stimuli presentation, embedded into a real world context;
- Permanent online remote availability of all recorded data;
- Generic architectural structure, applicable to different usage scenarios;
- Intuitively deployable system, based on accessible and widespread mobile technology.

Contributions

The main contribution of this dissertation is the development of a generic context-aware psychological monitoring tool. It is capable of performing non-intrusive ambulatory (outside of the lab) assessment of people's movement, heart rate and general behavior, providing an ecologically valid quantification of their condition. Additionally, it employs augmented reality techniques to deliver virtual stimuli as integral elements of the subject's real world perception, recording the reactions to exposure. Finally, it supports a cloud based data flow that ensures permanent online availability of all recorded data, with all the necessary information to allow synchronized analysis performance.

Since we had a generic system, we developed two application-level alternative versions of our system, adapted to very specific scenarios:

- EVerMoRE (impulsE Vital Musical REcorder), a version employing different monitoring modules, that records a musical concert and tracks its performer's physical and physiological information. It helps in the identification of key moments or mistakes in the music piece, and in the association between them and quantified/objective metrics regarding his/her posture and/or anxiety level, ultimately helping him/her to gain self-control. It also allows us to assess how the same music is experienced by different people;
- AWARE (Aware aWe-inducing Augmented REality), a version that implements augmented reality (AR) modules along with the monitoring features, in order to help in the processes of assessment and treatment of specific psychological phobias.

> Thanks to the convergence of synthetic and real world elements in the same context, we are able to help in the exposure therapy process of various different phobias, without compromising the ecological validity of its results or removing the patient's sense of presence during the experiments. This way, we confront him/her with the stimuli behind his/her disorder's existence, in a real but highly controllable and easily deployable mobile platform.

This work would not be possible without the collaboration of Gilvano Dalagna and Professor Filipa Lã (for the EVerMoRE case study) and Professor Sandra Soares (for consulting in the AWARE study scenario).

Structure

This dissertation is comprised of 6 chapters (excluding this one). The next chapter provides a brief overview about the impact of mental health disorders all over the world, as well as the consequent importance of the development of psychological assessment and treatment areas of study. It then gives a report about the types of therapy currently performed in order to combat mental disorders, followed by a review of their subjacent shortcomings, the identification of the major problem that motivated the project discussed in this dissertation and a small presentation of the new technologies that can help us provide a solution (virtual/augmented reality). It finishes with a description of two specific use case scenarios and how our system will resolve the previously identified shortcomings.

Chapter 3 provides a theoretical introduction to the concepts of virtual and augmented reality, comparing the respective advantages and weaknesses. It also reports different successful application examples of each one of them, especially those related to psychological assessment and psychotherapy.

Chapter 4, describes our proposed solution, AWARE. It begins with an expression of the main goals of the system and the description of the general workflow.

Chapter 5 describes all the system implementation details. It outlines the reasons behind the choice of our development resources, and explains the technical aspects of the different parts of the proposed solution.

Chapter 6 starts by defining our case studies, presenting the obtained results, together with their statistical analysis and interpretation.

Chapter 7, the final chapter summarizes the conclusions drawn from the development, testing and subsequent analysis of the proposed solution, ending with the discussion of possible improvements to the AWARE system and future research topics.

2. Psychological assessment: the questions and scenarios

All over the world, there are roughly 450 million people with mental health disorders, making them one of the leading causes of disability [8]. This type of illness can wield a significant burden in the sufferers' everyday life, potentially resulting in distress and impairment at work, school, family, relationships, and nearly all of their social or personal activities [9]. The individuals more severely affected also have an higher chance of simultaneously developing other psychological problems, and even of contracting related physical diseases (e.g. hypertension, respiratory problems) [10]. This reality makes psychological disorders one of the most life quality impairing types of condition in modern day society.

Despite their consequences, more than half of the sufferers end up not getting treatment for their mental illnesses [8], due to therapy access difficulty (high cost, long duration or lack of therapists), underestimation of the problem (by themselves and/or their community) or simply lack of knowledge that prevents them from even realizing that the problem exists. Therefore, it is vital to raise awareness for the existing treatments, and more importantly, develop more accessible and efficient methods of diagnosis and therapy for this type of disorder. While there are many contributing factors to the rate of that development, the reliable capturing and quantification of behavior and emotions is definitely one of the most important [2]. However, there are fundamental issues with the stimuli presentation and feedback acquisition methods in the current psychotherapy techniques, which undermine this goal. To better understand why, it is important to understand how the most common treatment procedures work.

Anxiety disorders, which include post-traumatic stress and specific phobia, are among the most widespread illnesses, being the most prevalent mental health problems in various different countries [11]. In the US, a national survey concluded that almost twenty percent of psychiatric problems are anxiety-related [3]. Diagnosis and therapy regarding them is usually based on two distinct approaches: self-assessment (through clinical interviews and questionnaires) and behavior therapy (through object or situation exposure, accompanied by real-time observation). While the former provides a simple diagnosis and comprehensive evaluation of the individual's experience, the latter is an ideal part of the assessment process, because it allows a direct observation and understanding of the patient's reaction to traumatic and/or phobic stimuli [5]. Since trauma, phobia and panic sufferers tend to avoid situations where they are exposed to the object responsible for their illness, and given the emotional intensity of their problem, exposure therapy produces objective data regarding the variables associated with the disorder, which may be less biased than self-assessment results [5]. However, it is essential to reproduce the conditions of a confrontation in a naturalistic setting, in order to be able to observe the patient's natural reactions to stimuli, thus obtaining ecologically valid and clinically reliable results. Assuring this is currently one of the major difficulties of exposure and general behavior therapy.

Exposure therapy

Exposure therapy (ET) is an integral part of behavior therapy, which is used to treat traumatic stress, specific phobias and general anxiety disorders. It helps people overcoming their illness by teaching them how to face the reason for its existence in a systematic way (i.e. through repetitive exposure to the stimuli, i.e. the responsible object or situation) [12]. The most frequently used stimuli presentation techniques in this kind of therapy are:

- In-vivo exposure: direct confrontation with the cause of the trauma/phobia (activity, object or situation). While it can be a very effective exposure technique, it usually involves handling live animals or potentially dangerous objects, which in turn generates some risk and uncontrollability associated with the test. In some cases, this unpredictability results in an incompatibility between in-vivo exposure and the patient [13];
- Systematic desensitization: this technique requires the patient to be in a relaxed state, and consists in helping him/her imagine the origin of the trauma/phobia/disorder and associate that mental image with the lack of anxiety (s)he is feeling. This technique is the cheapest and most simple to apply, but it does not ensure that the patient is actually forcing him/herself to imagine the scenario desired by the therapist;
- Multimedia reproduction: after becoming a possibility, the exposure to stimuli through the presentation of different media (images [14], sounds [15] or videos [16]) was widely accepted as an effective treatment technique, because it allows an isolated presentation of the stimuli in a perfectly controllable format, while, at the same time, making it possible to easily check if the subject is invested in the stimuli's presentation. In this scenario, one of the most frequently used stimulus sets in the International Affective Picture System (IAPS) [14], which contains various media elements, rated according to degree of expected attraction/aversion towards them.

While all the referred techniques have strong points, there are notable downsides associated with each one. Moreover, they all share a weakness in their conventional form, related to the nature of the psychological assessment: they are usually run in controlled lab facilities, a fact that influences the patient's behavior and the way (s)he reacts to the stimuli [5]. Consequently, it does not reflect the natural behavior in his/her familiar environment (the exact same one where the mental disorder manifests itself), and possibly lacks some of the emotional phenomena specific to his/her daily life. In order to capture these events, it is necessary to employ an ambulatory/"on the field" monitoring approach.

There have been successive attempts to improve the ecological value of the assessment results. In 2013, Ricardo Moreira, a master's student from the Computer and Telematics Engineering course of the University of Aveiro, developed BeMonitored, a psychological assessment tool that delivered multimedia stimuli to the user, while ensuring a synchronous acquisition of both physiological and behavioral data [17]. The solution also offered an ambulatory functioning mode, by running on a mobile phone (with accelerometer) that could be carried outside of the lab. It became possible to quantify and evaluate subject's response in a familiar environment (e.g. home) (Figure 1). But in spite of their measurability, the results still did not provide an accurate representation of the patient's natural behavior: since the stimuli were shown in a movie, there was no sense of mutual presence (the patient did not feel like (s)he was in the same location as the watched stimulus).

Figure 1 Session review interface in the BeMonitored Application [17]

In the past decade, there have been critical developments in the fields of virtual ad augmented reality (VR and AR), forms of media capable of levels of immersion higher than any other currently available one [18]. While not all traumatic/phobic disorders can benefit from these technologies (e.g. it is hard to simulate the conditions related to the fear of flying using AR), there are multiple situations (especially those related to specific stimulus or objects) where their employment might have a positive impact in psychotherapy support.

In AWARE, we employ augmented reality (AR) in order to blend both synthetic and physical worlds into a single perceivable environment, aiming to accurately assess the subject's ecologically natural behavior and psycho-physiological reaction. Our employed monitoring mechanisms assure that (s)he maintains his/her sense of presence in the real world, and the mobile nature of our system, as well as the unique advantages of AR (that we will explain in the next chapter) turn AWARE into an highly adaptable tool, that can be adapted for usage in a multitude of different contexts and scenarios.

3. Technical context

In the last few years, the evolution of virtual reality (VR) and augmented reality (AR) media and development tools turned a mostly theoretical subject into a blooming area of study, with numerous innovative practical applications. Researches began studying ways of adapting it to different professional contexts. In the field of psychology, it was found that these technologies can help giving birth to new therapy procedures that can revolutionize the way mental health disorders are diagnosed and treated.

Virtual Reality

When describing virtual reality (VR) and how it is used in psychological assessment, it is necessary to define the concept of virtual environment (VE). Every VR solution's development process implies the production of a synthetic "world", generated with computing technology. In it, there will be virtual entities, visual stimuli that share at least one attribute with a real world object (e.g. appearance), without necessarily sharing all of its physical features [19]. In this scenario, a VR application aims to "extract" the user from the real world and put him/her into the synthetic one, exposing him/her to virtual sensory information that emulates real life stimuli, and allowing him/her to navigate through, and interact with, the elements of that VE [20]. Sometimes, a VR solution uses multi-modal fusion, exposing the user to information perceived with multiple different senses, like haptic (contact), auditory or olfactory feedback [21].

VR systems can be categorized according to their level of immersion. This concept defines the quality and quantity of the stimuli employed to simulate the environment, and is closely related with the system's ability to isolate the user from foreign real world stimuli and immerse him/her into the VR experience [18]. Therefore, VR systems are divided into three categories, defined by Ma and Zheng (2011) [22] according to the following guidelines:

- Non-immersive: employs a conventional graphics workstation, using common human-computer interaction devices, like a regular monitor and a keyboard/mouse set;
- Semi-immersive: uses a relatively high performance graphics computing system along with a large display surface or collection of displays, allowing a more detailed perspective of the visual scene;
- Immersive: probably the most widely known category, and the ones that provide a better feeling of immersion and presence. The user wears some form of head display that helps delivering the different sensory aspects of the VE to him/her, and that may contain trackers or sensors to assess his/her movement and reproduce it into the scene.

Applications

Nowadays, virtual reality has many applications, and is used in a vast number of fields, including entertainment (e.g. immersive videogames), education/training (e.g. virtual classrooms), engineering (e.g. product schematic visualizers), media/marketing (e.g. virtual reality 3D paintings) and healthcare (e.g. psychological therapy), among others [23].

In psychology, VR systems have gained an important place in the last decade, 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 have the patients increasingly exposed to stimuli related to their anxiety disorder, over several sessions, progressively reducing their behavioral reactions [24].

Virtual Better, a VR system developed by A. Rizzo [25], has been used by the US Government to help treating post-traumatic stress disorders in veteran military soldiers, by introducing them to a virtual world simulating the sources of combat stress.

As specific phobia assessment and treatment solutions, there are systems designed around VRET for social phobia (fear of speaking/interacting with others)[26], agoraphobia (fear of open/crowded environments)[27], aviophobia (fear of flying)[28], among others. The effectiveness of this kind of approach has been tested and actually proven to be as effective as in-vivo exposure solutions, while improving the patient's acceptance to the treatment [29]. However, there are some shortcomings in using this type of technology, in terms of both logistics and technical aspects. The price of the needed hardware can ascend to several hundred or even thousands of euros at the moment, even though this value has been rapidly decreasing lately [30]. The software development time and cost is also high [27], as an entire VE needs to be created, and constantly redesigned in order to be used for each specific phobia. Moreover, many of the various VR systems' users experienced motion sickness. This condition is related to the discrepancy between physical (body) and perceived (brain) movement [31], and it might invalidate the option of using VRET in some cases. While the reasons for this phenomena that are related to field of view and tracking/movement latency are partially solved in modern VR devices, the motion sickness prevention mechanisms are still on research phase, and there's no definite solution to this problem at the moment [32].

Augmented Reality

At the beginning of the last decade of the twentieth century, a new exposure paradigm was developed, and named as Augmented Reality (AR). This form of technology is characterized by the introduction of computer generated stimuli onto an existing real environment. This way, AR systems introduce synthetic elements in order to enhance the user's perception of the real world [33], forming a subclass of VR systems defined as "Mixed Reality" (the merge of reality and virtuality, as shown in Figure 2) [34]. In contrast to VR, AR does not aim to "extract" its user from the physical space that (s)he occupies; instead, it is able to present virtual stimuli while maintaining the user's sense of presence, trying to improve reality, instead of replacing it [35].

Depending on the extension of the synthetic overlay, a system can be described as using Augmented Reality/AR (if the user's perception has mostly real world elements) or Augmented Virtuality/AV (if the user's perception is predominantly composed of virtual elements).

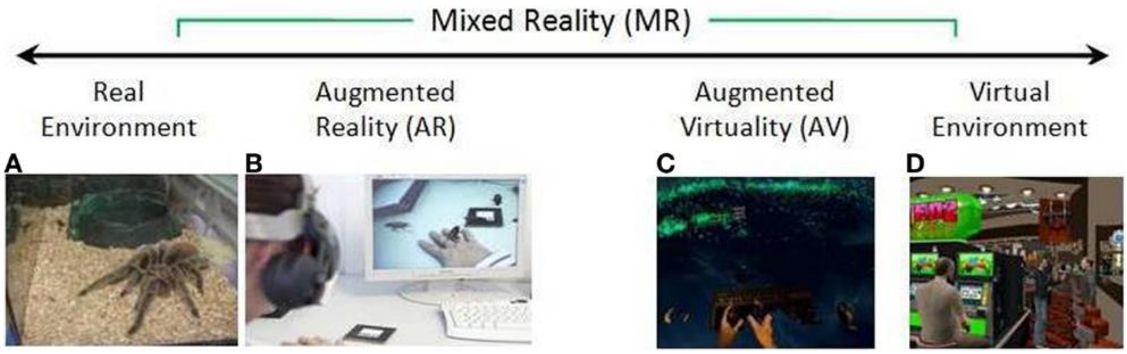

Figure 2 The "virtuality continuum", from the completely real world environment (A) to a completely virtual one (D). Augmented reality inserts synthetic elements in a mostly real background environment; Augmented virtuality inserts key real world elements (e.g. user's real body) into a predominantly virtual environment. Figure taken from [19] *(original concept from* [34]*)*

In terms of hardware, the requirements of developing and deploying an AR system are a lot less steep than the ones associated with the building of a VR equivalent. Since there is not a full Virtual Environment, the virtual stimuli models are the only elements that need to be rendered by the host platform. Therefore, the generic requirements for an AR-based solution [36] are reduced to:

- A means of referencing the user's spatial location/orientation;
- A real world "canvas" where the synthetic stimuli can be rendered into;
- A device capable of generating the 3D stimuli
- An interface able to present the stimuli to the user in the correct pose, according to his/her point of view.

The range of usage scenarios of an AR system is thus a lot wider than the expected with a VR approach. The notion of mobile (i.e. that does not constrain the user into a single room) and outdoors (i.e. that allows interaction on the field) solution is perfectly executable in an AR environment, using different types of tracking (e.g. GPS, sensors) and interface (e.g. handheld devices, headgear).

In terms of modes of operation, there are two main categories of AR systems [37], which define the mechanism through which the solution performs the placement of the stimuli:

- Vision-based: the most widely used nowadays, the systems from this type rely on the detection of visual patterns ("markers") to know where to present the synthetic models.

- Location-based: mostly used in specific outdoors systems, the placement of the models is performed according to the user's geographic location and/or orientation, gathered with GPS receivers and/or dedicated movement sensors.

Applications

In the last few years, due to the decrease in hardware costs and the availability of augmented reality frameworks, there has been an advent in terms of augmented reality applications. This form of technology is nowadays being implemented in solutions regarding various usage contexts, including tourism (e.g. tooltips with information about each place of interest in a city), security (e.g. markings about the real time crime safety value of an area), education (e.g. a real time cosmic scanner), and entertainment (e.g. videogames), among others [38]. Depending on the context, the AR solutions typically implement either visual clues/labels providing additional information about specific real world elements (left picture on Figure 3), or entirely new virtual elements that blend into the perceived world, along with the real ones (right picture, on Figure 3).

Figure 3 Examples of employment of augmented reality to add context-related information (left) or blend synthetic and real world elements into a unified perceivable view (right). From [http://new.doit-mobile.com] and [http://www.metaio.com]

In the field of psychology, AR also had a positive impact. By embedding the virtual fear element in the real environment and allowing a direct "own-body" perception of that environment, the ecological validity of the scenario (and therefore, the assessment data) is increased. AR is inserted in this context as a middle term between *in-vivo* and VR exposure techniques (Figure 4).

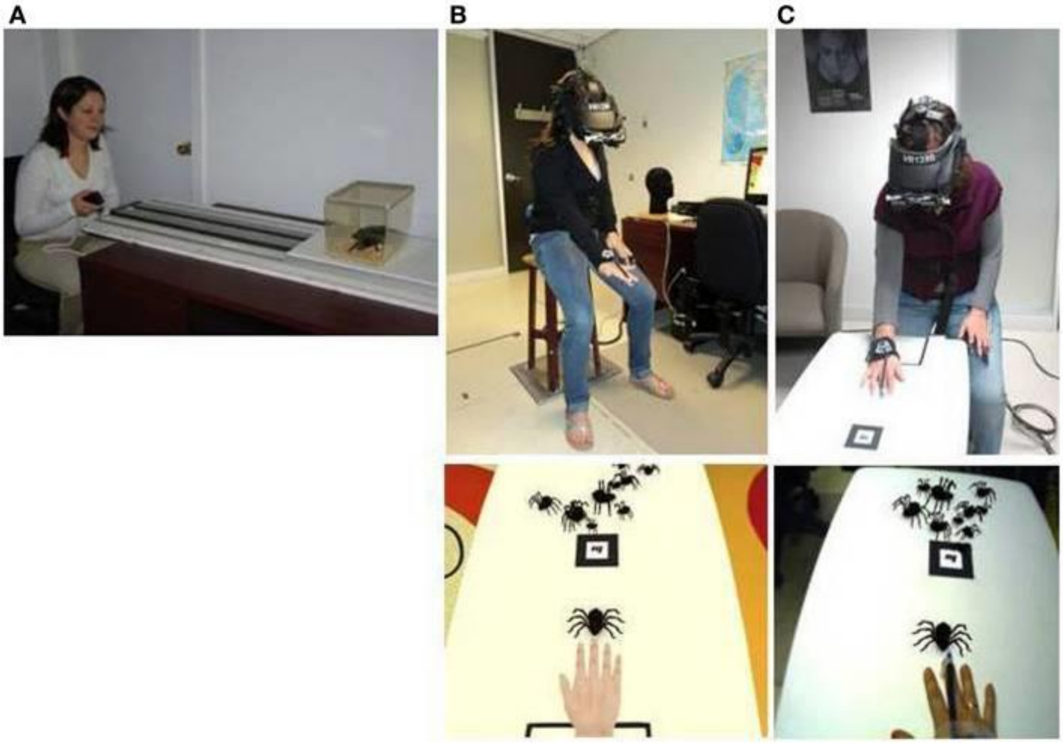

Figure 4 Comparison between in-vivo (on the left), virtual reality (on the middle) and augmented reality (on the right). Taken from [19]

In 2005, ARcockroach, a solution employing the ARToolkit framework [39], was used with a patient that suffered from cockroach phobia. While the test scope was limited to a single session, it produced visible results nonetheless (by the end of it, the patient was able to physically interact with real cockroaches) [40]. Later studies with the same system (this time using a group of patients and timespan of 3, 6 or 12 months) revealed similar results, at both the end of the sessions and the follow-up meetings [41].

In 2010, a study explored the possibility of inducing anxiety into phobic patients using an AR system, while evaluating their sense of presence [42]. Six participants with cockroach phobia were exposed to a series of synthetic stimuli in an AR environment, and a subjective assessment regarding their discomfort levels was conducted through questionnaires. The results showed that all participants felt anxious when using the system (thus validating it), and that the feeling of anxiety decreased when they were exposed to the same stimulus for a long time. In addition, the answers given to the questionnaires also pointed out that moving cockroaches had a higher impact on the subjects than stationary ones, hinting at the importance of movement in phobic phenomena.

At the end of 2010, an AR development team, in cooperation with the Canterbury University, adapted what used to be a miniature car racing using Microsoft Kinect [43] into a spider phobia exposure therapy system [44]. It featured context-awareness (the spiders were able to move through the environment and dodge or climb obstacles) and occlusion culling (the system was able to simulate the spider's movement even when it was not visible to the camera in some moments of its path). No known articles or publications reporting any kind of treatment test results were published, up to this date.

In 2011, after some preliminary trials [45], an AR solution was used to perform single-session treatment to five patients with spider and/or cockroach phobia [46]. The results were in line to the ones from previous experiments, with positive behavioral changes (anxiety and avoidance levels decreased after the sessions).

The advent of smartphones observed in the last few years, turned this kind of device into a familiar sight in everyone's daily life. Along with the development of this market, the associated mobile technology showed notable advances, in both processing power and extra features (e.g. GPS receivers, multiple integrated sensors) [47]. The improvements turned this devices into strong AR system component candidates, and played a vital role in the commercial viability of AR. A good number of companies also acknowledged their potential, and created various frameworks, aimed to help the developers abstract the host system's specification and focus on the generation of relevant AR content [48]. These features have been widely used by Android/iOS to create innovative products, in fields like entertainment [49] and education [50], with much lower production and deployment costs compared to any other existing VR or AR alternative. However, these features have not spread into the psychological assessment field.

The challenges regarding current augmented reality solutions are hinted by the kind of disorders usually addressed when they are tested. Most examples of AR solutions (especially the vision-based ones) demand the existence of a maximum distance and angle of view between the user and the place/marker where a stimulus is supposed to appear. Consequently, the failure of this criteria means the complete disappearance of the virtual model, impacting the quality of the experience. Furthermore, the lack of objective monitoring data might be impacting negatively the quality of the results: in all of the related articles and solution, even when there is a formal means of psychological assessment, it is based on subjective elements, like self-assessment tests. Given the unique ecological value of psycho-physiological data, this process would greatly benefit from the inclusion of objective and quantifiable metrics [17] (e.g. ECG [51] and EEG [52]).

4. Context-Aware Psychological Assessment: a common framework

AWARE performs a non-intrusive physiological and behavioral monitoring of its users, providing a much needed help in the ambulatory assessment of people's emotions. It is also completely flexible in terms of context, avoiding restraining itself to a particular context or monitoring scenario. Due to its mobile nature, and the pervasive monitoring mechanisms and devices used, it provides higher quality records of the patient's condition and behavior, in terms of ecological value, when compared to laboratory assessment.

Our proposed solution employs various monitoring resources in order to monitor the subject's movement, location, and general behavioral/vital conditions in real time. These include, among others, an autonomous heart rate measuring device (VitalJacket, or VJ [53]), consisting on three small electrodes stuck in the chest and a box that is placed in a dedicated slot in the Jacket. The data from these sources is gathered in a non-intrusive manner, keeping the subject oblivious about the whole monitoring process. This provides the retrieving of physiologically ecological data regarding his/her condition and behavior, making AWARE a relevant help in psychological assessment and study.

In addition to the monitoring capabilities, AWARE is able to present different synthetic 3d models in an augmented reality environment, allowing the exposure of a patient to stimuli related to various possible mental health disorders (e.g. anxiety, trauma, specific phobias). The smartphone where the application is executed is equipped with both location and orientation sensors, as well as a camera, which serves as a magnifying glass for the subject. The camera's input stream (set of frames it is capturing at each moment) is the real world "canvas" where the synthetic models are introduced. The device's screen acts as the AR stimuli presentation interface, allowing the user to get a mixed reality presentation of the surrounding environment while maintaining a sense of presence in his/her physical location.

Overall architecture

The Figure 5 illustrates the generic high-level components of our architecture, as well as the interaction between them. Most of its components are integral parts of the smartphone, and the mobile application acts as a proxy for their information.

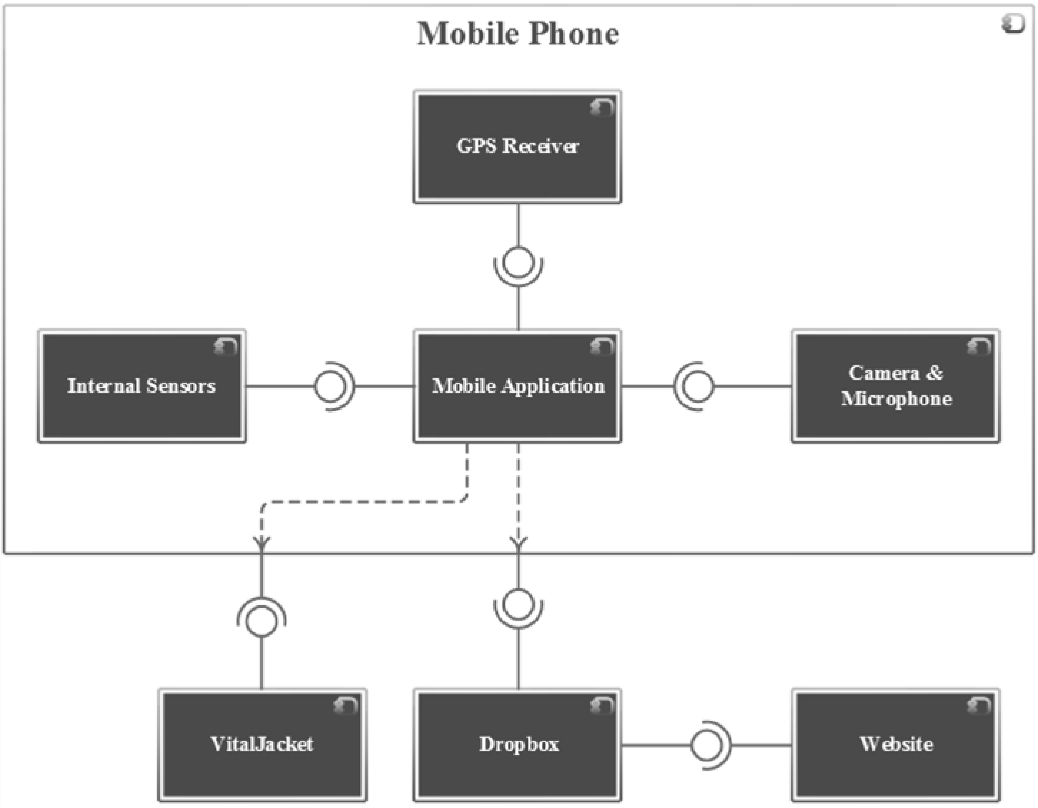

Figure 5 Component diagram of the high-level architecture of the AWARE system. The mobile application consumes information from the different presented smartphone resources, as well as VitalJacket. It then forwards all the gathered information to the Dropbox component, making it available to be downloaded and viewed remotely, or as part of a website.

The following topics briefly describe the purpose of each component of Figure 5:

- The mobile application is responsible for showing the augmented reality stimuli during the test (when applicable), as well as recording the entire process. It is also a proxy between the data acquisition and the data storage layers, gathering all the values from the different available sources and sending them to the Cloud. We opted for this approach in order to maintain a fully-ambulatory monitoring process;
- We use the phone's accelerometer and gyroscope in order to describe the movement/rotation speed of the subject while he walks his/her way through the test's terrain. All the measured values (Gx, Gy, Gz, Ax, Ay, Az) are stored in meters per second. By using this resources, it is possible to assess various movement-related information (linear and angular speed values) without employing any extra device (because the sensors are already present in the device running the application);
- Using the smartphone's GPS receiver, we are able to store all the data regarding the subject's geographic coordinates. The application is prepared to choose between satellite and network location tracking, allowing the execution of the tests both indoors and outdoors;

- The subject's heart rate data is one of the most important data sources to collect, since it provides information that may be impossible to determine with visual observation. In our solution, we use the VitalJacket product, by BioDevices [54]. The subject will wear it during the entire test. It consists in a set of three electrodes and a small box, responsible for measuring the raw electrocardiographic wave and calculating both the HR and RR values. It communicates with the smartphone via Bluetooth;
- One of the essential requirements of our solution was the provision of information about a given test to the therapist, without needing physical access to the device where the test was run. To achieve permanent remote data availability and to allow concurrent reading access to it, we created a Dropbox cloud database, to where the results of every test are sent. When a given test finishes, the relevant captured/measured data (which will be discussed later) is uploaded using the Dropbox Sync API [55], and organized according to its metadata (date, subject, etc.). The records from different monitoring sources (camera, microphone, GPS receiver, accelerometers, gyroscope, VJ) contain metadata that makes their synchronization a possibility. As a result, a therapist is able to check and analyze the relation between different monitoring sources' data. The constant availability of the uploaded data without the need of setting up a dedicated server were taken into account when opting for a Cloud-based storage. The existence of a simple and well-documented API was the main reason for using Dropbox.
- There is a web interface, which serves as an information access portal to the therapist. With it, it is possible to navigate through each subject's tests, choose which tests to analyze, visualize the test's records (video, audio, captured data), and check the evolution of a subject throughout all the tests (s)he performed. The data from every source, including the audio and video logs, are provided along with a timestamp tag, according to the moment in which each value or frame was measured/recorded. This allows the therapist to have a synchronized view of what the subject was experiencing at each moment, making it possible to assess the consequences of an event in each one of the measured sources' data type (movement, location, heart rate, voice, etc.). Since this dissertation is focused on the monitoring process, stimuli presentation mechanisms and inter-component communication, the data presentation layer is out of its focus, and its implementation will not be discussed further.

The overall workflow

AWARE is composed by different modules, which communicate with each other in order to achieve a fully functioning pervasive monitoring environment. Regardless of the usage scenario, the basic assessment procedure (Figure 6) is executed in a similar way: a dedicated test folder is created at the smartphone's external storage (either emulated or in a physical SD card), all the assessment data, as well as any context-specific events, are recorded and saved to the created folder, and finally, a synchronization service uploads the results to the Cloud, as soon as it is able to connect to the server.

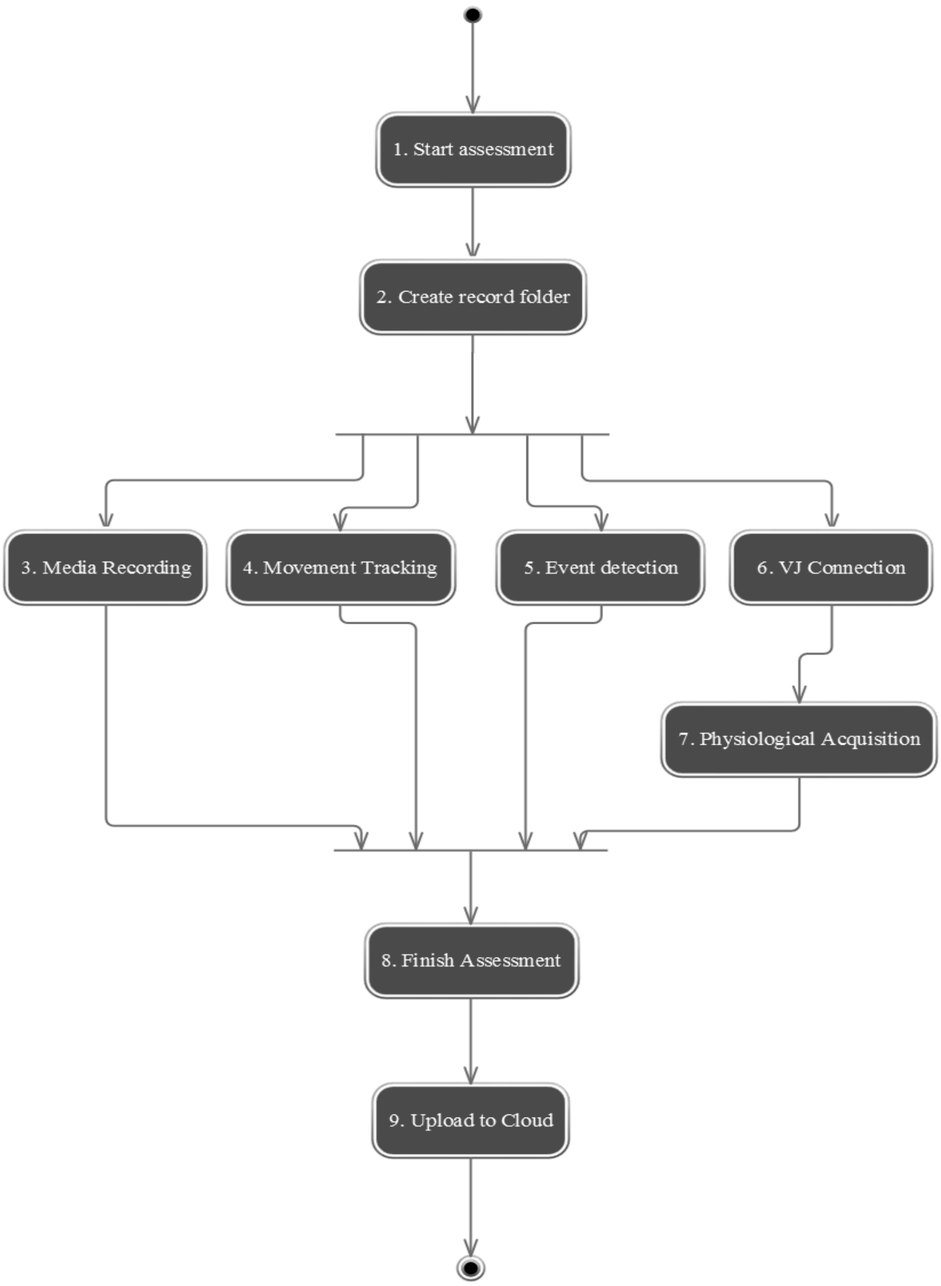

Figure 6 Activity diagram illustrating the basic AWARE workflow

The scenarios

Given the multitude of possible usage scenarios, we focused on two ambulatory experiments:

- Music (musician physiological condition during performances)
- Phobias (assessment of specific phobias and related behavior)

EVerMoRE (impulsE Vital Musical REcorder)

Nowadays, computing technology has already been applied in various different occupational areas, in order to enhance the quality of execution of a wide array of tasks. In sports, for example, there are numerous applications that measure relevant aspects of the athletes, like speed, heart rate or body temperature, and even give advice based on the analysis on that data, in order to more efficiently improve their physical skills [56]. In the musical field, the artists' psycho-physiological condition [57], as well as some physical aspects specific to certain instruments (e.g. body posture [58]) can have an impact on their performances and learning progression. Therefore, there is also a need for solutions similar to the ones described, in this area of knowledge. However, there are currently no such solutions available.

In the given context, the goal of the EVerMoRE application (impulse Vital Musical Recorder) is to help in quantifying and evaluating the impact of the musician's condition in the quality of his/her playing. It is able to synchronously measure the variations in the heart rate and body movement of each artist throughout a concert, while recording its video and audio. This type of objective monitoring can help relate the technical mistakes done, with the exact posture adopted by the musician and/or the amount of stress/anxiety evidenced in his/her physiological data. Ultimately, the knowledge and raising in awareness about these metrics have the potential to allow him/her to better realize how (s)he can fix those mistakes, thus becoming a more skilled professional. Additionally, the application can accomplish a comparison of the same metrics between different musicians playing together, or even between them and the audience (assuming various iterations connected to different people, running at the same time on separate devices). This feature allows us to find out how different people (performers and/or listeners) experience the same musical piece.

The architecture / setup

The setup of the solution is made before the beginning of a performance. It is relatively quick to do (about ten minutes long), and consists in the following steps:

1. The musician applies the three VJ electrodes in his/her body (Figure 7);
2. In order to ensure the correct placement of the electrodes, we use an application like DroidJacket [59] where we can see the complete ECG wave (or perform a "dummy" run of our application to see the respective values in text format) and check if there

are any anomalies (e.g. no communication with the device, no heart rate data received) or signal noise (e.g. very high R-Peak or irregular intervals and in the ECG wave when the subject moves his/her body);

   a. In case of anomaly, we make sure that Bluetooth is enabled in the smartphone and that it is paired with the VJ device, check if the VJ has enough battery to work;
   b. In case of noise, the 1st step is repeated and a new validation is performed afterwards;

3. (Optional) In case we want to have a video of the concert, to able to compare it with the heart rate data, we naturally search for a placement for the smartphone where its camera is able to focus the performing musician. Either way, the concert's audio will always be available.

Figure 7 Example of electrode body placement

Usage Scenario / protocol

This version of the mobile application was developed for the 1st Cycle of Concerts of the Artistic Tutorial Programme, from the Communication and Arts Department of University of Aveiro. There was a sequence of various concerts over the course of a couple of weeks. The goal was to observe any eventual relation between the music being played and its player's heart rate, as well as the comparison between the heart rates of different musicians playing together.

AWARE (Aware aWe-inducing Augmented Reality)

Specific phobia diagnosis and treatment is one of the sub-fields of psychology where the need for ecological and non-intrusive ambulatory monitoring, as well as a realistic and immersive stimuli exposure, becomes evident. Given the emotional burden associated with this kind of disorders, it is not easy to get a reliable view of a patient's condition through self-assessment techniques, because (s)he can have a distorted perception of his/her reaction regarding the object that origins the phobic behavior [5]. Furthermore, since the lab environment has an effect on emotive and behavioral reactions, the laboratory assessment of phobias might miss some psychological phenomena that only manifests in the patient's familiar/daily life environmental conditions.

In order to get an authentic and accurate reaction to the confrontation with a stimuli, the way it is presented is also relevant: *in vivo* exposure gives a fully realistic notion about the patient's reaction, but it is costly, difficult to control, impossible to perform for some specific phobias, and hard to reproduce for some others [27]; multimedia presentation, the most popular alternative [60], fixes most of those problems, but removes the sense of presence of a real world encounter for many patients, ecologically invalidating the results; virtual reality solutions, a growing trend in psychological treatment [61], provide a good middle ground between the two previous approaches, but are very costly and time consuming to develop, have a low flexibility in terms of adaption to different specific phobias, and decrease the ecological validity of the results by removing the awareness of the patient's physical context and putting him/her into a perceptual scenario with a virtual body instead of his/her own [19]. There is a clear need for a solution featuring "the best of all worlds", that is also able to collect objective and quantifiable data about the patient's behavioral and psycho-physiological reactions.

In this context, our proposed solution, AWARE (Aware aWe-inducing Augmented REality) establishes a compromise between the strong points of each different approach. It is the most complete version of our mobile application, employing augmented reality (AR) techniques into a smartphone-based system (using the Vuforia AR Framework), as well as all the monitoring modules used in EVerMoRE. It is capable of performing a pervasive ambulatory monitoring on the field (outside of the lab), while delivering to the patient a direct "own-body" confrontation with the causes of his/her disorder, all within the same physical context of his/her real world location.

The architecture / setup

Before a session begins, the therapist should choose which stimuli (s)he wants to show to the patient. When the stimulus set is chosen, the test setup can be executed. The setup regarding the monitoring components, namely the VJ device's configuration and validation, are done in the same way as previously described in the EVerMoRE section. However, it is now necessary to prepare the elements related to the augmented reality aspects of the system.

Terrain

The physical site where each test is performed needs to be prepared beforehand. In practice, the only action required on this subject is the placement of the different markers, which will be scattered through the field. A typical marker will look like one of the set shown in the next figure (Figure 8):

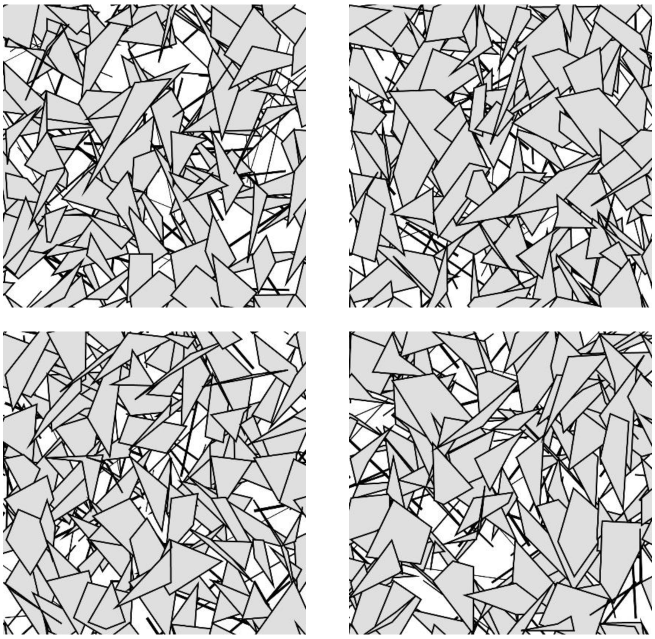

Figure 8 Example of different markers

The augmented reality SDK allows the replacement of the image targets, and although the camera calibration code is not open-source, it provides an online rating tool for each uploaded target [62]. All four of the presented markers, as well as every other ones in the application's database, were software-generated [63] and optimized to be used as augmented reality markers. Different images can be used for this purpose without decreasing the performance/stability of the recognition process: in general, the quality of an image as an AR target is defined by the number and distribution of detectable features [64] (sharp, spiked and/or chiseled visual details) contained in it (Figure 9).

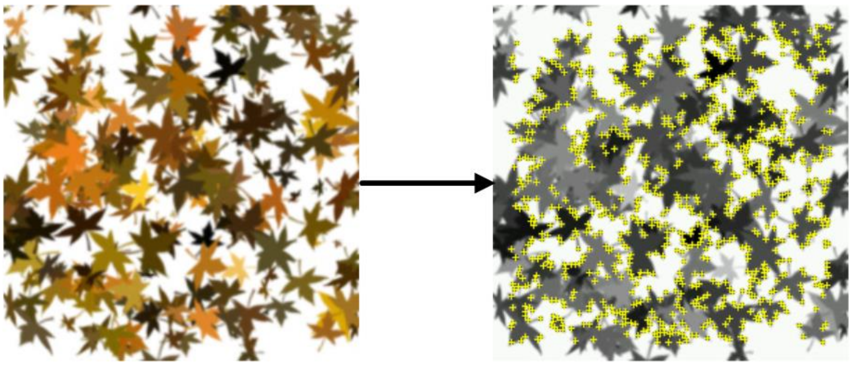

Figure 9 Example of feature (yellow dots) extraction process from a marker. Adapted from [64]

Each one of the markers is unique (so that it can be identified by the mobile application), but somewhat similar to the others (to the point that it becomes hard to distinguish them with human sight).

One of the practical advantages of using a marker-based approach is that, at any moment, the application database contains the information needed to detect and interpret every target previously uploaded into it. This means that, just by having a portfolio with several markers of each 3D model, the therapist can easily decide which stimuli the subject is going to see, and even how many times a specific stimulus is supposed to appear during the test.

The markers should be placed some meters apart from each other (up to 5-10 meters), allowing to observe the subject vitals' variation while (s)he moves through the test's field and letting him/her make a recover between stimuli. The layout of the marker set in the field should provide a notion of a path to the subject (on a straight line, forming some kind of recognizable shape, etc.).

A small object/token (Figure 10) is placed near the marker, which is supposed to be picked up by the subject. This will help fix the markers to the ground, and more importantly, it will ensure that the subject approximates and spends enough time next to the stimuli, looking at them from different perspective.

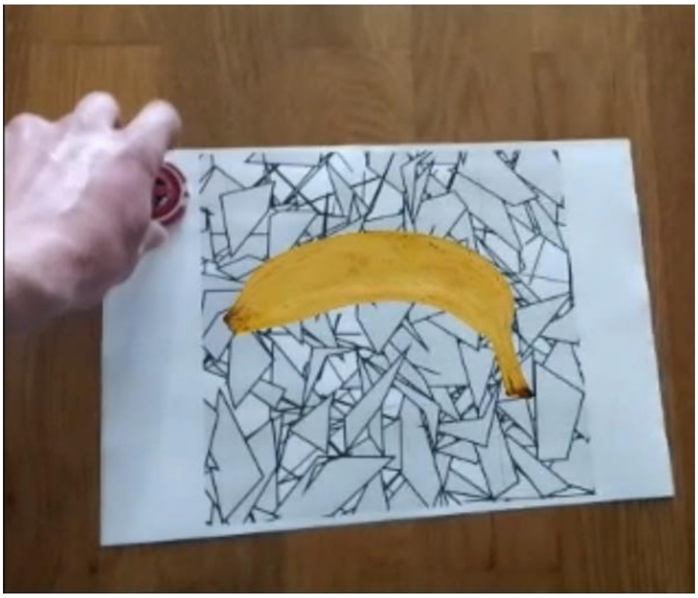

Figure 10 First-person view of a subject picking up a token, next to a neutral stimulus

Adverse weather conditions (wind, rain) can make it hard to tie and/or read the markers, depending on the material they were printed on. Therefore, it is recommended that they're not used in plain paper format, unless there's a more resistant surface to stick each one of them on. In order to (somewhat) combat some of the light-related issues we might face, there are alternative versions of the markers (Figure 11), using a colored palette instead of greyscale:

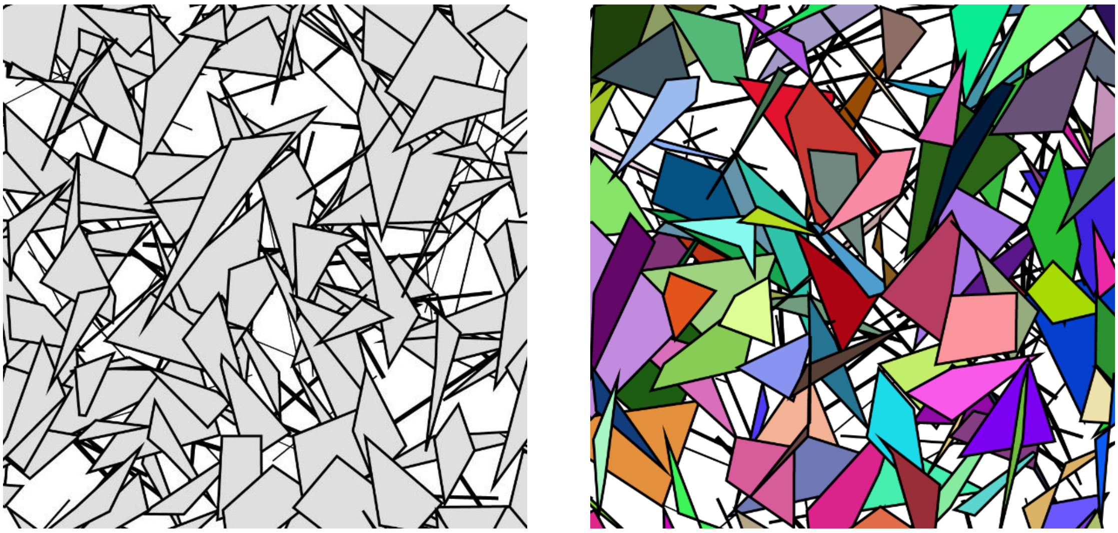

Figure 11 Comparison between greyscale and colored versions of the markers

In low-light or other hazardous conditions, it's easier for the application to detect the colored markers, improving the speed of the stimulus presentation process.

Model Selection

Before placing the previously described markers, the therapist must decide what kind of stimuli (s)he wishes to present to the subject. This can be done by choosing a set of 3D models out of all the available ones in the stimuli database.

In order to keep the solution flexible, we divided the stimuli/models collection into different categories, with various different examples for each one of them:

- Phobic (related to the most common sources of phobic disorder);
- Neutral (beings or objects that are not meant to induce any reaction in the subject, and emulate what one would expect to find in the test's physical context);
- Out-of-context (models which presence in the real world environment of the test site would be highly unexpected, absurd or impossible).

Figure 12 Example of stimulus from each one of the different types (phobic, neutral, out-of-context)

Usage Scenario

The AWARE application was designed to provide a reliable ambulatory assessment of each subject’s reaction to various stimuli, using context-aware augmented reality. In perspective, this general use case provides a means of helping diagnose and treat the psychological disorders associated with those stimuli.

During a session, the patient may be asked to take a test. In that case, the previously described setup is performed, and the patient is then directed to the test’s terrain. Once there, the smartphone is given to him/her, after the AWARE application is launched. It will contain the general instructions, which can be complemented with information authorized by the therapist, if the patient has any questions.

When the test starts, it is requested that the subject remains in the same place for about 10 seconds. This time is required for all the sensors and data sources to connect/initialize and for the first heart-rate metrics to be retrieved to the smartphone (the first discrete values are calculated inside the measuring device after eight samples have been successfully taken);

After the initial waiting period, the subject is asked to walk through the different markers that were previously placed in the field. After this moment, there is no more planned and intentional interaction between the person performing the task and the therapist/analyst.

During the entire duration of the experience, the subject carries the smartphone with him/her, acting as a magnifying glass: when (s)he arrives to a marker, (s)he points the smartphone’s camera to it, until the hidden “secret” is revealed, and then picks up the token next to it. These instructions were given in the application’s initial dialog, read by the user at the beginning of the test. No additional information or clues are provided, other than the goal of the activity (going through every marker, finding every model with the camera, and picking up every one of the tokens). The subject then chooses the path (s)he wishes to run and the order in which (s)he wants to pass through each marker.

When the subject gets to a marker and points the smartphone to it, the application will recognize the image target, and render the 3D model on top of it:

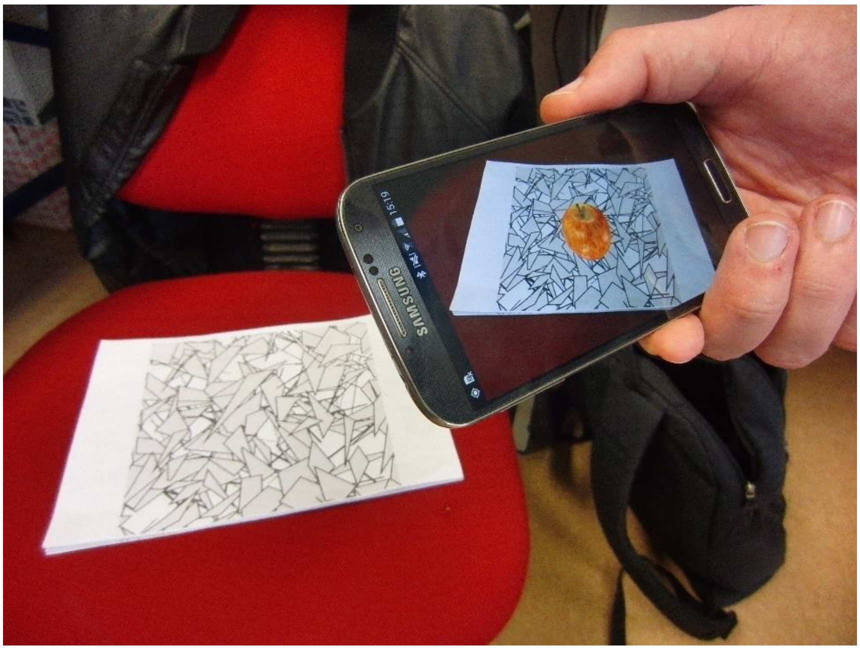

Figure 13 Rendering of an augmented reality stimulus on the detection of a marker

This process repeats itself until the number of different physical markers the user has passed through is as big as the number of stimuli that were defined to appear in that specific test. When that happens, the test is finished and all the recorded data is uploaded at background-level in the mobile device. All the tokens should be delivered as further proof of the marker passage.

After the test is finished, the monitoring recorded data is available in the cloud, and can be fetched and analyzed by the therapist, allowing him to assess the evolution of the treatment and to prepare an eventual future test.

5. The implementation

Since the beginning of the development stage of our project, we strived to build a modular and flexible base code structure. Most of our platform's modules (Figure 14) are ready to work independently, and can be quickly disabled when they are not needed. In addition, it is possible to add new features to the system by including the respective code modules, without the need to change the implementation of the existing ones. This way, adapting AWARE to work in different contexts becomes a much quicker and efficient process.

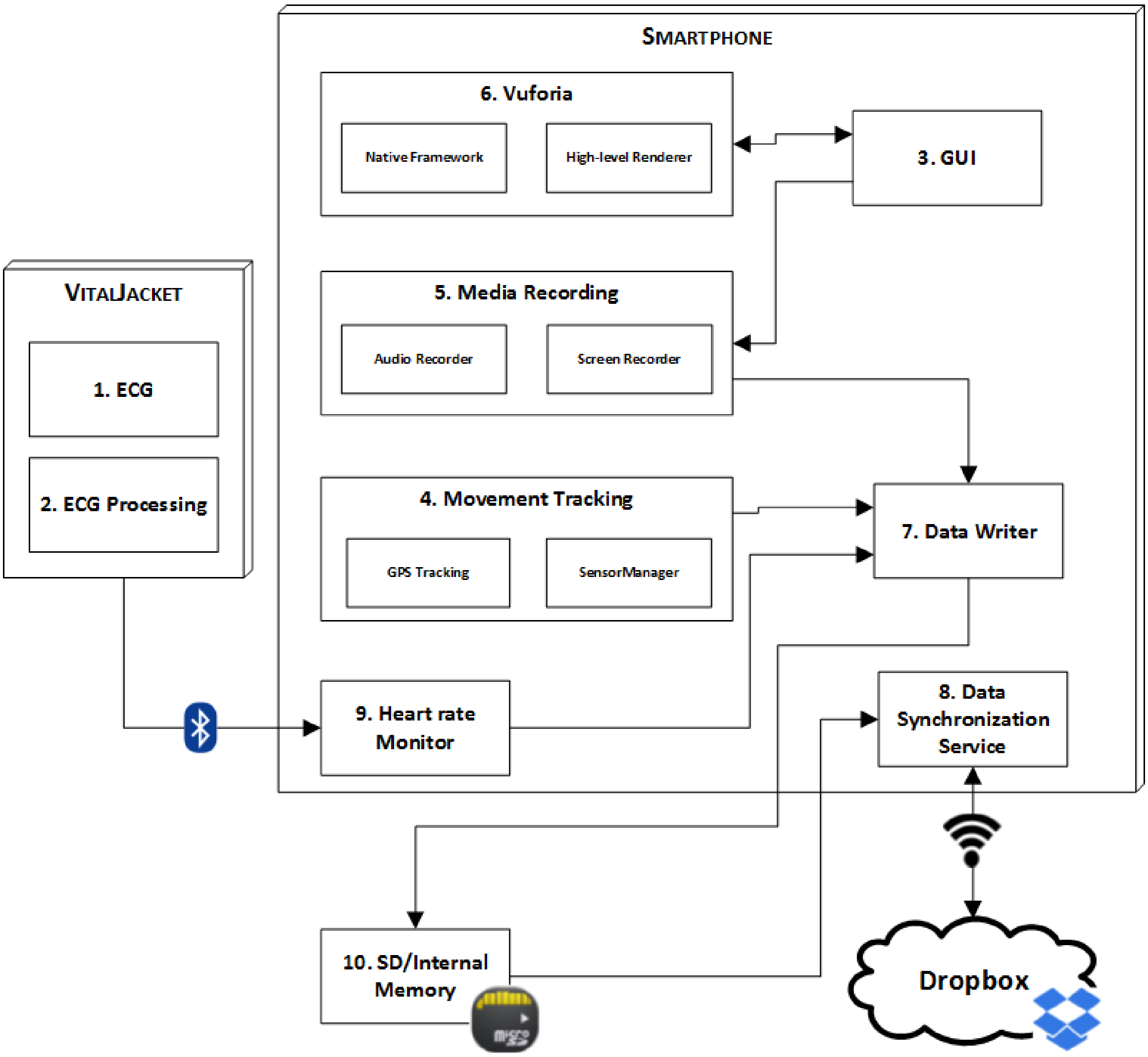

Figure 14 Diagram of the AWARE internal architecture. The GUI is the interface with the user, and uses the Vuforia module for stimuli presentation, if needed; The Media Recording module captures the application's screen or camera input, as well as the respective audio; the heart rate monitor uses the VJ API to receive the user's ECG wave and its calculated attributes; all this information, as well as the movement/location data, are stored in local memory using a centralized Data Writer, and later become available in the cloud thanks to the Data Synchronization Service

Our evaluation process involved two different test cases. Therefore, the two alternative versions of our mobile application (EVerMoRE and AWARE) were adapted to meet the requirements related to the respective usage scenario. In this chapter, we describe the technical details and constraints relative to each one of them.

Some constrains on the devices

As the Android platform evolved, some features related to it have been added, changed or even remove over time. During the adaptation process of our system to different contexts, it is necessary to introduce new modules and coding elements that might not have existed since the first version of the Software Development Kit (SDK). Consequently, not all versions of our mobile application will have the same compatibility requirements. In the case of EVerMoRE, the constraints related to video recording and multi-device communication require a smartphone with at least the version 3.0 of the Android (Honeycomb). Regarding the AWARE application, the screen record features that we needed require a device with Android v4.4 (KitKat) or later installed.

In our experiments we used two different mobile devices - relevant specifications (according to GSMArena [65]) in Table 1.

	Samsung Galaxy S4	Samsung Galaxy Fame
Picture		
Release	April 2013	March 2013
Android OS version	4.4.2 (KitKat)	4.4.2 (KitKat)
Primary camera	13 MP, 4128 x 3096 pixels, autofocus, LED flash	5 MP, 2592 x 1944 pixels, autofocus, LED flash
CPU	Quad-core 1.9 GHz Krait 300	1 GHz Cortex-A9
GPU	PowerVR SGX544MP3	Broadcom VideoCore IV
Internal Storage	16 GB	4 GB
RAM	2 GB	512 MB
Battery	Li-Ion 2600 mAh	Li-Ion 1300 mAh

Table 1 Relevant specifications of the smartphones used to test the AWARE mobile application

The Android device spectrum is not limited to smartphones. The application can also be used in a Tablet device compatible with version 4.4 of the OS (KitKat) or higher. This type of device has a bigger screen, although the usual resolution is on-par with the equivalent smartphones [66]. Some research shows that this can also improve the subject's depth perception regarding the image (s)he sees on-screen [67]. Despite this potential advantages, tablets have the downside of their size, which can make it harder to avoid their fall, when monitoring sensible subjects (e.g. highly phobic people). Due to availability issues, we didn't perform any experiment using this device, although we successfully ran the application on a Google Nexus 7 [66].

Common to EVerMoRE and AWARE

The following technical elements are related to the ambulatory monitoring and data communication features, being enabled in both versions of our mobile application.

Internal sensor data gathering

The values measured by the different internal sensors present in the smartphone (in this case, the Accelerometer and the Gyroscope) can be retrieved by using Listener objects. After we register a listener, we can then handle and store each new detected value of the corresponding sensor.

During the listener registry process, we can specify a sample frequency delay:

- SENSOR_DELAY_FASTEST: (up to ~20ms);
- SENSOR_DELAY_GAME: (up to ~40ms)
- SENSOR_DELAY_UI: (up to ~90ms)
- SENSOR_DELAY_NORMAL: (up to ~230ms)

This setting, however, is just a hint to the maximum delay between each sample: the sampling rate will not be a constant value, varying between zero and the defined maximum. Above that, there's also no guarantee that this setting will not be overwritten during the application runtime [68]. With these constraints in mind, we chose to set the delay to the lowest range available (FASTEST) and implement a scanning Thread that retrieves the last values measured by both sensors, once each 50 millisecond period. This way, we can store the samples at a fixed rate (20Hz), even though they're not being retrieved at that pace (Figure 15). We also had the heart rate measuring device's sampling rate in mind when choosing this value, in order to be able to match the samples from each source (500Hz = 25*20Hz for the raw ECG wave, and 1Hz = 20Hz/20 for the HR and RR calculated values).

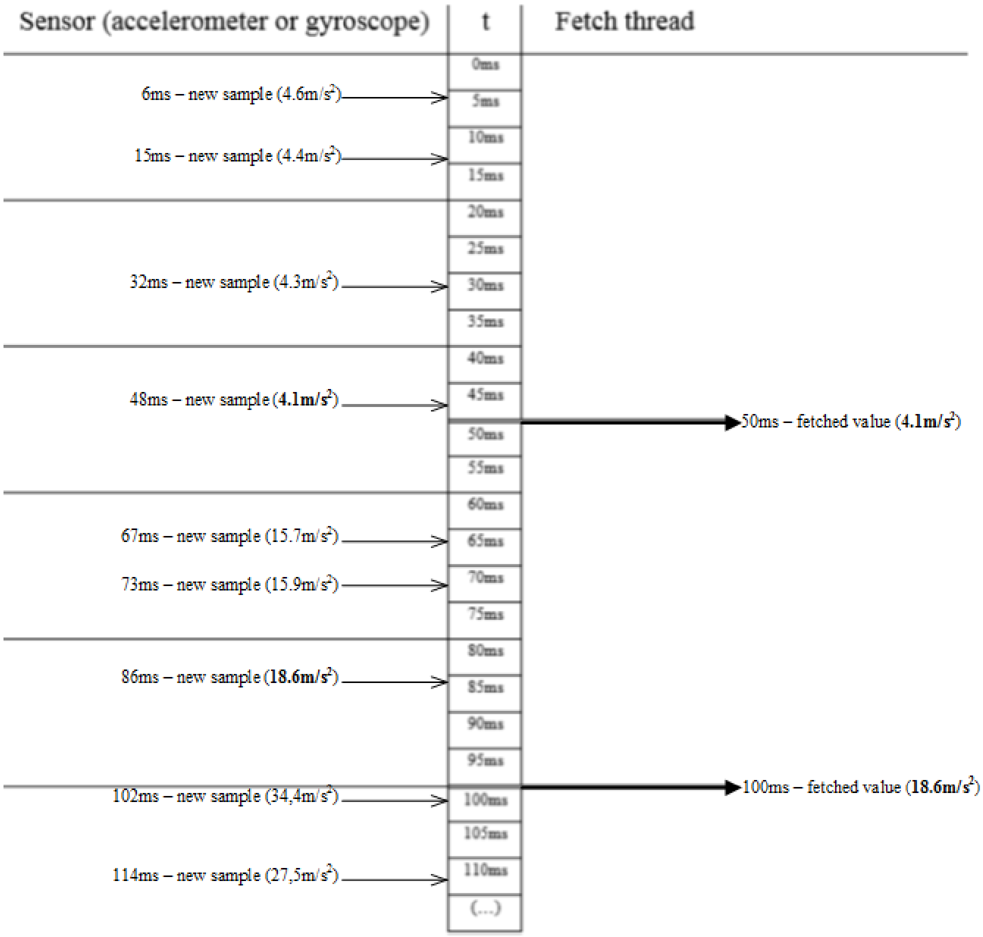

Figure 15 Example of a runtime sample fetching process, for a sensor value. While the samples are not retrieved at a fixed rate, the thread that moves them to persistent memory does so every 50 milliseconds, saving the last measured value. Since the origin samples are always 20 milliseconds or less apart, the time error margin is always lower than that value

Video recording

Having a clear notion of the subject's perception and behavior during the tests was crucial for the therapist. A video log, in particular, would give information that would not be recognized unless the therapist was present at the moment of the test (e.g. a real world event affecting the results) and could allow him/her to better understand some aspect related to the retrieved data (e.g. why the subject spent an unexpected amount of time at the same stimulus/marker).

The 4.4 version of the Android OS, also known as "KitKat", introduced a screen recording feature. By using it, we are able to store all the visual information provided to the subject by the application in mp4 format. Each screen recording session is limited to 180 seconds [69], so we split the video log into different files (we opted for 1 minute videos, providing a balance between number of video files and cloud synching performance under poor network conditions). This feature also depends on simulating an instruction that required root privileges, so we had to "root" [70] our device to be able to run root privileged commands.

Recording what the subject saw through the smartphone's screen revealed itself to be a technical challenge and we passed through some failed attempts at achieving it before arriving at the solution presented above. We needed to capture not only the phone's camera input, but also every augmented reality overlay information that was being shown on top of it, all of this without letting the subject realize that his/her actions were being recorder (in order to avoid inducing any unnatural change in the collected data). Using a MediaRecorder object (another alternative) would only give us the image captured by the camera, so we tried an indirect picture-based approach, by manually scanning the entire screen into memory and then dumping it into an image file. This way, we could get both the camera input and the AR overlay, capturing everything the subject was seeing in the screen. However, this proved out to be a suboptimal solution: the screen scanning task took (on average) 760ms, and induced a small but noticeable delay in the screen's image (even when done in a different thread); each image file creation's delay averaged at 2360ms, resulting in a lot of simultaneous threads open, and hundreds/thousands of files by the end of the test. These issues made us discard this kind of approach.

Stored test data structure

At the end of each test, there is a subfolder inside the AWARE data directory in the smartphone's internal memory, containing all the data that was recorded. For the text files with multiple samples, each one of lines start with two timestamp values: the smartphone's clock time (e.g. "09-05-2014 18:30:11:075") and an offset time number, with the amount of milliseconds passed since the moment when the test began (e.g. "95000" means that the test was underway for 95 seconds when the sample was read).

A test subfolder contains all the following files:

- Various "Videolog_<X>.mp4": these video files contain the screen captures of the entire test, split into one minute parts. The <X> is a sequence number that allows an easy temporal sorting of the different videos;
- audioLog.3gpp: audio file containing the sound recorded by the smartphone's microphone for the duration of the test;
- gps.txt: contains the user geographic location changes as detected by the network or satellite location tracking system.

  Format:

timestamp (datetime)	timestamp (offset)	latitude	longitude

- accel_gyro.txt: smartphone's sensor data, from both the accelerometer and the gyroscope, per axis.

  Format:

timestamp	offset	Accel(X)	Accel(Y)	Accel(Z)	Gyro(X)	Gyro(Y)	Gyro(Z)

- hr_accel.txt: also contains acceleration information, but in this case, the one measured by the sensor inside the VJ box. Not present unless the smartphone and the VJ were able to connect to each other during the test. Since the VJ accelerometer has unique scale specifications (it works in a 64-per-2G scale, i.e., the value "32" is equal to the gravitational acceleration, ~9.8m/s^2), the received values are converted to match the scale used by the smartphone's accelerometer:

$$a' = \frac{9.80665 \times a}{32}$$

Format:

timestamp	offset	VJAccel(X)	VJAccel(Y)	VJAccel(Z)

- hr_raw_ecg.txt: contains the ECG wave information arrays sent by the VJ device. Not present unless the smartphone and the VJ were able to connect to each other during the test.

Format:

timestamp	Offset:
<raw ECG values separated by commas. E.g.: "125, 123, 121, (…)">	

- hr_ecg.txt: contains the heart rate values sent by the VJ. Not present unless both devices were able to connect to each other during the test.

Format:

timestamp	offset	HR (average)	HR (instant)	RR

- events.txt: a log of all the relevant occurrences throughout the test (the moment of its beginning, the instant of appearance of each of the stimuli, the video and audio records start and finish timestamps, etc.).

Format:

timestamp	offset	<event description>

The subfolder is saved with the test timestamp as its name. The AWARE folder where it is contained can be found in the phone's external storage root directory (physical or emulated SDCard).

Heart rate measurement and recording

The subject's heart rate data is obtained using the Vital Jacket heart-rate module, from BioDevices. This device is capable of measuring ECG waves and calculating some parameters from it (R-Peak position, HR and RR). The subject will wear it inside the VJ Shirt from the beginning until the end of the test. The physical address of the device can be define in the application's configuration file, allowing a quick change of device unit if necessary.

When the application starts, it checks if Bluetooth is enabled (informing the user in either case), and as soon as it is on, a handler responsible for all the packets received from VJ starts running, and a pairing of both devices is attempted. If it succeeds, the Connect method is called, and the heart rate data exchange is initiated in passive mode (i.e. the smartphone will subscribe to the measuring device, receiving the packets without the need to actively asking for each one).

The packets sent by VJ only contain the raw ECG wave data at first, but after a setup period of eight to ten seconds, it is also able to provide the R-Peak position, HR and RR calculated from that wave. This way, we can simply parse the received packet, extract both the raw and calculated values and store them into files, saving time and processing power. The VJ also possesses an integrated accelerometer, whose values we store for later comparison with the smartphone's.

Cloud Synchronization

When a test finishes, the application starts a service that makes use of the Dropbox Sync API in order to upload the recorded data into the Cloud. In its manifest, AWARE encloses the user and key credentials for a dedicated Dropbox developer account [55]. Once it is able to validate those credentials and log in, it will start to upload every one of the test's files. If the service is not able to connect to the Dropbox server, or if there is not internet/wifi connection available, the synchronization process is able to resume at a later time, as soon as those conditions are met (it is possible various tests in an environment without internet connection. Later, when the service manages to connect to Dropbox, it will correctly upload the data of every test made).

AWARE specific

The following technical elements are related to the augmented reality technologies employed in the AWARE application to enable the presentation of stimuli.

Augmented Reality SDK - Vuforia

In order to be able to present the stimuli to the subject during the test, we needed to use or implement an augmented reality mechanism that was compatible with the Android OS. We were preferably looking out for a solution that would be easy to apply to an existing project, highly customizable, and at least partially free to use.

After some research and testing of different available AR SDK's [48], we selected the QCAR/Vuforia AR SDK, from Qualcomm. The reasoning behind this decision was related to both technical and logistic aspects:

- The Vuforia SDK was developed with mobile device in mind, with iOS and Android-specific versions;
- The developers provided a thorough documentation, with some example code, and were available to answer user-specific questions in the platform's public access forums;
- The SDK was free to use, without any limitation or downside.

Other SDK's were tested before we made our decision included Layar (excluded because of documentation issues that kept us from deploying a simple project easily), Metaio (excluded due to the watermarks shown in the camera in the free version, interfering with the subject's vision of the stimulus) and Wikitude (set aside because it used location-based augmented reality, instead of vision/marker based one).

3D Model Import

The Vuforia SDK used OpenGL ES 2.0 to perform the 3D model rendering [71]. The camera calibration was already done by the SDK as well and, although that part of the code was not open-source, it was possible to see and change both the UI presentation (SDK-level/Java) and the native rendering OpenGL code (NDK-level/C++). [72]

The SDK provided methods to build the different models from a set of matrices, describing the position/coordinates of each vertex, the mapping between the vertices and the textures and (optionally) the normal needed for lighting variations. All this matrices had to be loaded from C++ header (.h) files [72]. Since the 3D models available online were not in this format, it was necessary to convert them before trying to use them.

From the vast number of available model formats, one of the most intuitive to parse and convert into C++ header was the Wavefront OBJ model. This model's file structure contained all the data we needed to build the matrices, and its internal data organization was very similar to our header files' [73] (v – vertices, vn – normals, vt – texCoords).

Before the Wavefront files were ready to be parsed into usable header files, it was necessary to change their polygon mesh topology from Quads to Triangles (Figure 16), or the Qualcomm SDK would not be able to load them correctly:

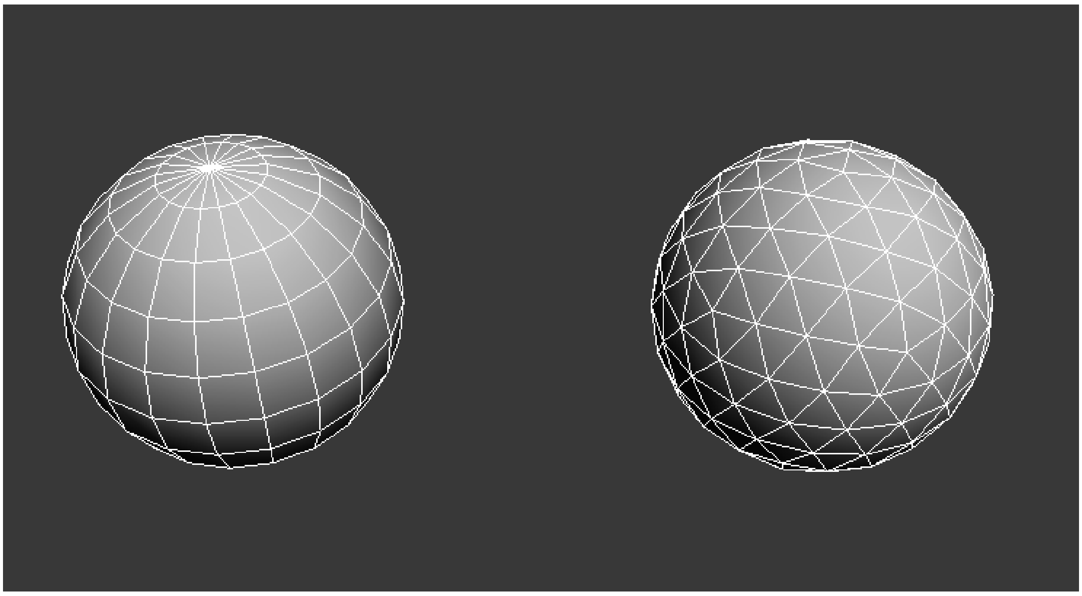

Figure 16 mesh topologies: quads (on the left); tris, the type supported by Vuforia (on the right)

This operation was achievable by using the mesh triangulation of the open-source software Blender [74]. This application also allowed us to import models from other file formats (c4d [75], 3ds [76]), and convert them into parseable Wavefront models.

Marker Recognition and 3D Model Rendering

The application that is installed in the smartphone contains the header files every stimulus that can be shown, as well as a .dat file, created using the Target Manager online service [62], with all the markers that can be detected. The textures necessary to correctly present every stimulus are also present in the AWARE assets.

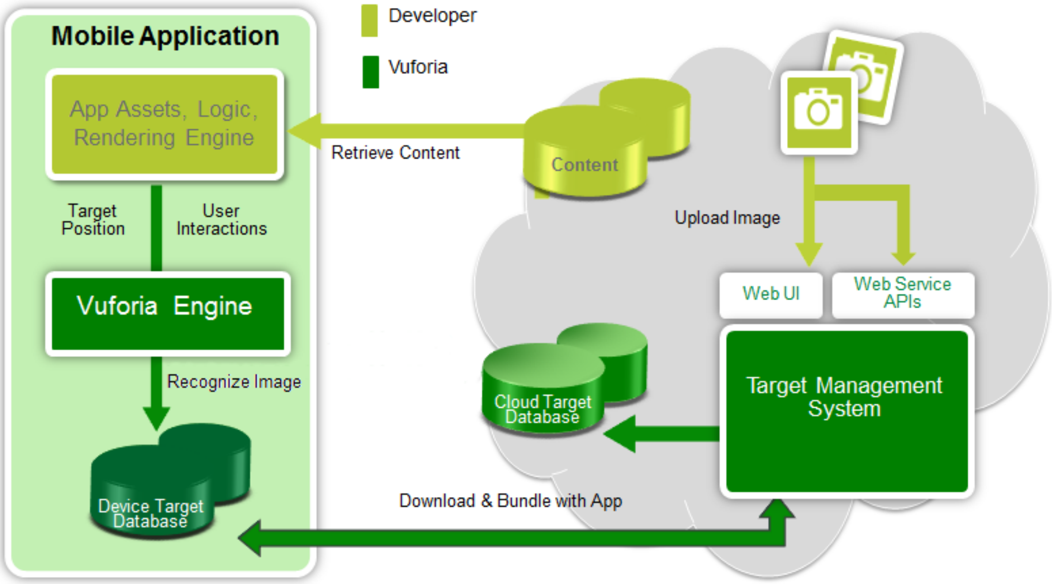

Figure 17 A diagram of the Vuforia Architecture, as used in our project. The images uploaded to the Web UI are the markers. After uploading the markers in the website, we can download our application's target database, which allow the framework to identify them during runtime. The Developer Content that is retrieved by the mobile application is comprised of all the necessary models, textures and miscellaneous assets. Image adapted from [https://www.vuforia.com]

During the application setup (from the moment it is started until the camera image is presented to the subject), a set of native functions import and prepare the model headers data in order to be able to render them when they're supposed to. At the same time, at the SDK level, a texture array is created (each element corresponding to the texture that will be applied to a particular model).

After the setup is complete, and while the subject performs the test, the camera image will be continuously scanned in search for known markers. When such an event occurs, another native method checks the name of the found marker. Depending on the result, a different header model data will be selected to render. As soon as the model is ready to be drawn, the same method fetches the corresponding texture from the previously created texture array, and finally presents the stimulus.

The native rendering function will keep drawing the model (the pose depending on the viewing angle of the camera), until the marker is no longer being detected. Each time a different marker is found, there information regarding its identity is also passed to the top-level/SDK rendering class, which is then responsible for validating it according to the protocol (checking if the list of visited markers/shown stimuli contains the newly detected one, counting the number of different markers (s)he has passed through, etc.) and calling the UI activity to inform the subject about the results.

6. Psychological assessment using EverMore and AWARE

The evaluation of AWARE was performed using two different scenarios:

1. EVerMoRE – impulsE Vital Musical Recorder, applied to musicians in order to collect behavior and vital data (Experiment 1);
2. AWARE – Aware aWe-inducing Augmented Reality, applied in the phobia treatment context, collecting behavior and vital data and presenting a set of stimuli in an AR environment (Experiment 2).

Experiment 1 – Scenario 1 EVerMoRE

EverMore was used to assess the movement and heart rate of different musicians, while they performed classical music pieces, solo or together with other musicians. We also performed an experiment where we monitored simultaneously a pianist and a violinist performing in duet (with some piano solos). We collected both behavior (using accelerometer and gyroscope), physiological signals (ECG using VitalJacket) and video for context characterization (audio for music / time segmentation and video for control/synchronization).

For the EverMore evaluation, we focused in the experiment with the two musicians - from a pianist and a violinist - to support the comparison of their heart-rate over time. The sequence consisted on a performance where at the start, the pianist performed a solo piece; followed by a duet and, finally, another piano solo. We studied the heart rate (HR) as a psychological status feature, measured at each second. We used a 5 points running window (5 seconds) to calculate an average HR and respective standard deviation. This time interval was chosen in order to get a balance between the level of detail (an higher time would not allow us to evaluate the evolution of the subject's reaction in short time intervals as clearly) and the stability of the data (a lower time would induce a bigger amount of noise in the signal).

The audio waves captured by the smartphone's microphone can be presented synchronously along with the heart rate (Figure 18), allowing us to assess the loudness of the sound heard by the musicians and the audience. The same operation can be achieved using the video records, providing us with a visual log of every moment of the concert (Figure 20). In this experiment, we did not perform any further analysis regarding audio or video.

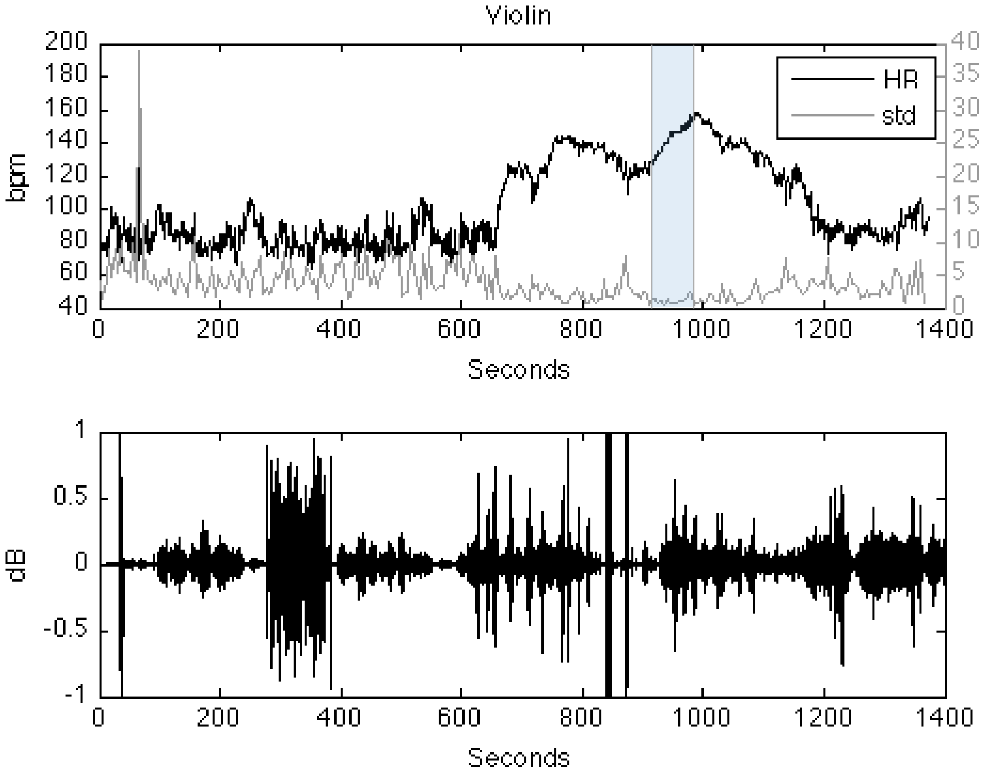

Figure 18 Upper chart: violinist's heart rate data (black line) and its standard deviation (grey line); Lower chart: physical strength of the audio recorded by the microphone. The area highlighted with blue represents a melodically distinct part that coincides with a notable variation of the HR (its maximum value, 160 bpm, is briefly reached right after the end of this section of the music)

Results

On the pianist we observed no visually relevant HR change along the performance (upper chart in Figure 19). The pianist maintains a relatively steady heart rate and standard deviation values, not showing any noticeable difference between the solo and the duet parts of the play. The same was not observed with the violinist HR. The violinist HR variation was related with the moments when the violinist played. The violin enters in the piece (approximately 630 samples) and its finish (approximately 1200 samples) which coincides with an increase in HR (black line on Figure 19) and decrease in variation i.e. standard deviation (light grey in Figure 19).

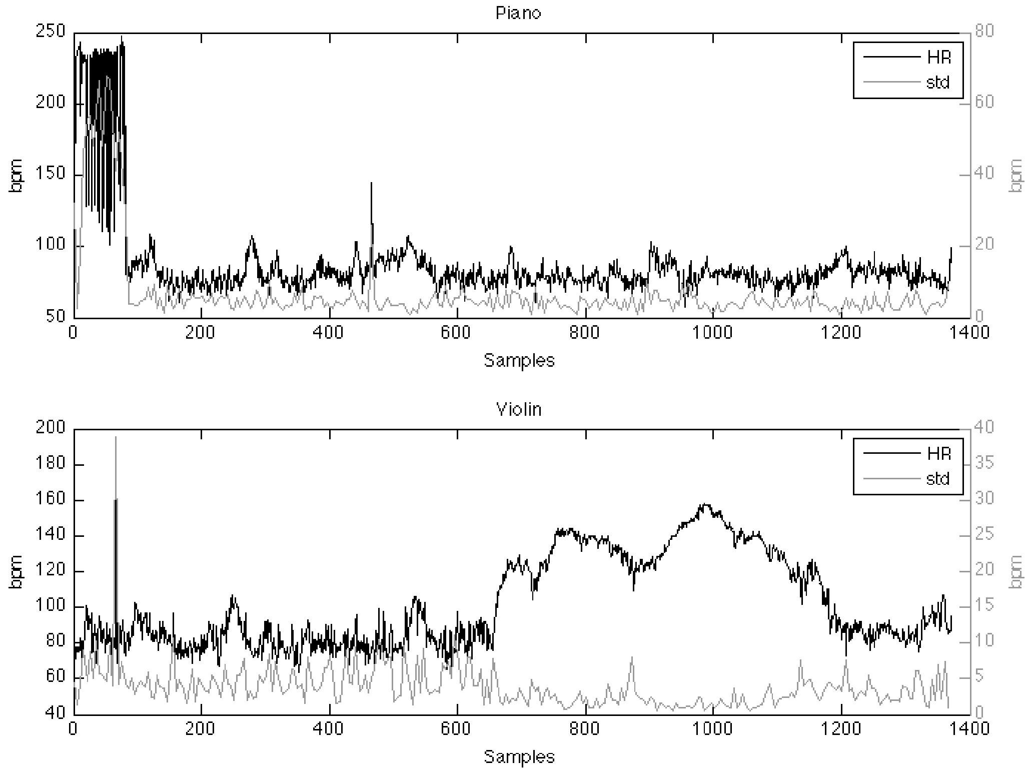

Figure 19 HR (black line) and its standard deviation (grey line) calculated over a non-overlapped 5 points running window over time for pianist (upper chart) and violinist (lower chart)

Analysis

The results support the common assumption that, while playing, the HR increases, like we observed in the violinist. However, the pianist displayed an unresponsive HR profile, apparently not influenced by the different moments – solo, duet. This apparent unresponsiveness of the pianist HR may be explained by the fact that she was under a medication used to keep a stable HR. The violinist was free of medication.

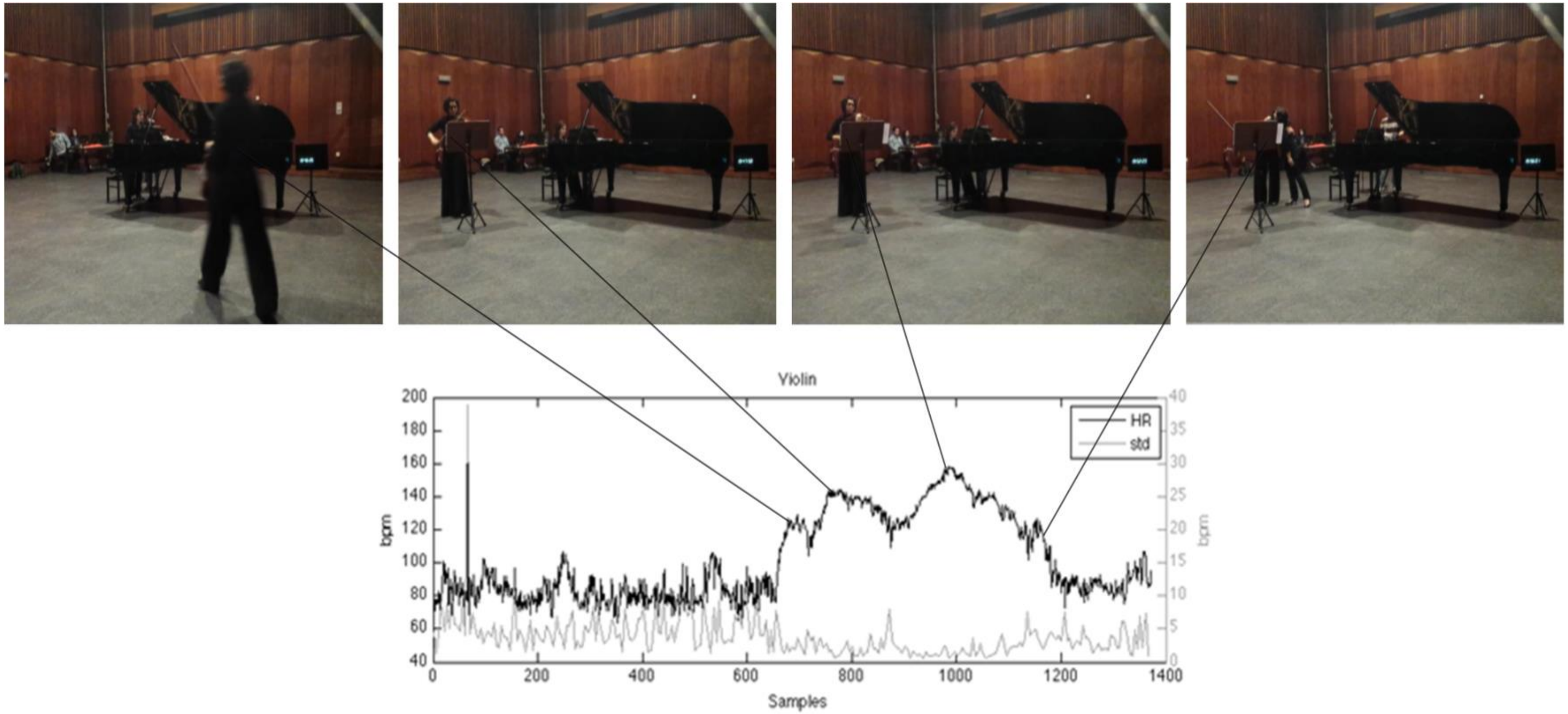

Figure 20 Video frames depicting the violinist in various stages of the concert (images on top) and connection between each one of them and the observed HR values (each line matches a picture to the respective moment's point in the HR chart at the bottom). From left to right: entrance in stage; shortly after the first note struck by the violin; right after the end of a melodically specific musical sequence, a few seconds after the end of the performance

Experiment 2 - scenario 2 - AWARE

We used the AWARE Android application in a phobia scenario with three volunteers (Subject 0, subject1, subject2). The goal of the experiment was to assess if it was possible to distinguish the volunteer's reaction when faced with phobic or faced with neutral stimulus. AWARE was used to assess specific psychological phobias. The stimulus consisted of 3D virtual reality overlays the smartphone screen when used by the volunteers as a magnifying glass while completing a pre-defined path. We collected both behavior (using accelerometer, gyroscope) and physiological signals (ECG using VitalJacket), as well as the video with the mixed reality user perspective (camera input + augmented reality overlay) and the audio captured by the microphone.

With the collected data, we were able to quickly identify any test event and its relation with an observed physiological phenomena (e.g. evaluate the progression of the heart rate values at the appearance and disappearance of a neutral or potentially phobic stimulus).

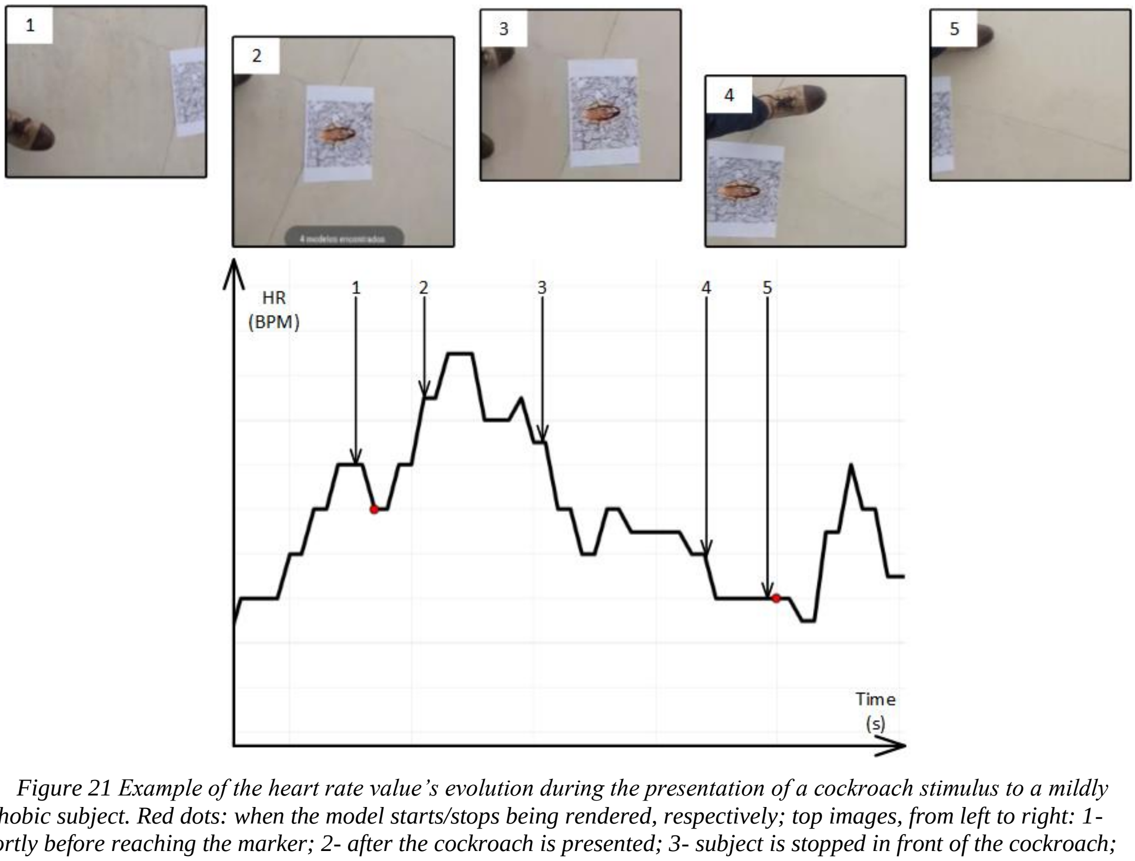

Figure 21 Example of the heart rate value's evolution during the presentation of a cockroach stimulus to a mildly phobic subject. Red dots: when the model starts/stops being rendered, respectively; top images, from left to right: 1- shortly before reaching the marker; 2- after the cockroach is presented; 3- subject is stopped in front of the cockroach; 4- subject starts leaving the marker; 5- just before cockroach is no longer visible

We used a pilot test to fine tune the process. In the pilot test, subject0 evaluated himself as mildly phobic to cockroaches and spiders. The pilot test assessment was used to tune the second data collection with subject 1 and subject 2. The stimuli order was the following:

Test(s)	Stimuli order
Subject 0	1. Apple
	2. Snake (*)
	3. Spider1 (*)
	4. Cockroach (*)
	5. Ball
	6. Snake (*)
	7. Ball
	8. Stone
	9. Mushroom
	10. Banana

Table 2 Stimuli presentation order in Subject0's test (marks potentially phobic stimuli)*

In the second trials, Subject1 and Subject2 identify themselves as without known phobias and performed two tests. In the trial subjects repeated the same path but with different stimuli sequence unknown to the subjects. The following table enumerates the stimuli that were presented to the subjects in each one of these tests, as well as their order of appearance:

Sequence 1	1. Apple
	2. Spider1 (*)
	3. Spider2 (*)
	4. Snake (*)
	5. Cockroach (*)
	6. Mushroom
	7. Ball
	8. Banana

Time interval (< 5 minutes)	
Sequence 2	1. Apple
	2. Spider1 (*)
	3. Mushroom
	4. Ball
	5. Cockroach (*)
	6. Snake (*)
	7. Banana
	8. Spider2 (*)

Table 3 Stimuli presentation order in each test of subjects 1 and 2. (marks potentially phobic stimuli)*

Results

In the pilot test, we observed a HR value variation that suggested alterations (increase) when subject 0 observed the potential phobic stimuli (spiders, snake and cockroach). From an early assessment on this test, we increased the distance between markers to allow the subject's heart rate data to stabilize from one to another – we verified that the time intervals did not ensured that changes induced by a given stimulus would not influence the reaction to the following one.

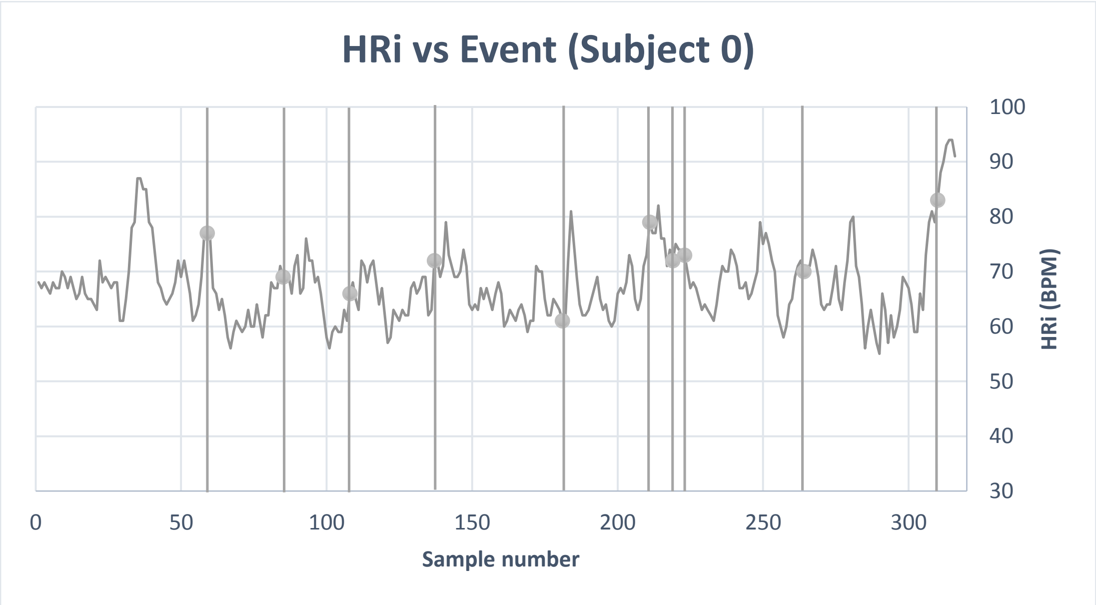

Figure 22 instantaneous HR variation in Subject0, with marks for each stimulus' appearance moment

In Subject1's and Subject2's tests a similar pattern was observed that allowed distinguishing neutral stimuli from the phobic but now with an increase in the neutral.

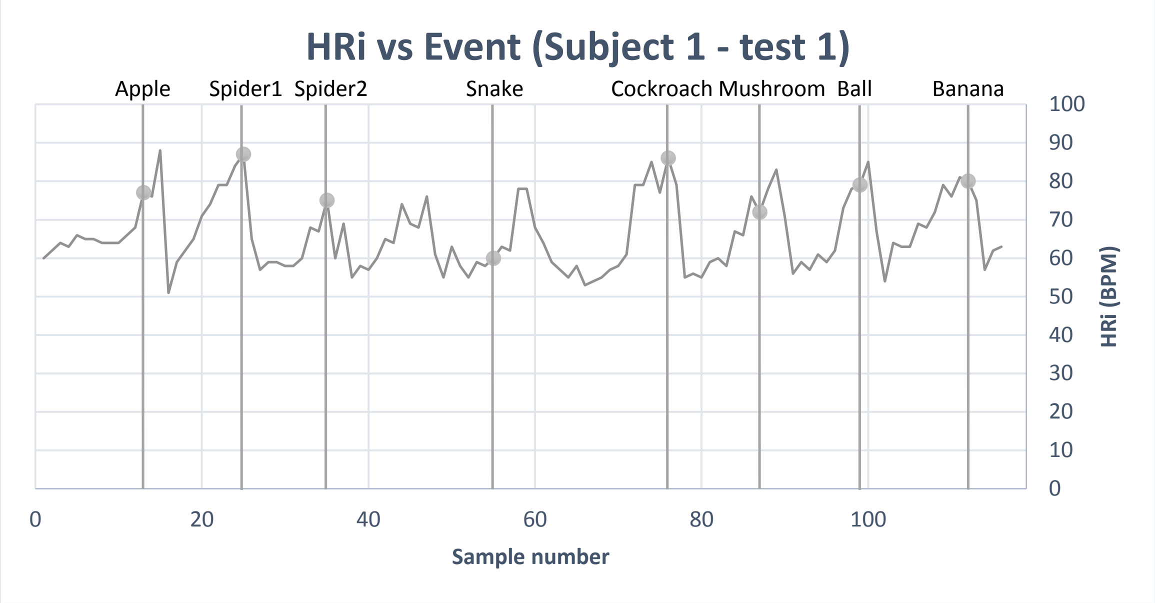

Figure 23 instantaneous HR variation in Subject1's first test, with marks for each stimulus' appearance moment (the name of the stimulus is written at the top of the chart)

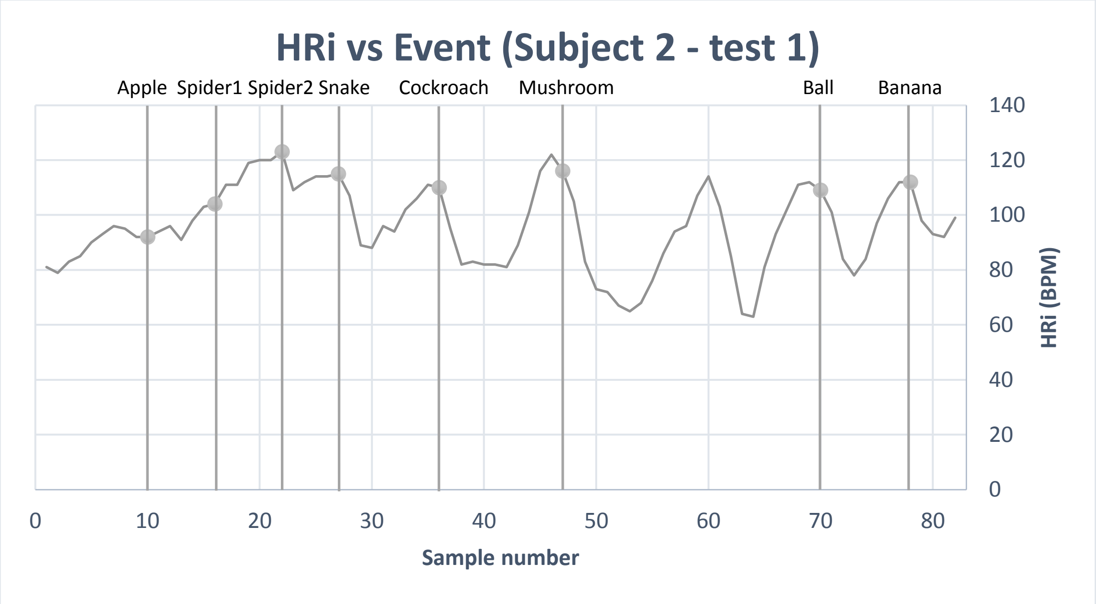

Figure 24 instantaneous HR variation in Subject2's first test, with marks for each stimulus' appearance moment (the name of the stimulus is written at the top of the chart)

We also wanted to evaluate the physiological differences between the first and second tests, in subjects 1 and 2. Consequently, we calculated and compared the instantaneous HR values, as well as the respective average and standard deviation, for each of these tests. The obtained results are presented in the next table:

Subject	Test 1		Test 2	
	HRi		HRi	
	Avg.	St. Dev.	Avg.	St. Dev.
1	66.172	9.121	68.750	9.464
2	96.061	14.920	95.246	11.990

Table 4 instantaneous heart rate average value and standard deviation, between the first and the second test runs, for Subjects 1 and 2

Analysis

Considering the case study, it is expected that phobic participants will react to stimulus. Also, the continuous or repetitive exposition to stimulus will produce a psychological habituation [77], which will lead to a decrease on subject reaction.

The AWARE results suggest that even non-phobic participants present HR alterations induced by stimuli presentation (as visually inspected as a cyclic pattern, Figs. 21, 22, 23).

Only non-phobic participants repeated the test, and there is not a distinguishable pattern from the first to the second test's values (they do not suffer any substantial increase or decrease). If we tested phobic subjects, it was expectable for the values to steadily decrease, as a consequence of habituation. Since both of our volunteers identified themselves as non-phobic, it is not surprisingly to miss this decrease.

Results suggest that using AWARE, we can measure stimuli induced changes. However, to clearly assert the value of augmented reality as an in-loco stimulus for phobias assessment/study, a large and representative sample would be needed to support any conclusion in either way.

Discussion and conclusions

The evaluation showed that the AWARE system could become a viable and helpful tool to physiological and psychological assessment scenarios. In our evaluations all results indicate that the system provides support for a useful quantified assessment, but in both cases we need to increase the sample of either scenarios to prove its usefulness in supporting scientific/clinical valid conclusions.

However it is important to stress that, from our evaluation, it was clear that the main constrains to the physiological and psychological evaluation was on the experimental conditions / research questions and not on the technical solution.

In the music scenario (experiment 1), using EverMore, we detected hints that could lead to interesting findings, namely relating the coupling between HR and specific music details (e.g. the violinist achieved the maximum heart-rate value in a very melodically distinct part of the music, delimited in Figure 18). By performing a technical evaluation (based on music theory concepts) it may be possible to objectively associate the notes being played with their effect on the player.

The absence of notable HR changes in a medicated person may justify the study of medication impact on performance related variables.

The phobia scenario (experiment 2) allowed us to lightly explore the relevance of using augmented reality as a stimuli in in-loco psychological assessment. Increasing the number of subjects, covering the spectrum from extreme phobic to completely non-phobic, may confirm (or disprove) the observed HR variation tendencies when subjects were presented with stimuli. Some technical evolutions may also provide richer and more realistic experiences. Using animated models is one natural option – it may be possible to accomplish using for example the Unity extension to Qualcomm Vuforia. The expected arrival of the wearable devices' trend, including AR glasses [78][79], could potentially replace the smartphone, enhancing the system's immersion level (it avoids the need for the subject to look at a screen to be able to see the stimulus).

7. Conclusions

In this dissertation, we proposed AWARE, a psychological assessment system for non-intrusive monitoring of subjects in real world conditions (i.e. outside the lab), based on a smartphone. The modular architecture of AWARE allowed customizing the system to different contexts through sensor stimuli delivery selection.

Currently AWARE offers two fully deployable mobile (Android) applications, based on the same underlying architecture:

- EVerMoRE, used for non-invasively monitoring the subject’s performance based on multimedia records (camera and microphone input), ECG and movement (accelerometer).
- AWARE (the application), that extends EVerMoRE introducing augmented reality features allowing virtual visual stimuli presentation and recording subjects own perspective (what is observed, reaction to stimuli). Using an augmented reality framework, it overlays through the smartphone realistic 3D models to the subject’s perception of his/her surroundings.

AWARE has a high adaptability to specific monitoring contexts and requirements. Each of the AWARE applications was tested in specific scenarios, and both were able to acquire objective and quantifiable data. Furthermore, the mobile aspect of the solution allowed us to successfully and non-intrusively gather various types of ecologically meaningful information. Although not all available datasources were used in our preliminary studies, they are still available for posterior analysis – in some cases with the possibility of high impact, namely relating music sound with musician performance and physiology.

With AWARE, the employed augmented reality (AR) techniques proved to be a straightforward method to trigger physiological and behavioral reactions in the subjects. The usage of a visual/marker-based AR framework provided a good solution that allows changes to the tests’ protocol on-the-fly, without any logistic constraints or application tweaking. The results give us enough reason to believe that AWARE has enough intrinsic value to be applied in a wide range of real life activities where non-intrusive ambulatory psycho-physiological assessment is relevant, although we need to increase our sampling further to confirm this. In the future, the appearance and massification of new multimodal interaction paradigms and hardware (e.g. dedicated augmented reality wearable devices able to replace the smartphone) might increase the system’s potential even further.

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