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**BeMonitored: Monitorização Psicofisiológica
Usando Dispositivos Móveis**

**BeMonitored: Psycho-Physiological
Monitoring Using Mobile Devices**



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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 Prof. Doutor José Maria Amaral Fernandes, Professor Auxiliar, do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro e da Doutora Susana Manuela Martinho dos Santos Baía Brás investigadora do IEETA e do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro

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palavras-chave

Monitorização,comportamento, psicofisiológica,smartphone ,android, fobias,bio feedback.

resumo

O dia a dia nas sociedades modernas, tem um grande impacto nos indivíduos. O stress continuado, mudanças, traumas e as experiências de vida, são alguns dos fatores ambientais que potenciam o desenvolvimento de doenças de ansiedade. Este tipo de doenças podem conduzir ao isolamento social, a depressões, à diminuição da capacidade de trabalhar, estudar ou executar tarefas do quotidiano. Apesar de existirem inúmeras terapias eficazes no tratamento deste tipo de doenças, os sofredores, não procuram tratamento, ou por desvalorizarem o problema, ou devido à duração e custo associado ou pelo difícil acesso.

Deste modo, é da extrema importância que os investigadores consigam recriar as condições da vida real no estudo de doenças do foro psicológico. Contudo, tal nem sempre é possível.

As recentes evoluções ao nível dos sensores biomédicos fazem deles uma solução simples para adquirir sinais biológicos. Contudo, o seu uso isolado é de certa forma limitado. Por outro lado, combinando estes sensores com um Smartphone, criamos uma solução independente, com enorme potencial, devido ao avançado poder computacional e conectividade destes dispositivos.

Nesta dissertação propomos o sistema BeMonitored: uma solução baseada em Smartphone para suportar um estudo ecologicamente válido a nível da monitorização de doenças do foro psicológico. BeMonitored é uma solução que permite expor os sujeitos a um estímulo audiovisual configurável, que usando sensores biomédicos ligados por Bluetooth ao Smartphone, juntamente com os seus recursos de hardware (ex: câmara, GPS), é capaz de adquirir o comportamento e a fisiologia dos sujeitos, bem como o contexto envolvente.

Como prova de conceito, o BeMonitored foi testado num estudo de fobia a aranhas, onde foi possível obter resultados que nos permitem separar os sujeitos fóbicos dos sujeitos de controlo usando apenas o movimento facial capturado com a camera do smartphone. Encontraram-se também diferenças na frequência cardíaca entre os segmentos de vídeo com aranhas e neutros. Apesar do estudo ser focado nas fobias a aranhas, os resultados obtidos confirmam a validade e o potencial de utilização do BeMonitored em outras fobias, bem como em cenários de terapia cognitivo-comportamental(CBT), quer para a avaliação do nível de fobia quer na exposição gradual de estímulos de video de acordo com as directizes aceites na área da psicologia.

keywords

Monitoring,behavioral,psychophysiological,smartphone,android,phobias,biofeedback.

abstract

The daily life in modern societies has a high impact in individuals. Long-term stress, changes, traumas and life experiences are some of environmental factors that lead to the development of anxiety disorders. Anxiety disorders affects many people in their daily lives, since they may lead to social isolation, clinical depression, and can impair a person's ability to work, study and routine activities. Nevertheless, there are many effective therapies available for such disease, sufferers do not seek for treatment, because they underestimate the problem, the treatments duration, cost or difficult in access.

In result, it is of the utmost importance that researchers can recreate, as accurately as possible, real life conditions in psychological studies. However, that is not always possible.

Recent improvements in sensors technology make then a straightforward solution to gather physiological data. However, their standalone use is quite limited. Nevertheless, combining those sensors with a Smartphone creates an independent solution that without any more requirements has an enormous potential, due to the advanced computing power and connectivity features available.

In this dissertation it is proposed the BeMonitored, a Smartphone based solution to support more ecological valid monitoring of psychological experiments. BeMonitored delivers customizable specific context dependent audio-visual stimuli and using external resources connected via Bluetooth or Smartphone own resources (camera, gps), is able to capture the subject's behavior, physiology and environment.

As a proof of concept, BeMonitored was tested in a spider phobia population, where it was found that spider phobic was separated from control subjects using solely the face motion captured with the Smartphone camera. Also, heart rate differences were found between spider and neutral stimuli. Although current study focused only on spider phobia, the results support the validity and the potential of using BeMonitored in other phobias related, especially in cognitive behavioral therapy (CBT) scenarios, either for assessment of the phobia "stage" or to deliver a stepwise sequence of video stimuli according to accepted psychology guidelines.

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List of Abbreviations and Acronyms

AD	Anxiety Disorders
API	Application Programming Interface
BAT	Behavioral Approach Test
BPM	Beats Per Minute
CBT	Cognitive Behavior Therapy
ECG	Electrocardiogram
EEG	Electroencephalogram
EMG	Electromyography
ET	Exposure Therapy
FPS	Frames Per Second
GPS	Global System for Mobile Communications
GUI	General User Interface
HR	Heart Rate
HRV	Heart Rate Variability
HTTP	Hypertext Transfer Protocol
IEETA	Instituto Engenharia Electrónica e Telemática de Aveiro
OS	Operating System
PPG	Photoplethysmography
SP	Specific Phobia
UI	User Interface
VR	Virtual Reality

1. Introduction

The daily life in modern societies has a high impact on individuals. Environmental factors such as long-term stress, changes, traumas and life experiences may lead to the development of anxiety disorders that regardless of their relevance still lack a proper quantified assessment and follow-up [1].

Specific phobias are the most common psychological disorders, thus causing a significant clinical burden [7]. Spider phobia is one of the most widespread forms of specific phobia. People with spider phobia experience persistent and intense fear towards spiders and develop avoidance behavior of every context related to this animal [3]. Although animal phobia may be considered as having limited clinical relevance, this circumscribed anxiety disorder offers a valuable scientific model for investigating physiological reactions (e.g., heart rate) and behavioral changes (e.g., avoidance).

The most common and effective treatments for this kind of disorder are Cognitive Behavior Therapy (CBT) and Exposure Therapy (ET). Their aim is to help people overcome anxiety by learning how to face their fears in a systematic way. Furthermore CBT aims to change patterns of thinking, beliefs and behaviors, by exposing a person to situations that trigger anxiety [31]. Nevertheless, sufferers do not seek for treatment because they underestimate the problem, the treatments duration, related costs and difficult access [10]. Furthermore, assessment is carried out in laboratories, which in itself introduces disturbances in individuals (e.g., high blood pressure levels or stress reactions). This frequently leads to an overestimation of clinical features that may interfere with the results and treatment follow-up [2][8]. Consequently, capturing and quantification of physiology and behavior in realistic environments is very relevant in psychological science [1]. However, due to technical difficulties (i.e., logistic, lack of mobile setups), most studies have been performed in highly controlled settings, regardless of the relevance of the context and environment in the studied phenomena. While the benefits of laboratory studies are undeniably relevant, they do not portray real life scenarios. As a result, by exclusively relying on laboratory-conducted treatments, therapists likely to miss important aspects of emotional functioning that may be central to life outside the laboratory environment (e.g., stress at work, family context, etc).

With the recent developments of biomedical sensors, Smartphone and the diffusion of wireless telecommunications, it becomes easier and more natural the introduction of new mobile devices in the assessment of certain diseases, allowing new scenarios. Mobile could provide solutions to quantify the reaction to phobic stimuli in the assessment of the phobia level or in the treatment follow-up – all in a more realistic and ecological context. Consequently, with the advent of both sensor technology and mobile phones, new scenarios for data gathering outside the laboratory environment are a reality, allowing a quantifiable follow-up.

In this dissertation it is proposed the BeMonitored, a system supported on a mobile device. BeMonitored intends to explore the use of mobile systems in the assessment and study of psychological disorders outside the laboratory. BeMonitored can deliver context aware stimuli (e.g. time, GPS location) based on both audio and video while monitoring both behavior (e.g., face motion and expressions using the Smartphone camera and sensors) and physiologic variables (e.g., ECG as in the present configuration using an external wearable device).

As a proof of concept, the BeMonitored was tested in phobias, more specifically, spider phobia. Since it is triggered by a very clear and specific ecological stimulus, it is the ideal disorder to evaluate the impact of using a mobile monitoring solution

1.1 Objectives

The BeMonitored is a system (architecture and software application) that is supported on a mobile device that:

- Delivers in more realistic environment (out of the lab) psychology protocols to support the assessment and follow up of psychological disorders.
- Supports in-place multimedia stimulus delivery.
- Allows monitoring and review of both physiology and behavior of individuals' responses to stimuli.
- Supports minimal patient/carer workflow used in CBT (Cognitive Behavior Therapy) based therapies, allowing customizable stimuli design.
- Assess diagnosis process and treatments outcome.

1.2 Contributions

The main contribution of this dissertation is the development of a solution BeMonitored. BeMonitored uses mobile systems in the assessment and study of psychological disorders outside the laboratory and therefore being more valid and ecologic. It allows the simultaneous measuring of behavioral and physiological data, while an audio-visual stimulus is presented using Smartphone resources. BeMonitored supports an IT (Information Technology) flow for storage, reading and analysis of all acquired information and allow a remote assessment of the individual.

A paper describing the BeMonitored system was submitted to the 17th ISWC International Symposium on Wearable Computers, themed *"from Mobile to Wearable"* to be held in Zurich, September 9-12, 2013. In addition to this, a poster describing BeMonitored system was presented on the 8th *"Encontro Nacional da Associação Portuguesa de Psicologia Experimental"*.

1.3 Document Structure

This document is structured in seven chapters. In Chapter 2, it is made an overview of psychological diseases, the assessment techniques used, relevant measures to monitor, problems and the technologies involved in order to monitor relevant variables. Chapter 3 presents a conceptual architecture for the assessment of psychological disorders outside the lab environment. The challenges involved and the system's requirements are also discussed. In chapter 4, the BeMonitored solution is presented, considering the conceptual architecture requirements, and the functional description of system components. In Chapter 5 is explained the system implementation details and choices made, as well as the processes involved and data flow between the several system components. Finally, in Chapter 6 we present the case study conducted, results obtained and discussion, which is followed by Chapter 7, that contains the main results, conclusions and future work.

2 Psychological Assessment of Anxiety Disorders

Anxiety Disorders according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) [3] are the most frequently occurring emotional disorder in the United States. Anxiety disorders, according to the DSM-IV categorizing system includes Obsessive-Compulsive Disorder, Acute Stress Disorder, Posttraumatic Stress Disorder, Generalized Anxiety Disorder (GAD), panic disorder and phobias [3].

Anxiety is a normal human physiological mechanism designed to help the body in the response to a threat. The autonomic changes that occur in anxiety are essential to avoid danger. However, when anxiety is associated with very high levels of autonomic arousal¹, erroneous cognitions including exaggerated threat perceptions and dysfunctional coping strategies, it may result in significant distress and impairment at work, school, family, relationships, and/or activities of daily living [4]. Individuals severely affected with such disorders, are also more likely to have either another type of anxiety disorder, major depression or dysthymia, alcohol or substance abuse, or personality disorder [32]. Generalized anxiety disorder (GAD) is a prevalent, disabling, and one of the most common anxiety disorders [5]. The *National Institute of Mental Health (NIMH)* estimates that 18 million Americans aged 18 or older experience an anxiety disorder each year. Although the anxiety disorders have devastating effects on these patients' lives, only 15 to 36 percent receive treatment [5]. For a variety of reasons, many individuals may not seek treatment for their anxiety, because they may consider their symptoms not severe or normal, or the symptoms themselves may interfere with help seeking. Treatments duration, cost and access may also be a reason for not looking for treatment [33].

The typical recovery rate of such condition is about 40%, considering the current psychological treatments [41][42]. Therefore, a better understanding of potential psycho-physiological mechanisms related with anxiety disorders is outmost importance [6].

2.1 Specific Phobias

Specific phobias (SP) are the most common psychological disorders, thus causing a significant clinical burden [7]. SP is defined as a persistent, irrational, intense fear of a specific object, activity

¹ Arousal is a physiological and psychological state of being aware or reactive to a stimulus. It involves the activation of the reticular activating system in the brain stem, the autonomic nervous system and endocrine system, leading to increased heart rate and blood pressure and a condition of sensory alertness.

or situation (the phobic stimulus), which is recognized as being excessive or unreasonable by the individual himself. The distress associated with the SP can significantly interfere with the person's ability to function and therefore has a strong impact on their daily lives [3]. Once SP is a fear unreasonable in its degree or nature, it is powerful enough to “force” the distresser to avoid the feared object or situation. This turns the disturbed individual extremely anxious, even panic stricken when forced to confront it or even thinking in such object or situation. Even if the feared object or situation does not appear regularly, sufferers may find out, that a lot of time is spent warning that it may appear or figuring out how to avoid it. Depending on phobia type, distressers might find it a real struggle to run errands, go out with friends, socialize, met new people or even work every day. These limitations can make phobia sufferers feels isolated becoming reclusive and depressed [8].

Specific phobias is among the most common psychological problems and are seldom the primary reason that the individuals seek for treatment as SP is rarely the focus on clinical attention. This is because there is a common perception, in many cases mistaken, that this kind of disorder is straightforward and uncomplicated. In addition to, as the fear associated with SP is typically limited to the phobic stimuli and rarely associated with pervasive anxiety outside the phobic episode, it is a common believe that SP are less severe than other anxiety disorders, which is quite wrong [8].

The diagnosis of SP can be challenging since they are frequently confound with other anxiety disorder and frequently share many features. Although no formalized protocols have been established for evidence-based assessment of SP, literature suggests that the core dimensions to be assessed include diagnostic features, signals and triggers, avoidance and safety behaviors, physical symptoms among others [8][9]. SP are sometimes associated with complex symptom profiles, which are associated with intense levels of anxiety with both physiological and psychological manifestations. Some of the more common physiological symptoms include raised heart rate and breathing rate, sweating, shortness of breath, tightness in the throat chest and nausea [9]. The psychological symptoms include a fear of losing control, fear of dying and a sense of disorientation and confusion and are associated with extensive coping and avoidance behaviors [8].

Assessment of Associated Features:

The cognitive-behavioral model of specific phobia stresses the role that *cognitions* (e.g., "If a snake bites me I will die") and *behaviors* (e.g., escape and avoidance) play in causing and maintaining the phobia [8]. People, who have this kind of disorders frequently, overestimate the danger of the feared situation and underestimate their ability to handle with the situation. Since

they usually avoid the situation, they do not have the opportunity to learn that their beliefs are unrealistic [35].

Cognitions

Several studies have implicated cognitive variables, such as anxious beliefs, pre-cognitions, and expectations, in the maintenance of specific phobias. Identifying and monitoring the specific beliefs that may be maintaining the phobia provides targets for intervention and an important role in treatment progress and outcome [8].

Escape, Avoidance and Safety Behaviors

According to cognitive-behavioral models, avoidance behavior is one of the primary factors that maintain anxiety. Avoidance behavior can be overt, such as refusing to confront the feared object or situation, or escaping from a fearful situation [8][18].

However, avoidance behaviors can also be subtle, such as using safety behaviors, distraction, or other maladaptive coping behaviors when in the feared situation. Safety behaviors are coping strategies that are intended to reduce one's anxiety and prevent some feared outcome from occurring [8].

Although avoidance behaviors may help to reduce fear in the short term, they are thought to maintain the disorder in the long term. As a matter of fact, avoidance tends to make individuals fear stronger in the long run, since it prevents them from learning new information. A possible reason for this is because individuals may come to believe that the coping behavior was responsible for preventing the feared outcome or enabled them to manage their fear in the situation (e.g., "The spider didn't bite me because I was wearing a protection") [8].

2.1.1 Assessment Strategies

To examine the diagnostic and associated features described earlier, a comprehensive assessment should include a range of strategies, including a clinical interview, behavioral assessment, and self-report measures [44]. Although psycho-physiological measures, such as skin conductance, heart and respiration rate, and muscle activity, are frequently used in academic and research contexts, they are rarely used in clinical practice, and there are several reasons for this [8]. Firstly, there can be considerable cost and training investments required for physiological measuring equipment. Secondly, interpreting the various physiological indices can be challenging since no clinical cutoffs or guidelines exist. Also, arousal is influenced by many different variables and is not specific to the clinical situation. Finally, changes in physiological measures may not

correspond with changes in fear. Nevertheless, in some cases, measuring aspects of physiological arousal (e.g., heart rate) can be clinically useful [8].

Specific phobias are highly treatable and are most effectively treated by psychological rather than biological treatments [44]. The primary goal of most treatments approaches for specific phobias is to reduce fear, phobic avoidance, impairment, and distress. Besides they are highly treatable, only 12%–30% seek treatment for specific phobias [10]. In the following paragraphs it is made an overview of the treatments/approaches used to assess these disorders.

The *clinical interview* is the most frequently used method of assessment for specific phobias. In addition to establishing a diagnosis, the interview also allows for a comprehensive evaluation of the idiographic nature of the individual's experience, including cognitive, behavioral, and other associated features [8].

Using *Self-Reported measures* is another way of Measuring patients' symptomatic experience through questionnaires or standardized interviews. This approach is the gold standard method for evaluating the presence and severity of a mental disorder. Therefore, most outcome studies of anxiety disorders treatments have used questionnaires and self-report to assess treatment efficacy [8].

Concluding, self-report measures should be used to guide the clinician to potential areas of concern, supplement information obtained from other assessment types, and monitor symptom changes during the treatment plan. Although self-report scales can provide a unique and rich source of clinical information, they should be used in combination with, not as a substitute for, other assessment strategies [8] [18].

Behavioral Assessment

Behavioral observation is a simple, highly efficient, and informative method for assessing specific phobias. Since phobic sufferers may become extremely anxious or nervous when discussing their phobic fears, behavioral observation, is an ideal part of the assessment process, as it allows the clinician to directly observe the patient's reaction to various representations of phobic cues in "real time" [49]. Since most of specific phobia sufferers have a longstanding history of avoiding the feared object or situation, they may have difficulty in remembering specific details about the factors that affect their fear or overestimate the intensity of their fear in the phobic situation. As a result, behavioral assessment strategies provide objective data that may be less biased than self-reports about the variables associated with the person's fear. Self-Monitoring diaries as well as the BAT are some of the most frequently used behavioral assessment (BA)

strategies. Self-Monitoring involves phobic sufferers' observation and recording of encounters with their feared stimulus and note specific variables of interest (e.g. fear signals, thoughts, physical sensations, and coping and avoidance strategies). The Behavioral approach/avoidance test (BAT) is a common behavioral observation method used to assess specific phobia [18]. This approaches involve the individual enter the fearful situation and measuring his/her response. The variables usually assessed include the proximity to the feared object, environmental and contextual variables (e.g. size, color or movement of the stimulus, environment lighting or temperature), physical sensations (e.g., Heart rate, sweating, shaking), thoughts (e.g., predictions. expectations or observations), and coping behaviors (e.g., escape, avoidance, safety behaviors).[8] Although BAT proves to be effective in SP assessment, it can incur some potential limitations that therapists should be aware of. Since BATs are conducted in a clinical setting may not be representative of encounters with the feared object or situation in a naturalistic setting [8]. In order to improve external validity, efforts should be made to make the approach task representative of the subject's fear in everyday encounters. Ideally, this can be achieved by working collaboratively with phobic subjects to create an individualized fear and avoidance hierarchy. Despite these considerations, behavioral assessment is an important and valuable component of an evidence-based assessment for specific phobias.

2.1.2 Overview of Evidence-Based Treatment for SP

The evidence-based treatment for specific phobia is divided in three main groups: cognitive behavior therapy (CBT), exposure-based therapy (ET) and personal biofeedback training therapy.

Cognitive behavioral therapy (CBT) is the most widely used treatment for specific phobias [31]. The main objective is to change the way the person thinks and behaves when confronted with their fear/phobia. CBT works on the principle that the thoughts that procedure and maintain anxiety can be recognized and changed, by using various techniques that modify behavioral responses and eliminate the anxiety reaction [48]. Treatments were adapted to this principle by combining the cognitive approach (changing the pessimistic ideas, unrealistic expectations), with behavioral exercises (exposure to the feared situation, stress and anxiety management).

The basic element of CBT is to have patient increasingly being exposed over several sessions to their fear to gradually reduce anxiety until the symptoms do no longer occur [34]. This exposure is done by using a systematic approach with resource to specific sets of techniques described below. As an outcome the patient will overcome the irrational thought that provokes the anxiety and fear, instead of avoiding it, reducing the SP symptoms.

Cognitive-behavior therapy for specific phobia includes several types of interventions:

- **Monitoring:** This process involves learning the physiological, cognitive, and behavioral components of sufferer's phobia.
- **Cognitive:** Identify sufferer's beliefs about the phobic object or situation, challenge them, and correct their misperceptions.
- **Behavioral:** Patients and therapist may devise a plan to gradually and systematically expose distressers to their feared object or situation. This can be done in real life or in imagination or both. With repeated practice, sufferers will challenge and change their negative expectations, gain confidence in their ability to cope with the feared situation, no longer associate the situation with anxiety and fear, and decrease their anxiety and physiological arousal in feared situations. If individuals fear certain sensations (for instance, increased heart rate), exposure treatment will involve gradually and systematically bringing on and experiencing those situations in order to overcome sufferers' fear [35].

Exposure therapy is an integral part of CBT, and as the name suggests, involves the person being repeatedly confronted with the fear object or situation in a systematic and controlled manner while preventing behavioral and cognitive avoidance. The idea is that through repeated exposures, distressers will feel an increasing sense of control over the situation and their anxiety will diminish. The exposure therapies techniques frequently used are:

- **Systematic Desensitization:** This approach requires the individual in a relaxed state to visualize features of the phobia. The objective is to teach the patient to associate stimuli with a relaxation state (de-sensitization). Systematic desensitization allows individuals to gradually challenge their fears, build confidence, and develop skills for controlling panic.
- **In-vivo Exposure (Active Exposure):** In-vivo exposure refers to the direct confrontation of feared objects, activities, or situations by a sufferer. With time, less anxiety occurs in the phobic situation, a phenomenon known as habituation.
- **Virtual Reality (VR):** This therapy involves exposure to the feared situation via technology (photographs or video film), which creates the phobic situation that is feared similar to that experienced in reality.

Graduated exposures give the patient a greater degree of control over the length and frequency of exposures. In both cases, the patient experiences the anxiety over and over again until the stimulating event eventually loses its effect. Combining exposure with standard

cognitive therapy may be particularly beneficial. This approach has helped certain patients in most anxiety disorder categories [48].

There are no side effects other than the discomfort of temporarily increased anxiety. The main disadvantages to these therapies are related with the time consumption in therapy (approximately 12-20 weeks), the inherent cost and difficult access [36].

Biofeedback, or applied psycho-physiological feedback, is a patient-guided treatment that teaches an individual to control muscle tension, pain, body temperature, brain waves, or other body functions and processes through relaxation, visualization, and other cognitive control techniques. The name biofeedback refers to the biological signals that are feedback, or returned, to the patient in order to develop techniques to manipulate them [11]. By displaying, in real time, patients' physiological activity (e.g. heart and breathing rate, blood pressure, skin conductance), Biofeedback helps them to recognize which events triggers their body anxiety responses and use these signals to learn how to control their body responses, using relaxation techniques (e.g. progressive muscle relaxation, controlled breathing)[51].

Biofeedback training is a part of the behavioral treatment plan of anxiety disorders since it offers a non-pharmacological approach to direct symptom reduction. Biofeedback training methods may combine CBT, with one or more biofeedback training: Electroencephalogram (EEG) biofeedback (brain electrical activity), Electromyography (EMG) biofeedback (skeletal muscle activity), Heart rate variability biofeedback (timing between heartbeats), Respiratory biofeedback (breathing patterns), Skin conductance biofeedback (sweat gland activity), temperature biofeedback (blood flow through small arteries) [37]. Personal biofeedback training proved to be an effective treatment for anxiety disorders that produces results comparable to those achieved by relaxation procedures like meditation and Progressive Relaxation [37].

2.2 Delivering stimuli within psychological assessment

Regarding the treatment plan and evaluation of anxiety disorders, especially specific phobias, the Exposure Therapy (ET) and Cognitive behavior therapy (CBT) are the most often used. Typically they rely on in-vivo exposure and audio-visual stimuli display such as images, videos and sounds [45].

Exposure	In-vivo [69]	Imagination [8]	Single Media [66][67]	Multimedia [68]	VR [70]
Covers all sensitivities?	Yes	Yes	No	More/less	More/less
Focus on stimulus?	No	No	Yes	Yes	Yes
Active participation?	Yes	More/less	No	No	Yes
Applicable to any phobia?	Yes	Yes	No	More/less	Yes

Table 1: Exposure solutions Overview (Advantages and Disadvantages).

In-vivo exposure [69] refers to direct confrontation of the feared objects, activities or situations by a patient. However it is not always the best solution. A side effect of covering perfectly every cause of anxiety is the difficulty for therapists to isolate stimuli in order to reduce the number of variables influencing the patient [50]. Consequently, they often use single media exposure with pictures [66], sounds [67] or touch. In this scenario, one of the most frequently used stimulus set is the International Affective Picture System (IAPS) [66], which contains a large number of pictures, with normative ratings for their level of experienced valence² and arousal. Similarly, a set of sounds of several durations has been assembled for the same purpose (International Affective Digital sounds, IADS) [67]. Such kind of stimuli has been used to prove basic affective response tendencies in short-term reactions. However, by using these approaches, the sensitive of the patient to one medium or one stimulus limits the exposure impact. This issue can be improved by using multimedia technologies [68], for instance video. This method employs viewing brief video clips films, containing the feared stimuli, and has proven highly effective in eliciting various emotions (e.g., anxiety, anger, sadness, etc.), in relation to long-term dynamic emotion processes [2]. However, none of mediated exposure requires an active participation from the patient (table 1). Exposure in imagination [8] has the opposite approach but does not ensure that the patient actually forces himself to face the feared situation. According to these criteria (table 1), Virtual Reality (VR) [70] and Multimedia [68] seem to propose a good compromise: they can focus on specific stimuli, cover many media and sensitivities. VR has found a wide acceptance in this kind of treatments since beyond these aspects, it still ensures that the patient is active.

² Valence, as used in psychology, means the degree of attraction or aversion that an individual feels towards a specific object or event.

2.3 Monitoring Physiology and Behavior

Monitoring a person, can be very important in some areas and can be achieved in different ways. Monitoring physiological data like ECG or derived variables (e.g., heart rate), blood pressure, are vital in the prevention or monitoring of certain diseases (e.g., diabetes, heart diseases). Moreover, the continuous monitoring of these variables allows the early detection of potential risky situations in person's daily routine or in treatment plan of progressive diseases (e.g., mental disorders) [38]. Considering physiology monitoring, heart and respiration rate, skin conductance and muscle activity are the biological measures typically used to evaluate anxiety levels [2][8].

Monitoring patients behavior is also very important and useful in diagnose and treatment plan of certain psychological disorders (e.g., anxiety disorders). Cognitive behavior therapy and Exposure therapy are examples of treatments used to assess these problems, where evaluating individual's behavioral response is vital. Considering behavioral monitoring, there are several options, namely activity, location, face expressions, voice, etc. These measures are frequently used to evaluate person's response to a certain event or stimuli [2][8].

2.4 Mobile Physiological Monitoring Applications

Regarding some of the problems/limitations existent in the assessment and seeking treatment of anxiety disorders (e.g., treatments cost, duration, availability, and the fact that they are conducted in clinical setting) and the biological variables frequently measure, several research was done on systems where mobile devices (e.g., Smartphones, biomedical sensors) are used to perform physiological monitoring, namely heart activity of the patients and allowing therapist/remote entity supervision.

Considering biomedical sensors, there are various options on the market, namely heart rate monitoring devices such as Zephyr HR Bluetooth heart rate monitor [52], polar Bluetooth heart rate monitor [53], Wahoo Fitness ANT plus Dongle [54] and many more. They all enable accurate and reliable monitoring of people's heart activity by monitoring their heart rate values and have Bluetooth connectivity, which allows data forwarding in real time to other devices. These devices, which allow continuous heart activity monitoring, are portable/wearable (e.g., t-shirts, watches, wear-link), have rechargeable batteries, and allow the storage of the data collected for later review or exportation. Nowadays, these sensors are frequently combined with Smartphones in order to provide more functionality to the user, namely in training applications (e.g., polar beat [53], wahoo fitness [54]) or in remote healthcare [12][14] scenarios. The following systems are some examples of

Smartphone based applications available that together with biological sensors allow ambulatory physiological monitoring of individuals, enhancing its use in remote health care scenarios.

UAHealth [12] is an iPhone application for health monitoring and management, designed to monitor physical activity, weight and heart activity. This system relies on an iPhone communicating with several wireless sensors to collect information about the user's physiological signals. All relevant data acquired is uploaded to a remote server, which can be accessed by the user or any other approved entity. As most of the users not always have an available Internet connection, the authors contemplate the problems of intermittent connection. Therefore, the system is capable of working both online and offline, by monitoring Internet connectivity to determine the right moment to upload health related information. For this reason, the application includes both local and remote database.

Droid Jacket [13] is a team monitor solution that relies on an android based Smartphone for monitoring First responders on the field since they are frequently exposed to extreme environmental conditions, inducing stress/fatigue during extensive periods of time. Based on the existence of an ECG wearable monitoring solution- the Vital Jacket®, the authors [13] proposed this Smartphone based solution, in order to provide data aggregation, processing, visualization and relaying services to a remote user. The DroidJacket design is plug-in oriented, integrating analysis modules, namely online ECG plug-in for both real time and arrhythmia detection.

Heart Monitor [14] is a heart rate monitoring system based on mobile phones. The author's targets are patients with high risk of cardiac problems, so they designed a system able to analyze ECG data in real time. The Smartphone can automatically alert a pre assigned entity and also give advice to the patient, based on sensor data. In order to monitor heart activity the system uses different types of sensors- ECG, accelerometer, oximeter, weight scale or blood pressure monitor. The sensors used can be customized by the patient's doctor by selecting one or more sensors to be used for a particular patient and configure threshold levels for each of them. The prototype, proved to be fully functional, being able to detect life-threatening arrhythmias. The authors focused on two life threatening arrhythmias (Ventricular Fibrillation and Ventricular Tachycardia), using an open source beat detector and classifier, based on the algorithms developed by Pan and Tompkins [15]. The project also includes the detection of falls and patient's location, personalization of the sensor's and an emergency procedure.

2.5 Mobile Behavior Monitoring Applications/Techniques

The research made over specific phobias, revealed that the diagnosis of such disorders can be very challenging since they are frequently confounded with other anxiety disorders and often shares many features [8]. Moreover, most of behavioral assessment is based on observation and is not quantified [1][50] and consequently, therapists are likely to miss important features of

sufferers' behavior [2]. Considering these issues, it is of outmost importance that therapists have solutions to quantify individual's behavior (e.g., by identifying avoidance, safety and copying behaviors), helping then in the diagnosis process and patients follow-up.

Studying the complexities of human behavior, whether in the lab or in the natural environments, requires data collection methods that are discrete as well as accurate. Some of the techniques used for both qualitative and quantitative behavioral monitoring include monitoring subject's activities, location, voice activation, facial expressions and movements [2]. As a consequence, face and eye detection/tracking solutions, video monitoring, activity recognition by using sensors (e.g., accelerometers and gyroscope), location acquisition (GPS) and audio recording are some of the frequently used techniques to achieve this purpose.

Qualitative Behavior Assessment

Video Monitoring

Video has become widely accepted as one of the most valuable sources of information [55]. Video is an electronic medium for the recording copying and broadcasting of moving visual images, which are usually captured by a camera with an electronic image sensor. The number of still pictures per unit of time (frames per second) corresponds to the frame rate of the video.

Video monitoring can be defined as the act of monitoring by recording a video of the person/place to be supervised. Video monitoring can be performed remotely by someone who watches a video that was or is being recorded by camera at the location of the person/object to be monitored [84]. This approach is used in healthcare namely to supervise patients at the hospital [60] or at home (e.g., elderly people) [59][61][62]. Video monitoring has other applications for instance in security surveillance systems and emergency service areas. The capture of a video can also be used for leisure, for example in recording person's day-to-day activities [63].

Audio Recording

Human voices can transmit a considerable amount of information to a listener and can be used for assess a number of qualities and emotions about a person.

Frequency and distribution of speech behavior across the day is a relevant variable in emotion research due to their relationships with mood, social isolation and depression [2]. Nevertheless, these simple parameters of speech activity have only recently begun to be systematically collected. A promising new ambulatory assessment method for this purpose is called electronically activated recorder (EAR) [77]. It uses a portable audio recorder that samples sound segments of a few

seconds every few minutes from participants' immediate environments. By tracking moment-to-moment ambient sounds, it yields an acoustic log of a person's day as it naturally unfolds. As a naturalistic observation method, it provides an observer's account of daily life and is optimized for the assessment of audible aspects of participants' social lives [2]. The sound snips can be rated by trained coders for various informative categories, such as surrounding context (e.g., inside, outside, restaurant, lecture, conversation, etc.) amount of speaking (word count).

Quantitative Behavior Assessment

Activity Recognition

Activity recognition is an important technology in pervasive computing since it can be applied to many real-life, human-centric problems namely in eldercare and healthcare [71].

The goal of activity recognition is to recognize common human activities in real life settings. Different types of data can be used to recognize activities, but the most commonly used are the data obtained from one or more sensors. From these data it is possible to extract features, which are the input of a classifier that is able to identify a given set of activities (e.g., sitting, standing, walking, lying, etc) [84]. Activity recognition use mainly accelerometers [72][73]. However, combinations of different types of sensors have also been used, such as accelerometer together with orientation sensor and magnetic field sensor [74]. More recently, gyroscope has also been used either alone or combined with other sensors [75]. Once current Smartphones include many embedded sensors, these devices are increasingly popular in activity recognition [72][74][76].

Face Detection

Face detection is a computer technology that determines the locations and sizes of human faces in arbitrary (digital) images. It detects facial features (e.g. eyes, mouth) and ignores anything else. In recent years, face detection has attracted much attention and its research has rapidly expanded by not only engineers but also neuroscientists, since it has many potential applications such as in human computer interface, video surveillance, face recognition, image database management and tracking [55]. The focus on face comes from the fact that among human body parts, the face has been the most studied for visual human tracking and perceptual user interface, because face appearance is more statistically consistent in color, shape and texture, thus allowing computer to detect and track with robustness and accuracy. Furthermore, facial (head) pose contains information about one's attention, gaze, fatigue levels, expressions and coping behaviors.

Eye Detection and Tracking

Eye tracking is the process of measuring either the point of gaze or the eye movements relative to the head. An eye tracker is a device for measuring eye positions and eye movements. Eye trackers are used in research on the visual system, in psychology [50], healthcare, in testing the usability of websites and software [58], in human computer interface [55], monitoring human vigilance [64], gaming [56][57] and in accessibility, by assisting people with disability [79]. The most popular variant methods for measuring eye movement rely on video images from which face is detected and the eye position is extracted.

Regarding the use of mobile phones, these devices are suitable solutions for image capture, audio recording, activity recognition, location awareness since they are carried out on daily basis, and most of the recent models includes two cameras (one on the front and other on the back of the device), microphone for audio recording and embedded sensors (GPS, accelerometers and gyroscope). These resources make then the perfect devices to assess and quantify the measures typically used for behavioral assessment.

3 Assessment and Study of Psychological Disorders Outside Lab Environment

Laboratory and self-report approaches were the most feasible strategies in the past, if not almost the only ones in the assessment of specific phobias [8]. These approaches still possess distinct advantages: questionnaires and interviews provide easy access to emotion experience and self-observed behavior, and can be used quickly and cost-effectively to evaluate stable characteristics of personality, attitude and cognitions relevant for understanding the emotional phenomena. However, while the benefits of laboratory studies are undeniably relevant, they do not portray real life scenarios. Consequently, by exclusively relying on laboratory conducted treatments and self-reported data, therapists may miss important aspects of emotional functioning that may be central to life outside the lab context [2][8].

Moreover, there are clearly other phenomena, such as emotion or stress, for instance at the workplace, in the family context, at school, or even outdoors, that require examination under naturalistic conditions. Consequently, an increasing number of studies have demonstrated an added value of ambulatory approaches [2].

Furthermore, laboratory baseline conditions may also not closely represent real world functioning in result of specific patterns of emotional reactivity to the setting. This frequently leads to an overestimation of clinical indices [2][8]. A common example of this effect is the "white-coat hypertension", i.e. high blood pressure levels during baseline periods or stress reactions. Consequently, any elevated physiological or behavioural indices of anxiety may merely be an artefact of the laboratory situation. In result it has been argued that real life assessment over longer intervals of time is required to establish the validity of laboratory results [2].

Motivated by the problems previously identified in laboratory assessment, in this chapter we will introduce an alternative paradigm of ambulatory assessment and field experimentation which, up to date, remains relatively rarely used in psychology disorders and emotion research.

3.1 Motivation and challenges

Our challenge is to devise and implement a system to the assess and study of psychological disorders outside the lab environment exploring the use of mobile systems. The system should allow the monitored patient to self-assessment by monitoring his psycho-physiological responses, while confronting a video stimulus (Figure 1).

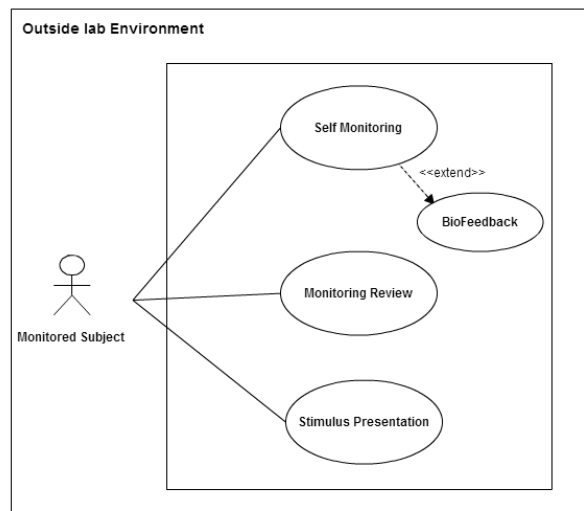


Figure 1- Use Cases for the monitored subject (patient).

In this context, although not an explicit requirement, there is a need to support all the process not only for the perspective of the individual Cognitive Behavior Therapy (CBT) and biofeedback scenario, but also from the perspective of the individuals' therapist/carer. The therapist/carer must not only be able to coordinate the process, such as defining and delivering the stimuli protocol (i.e. define the stimuli, when to present it), but also to assess and evaluate the results of the acquisitions (e.g. quality control, support therapy changes/ options, etc.). In this context, it is mandatory to find solutions to 1) acquired both physiological and behavior data 2) store the information, 3) process and 4) visualize/assess the data.

To accomplish a reliable session review and assessment, and guarantees compliance with the delivery protocol stimulus, while ensuring data integrity, it is mandatory to maintain the application context remotely. These technological challenges can be translated in a set of use cases illustrated on Figure 2.

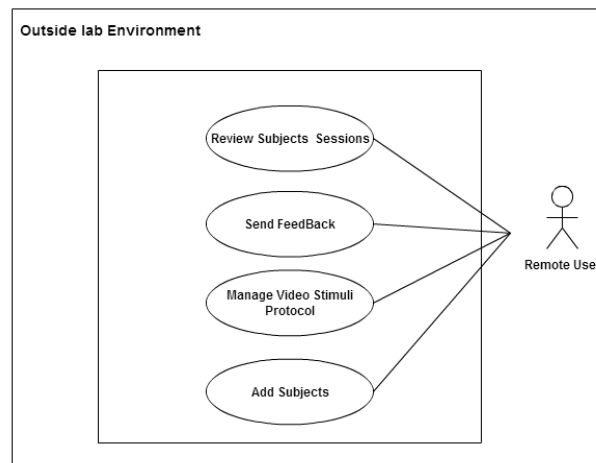


Figure 2- Use Cases for the remote user (therapist/carer).

Summing up, there is a set of functionalities / features that were identified as clearly needed to obtain a suitable solution:

- It must allow monitoring and reviewing both physiology and behavior of individuals – this implies identifying the relevant measurements and solutions to acquire them.
- It should be able to deliver in a realistic environment (out of the lab), psychological protocols to support the assessment and follow up of psychological disorders supporting in-place multimedia stimulus delivery - This implies to find technical solutions, which are able to transport the sensor data to the data gathering and processing solution. It is also related with to the ability to gather that information while delivering a stimulus in a useful way that enables storage, visualization, processing, and exportation to a remote entity, for further analysis.
- It must support patient / therapist workflow that will be used in Cognitive Behavior Therapy (CBT) - it must be possible to customize stimuli delivery to a subject/therapy following accepted psychology protocols. The stimuli must be also synchronized with the physiology and behavior measurements, in order to provide a safe ground / reference to any psychology related reasoning, either for simple scoring or patient follow up (i.e. evolution).

An Abstract /Conceptual Architecture

Combining all the approaches used, variables frequently measured, the constrains and issues mentioned, the following high level and abstract architecture is proposed.

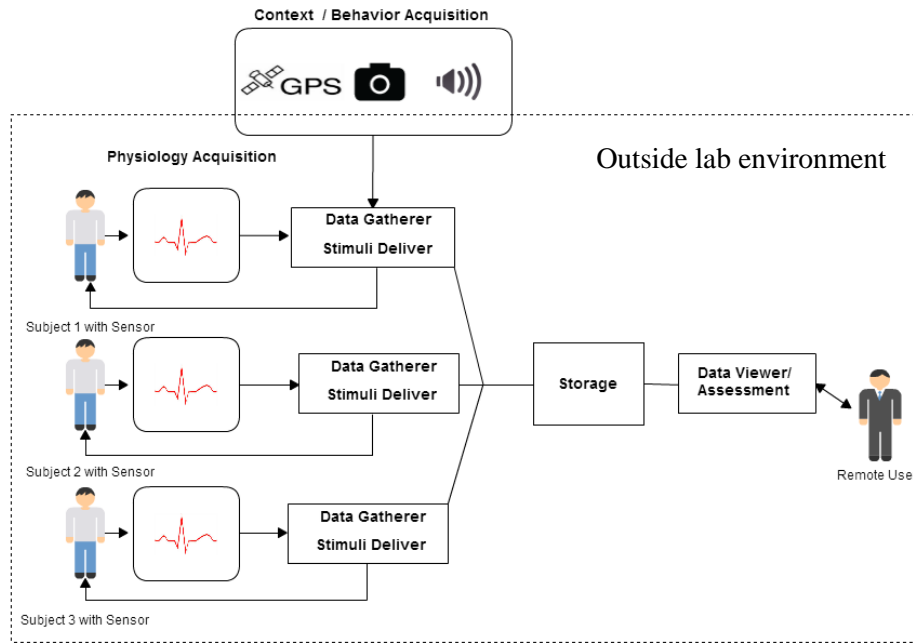


Figure 3- Conceptual architecture to a behavior and physiological monitoring system. On the left, a solution that allows physiological (ECG) and behavioral (photos, audio and context location) data acquisition from subjects while delivering a stimuli. On the right, remote session review/assessment by the therapist.

This conceptual architecture is composed by three main abstract components:

- **Data gatherer/Stimuli Deliver** – Acquire biological information from sensors (e.g. ECG), obtain behavioral data (e.g. voice and photos) and context information (e.g. GPS location), while delivering stimuli to subject.
- **Storage Service** – Store and maintain the information, namely supporting multiple subjects monitoring remotely.

Data viewer / Assessment – An application with UI (User Interface) capabilities for a remote user/carer.

The challenge here is to find a solution that while presenting a stimulus to the monitored subjects is able to ensure a synchronous acquisition of both physiological and behavioral data , in order to quantify and evaluate subject's response in an ambulatory environment, for instance at home. Another pointed challenge is to find a reliable solution that allows data exportation to a

remote platform, that can be accessed, for instance by a therapist for further evaluation. The proposed solution should enhance patient's treatment outcome and assists the therapist in the diagnose process and treatment follow-up.

4 BeMonitored Our Solution

In this chapter we present BeMonitored as our individual monitoring assessment and study of psychological disorders system to be used outside of lab environment and illustrate its use in the specific case of phobias. The final goal is to show that BeMonitored can help phobia sufferers to overcome their fear and at the same time, assessing the therapist diagnose and the evaluation of the treatment plan progress.

BeMonitored architecture is presented on Figure 4.

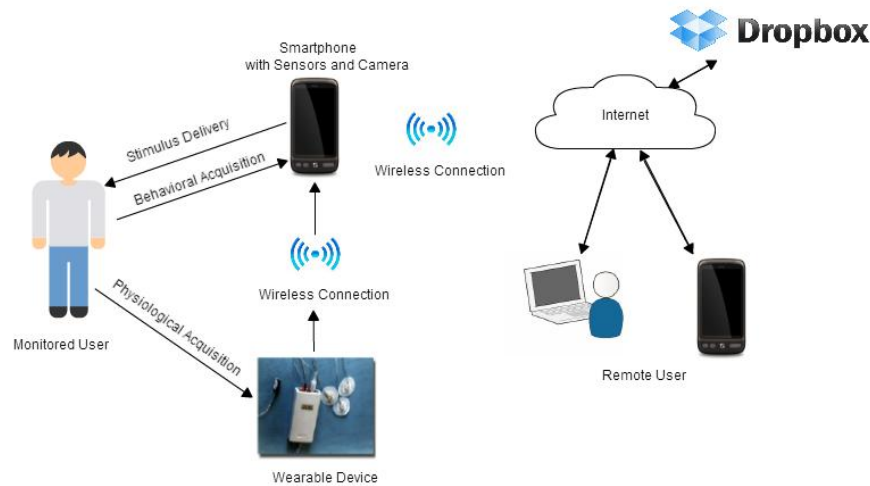


Figure 4-The BeMonitored System Architecture-The monitored user uses two devices: a Smartphone and a wearable device, wirelessly connected to perform individual monitoring. The Smartphone with sensors and camera are responsible for behavioral data acquisition from subjects, while delivering a stimulus. The wearable device is responsible for acquiring vital signs from individuals and transferring them to Smartphone. Acquired and processed data is exported to a remote storage and accessed by a remote user for later review.

The BeMonitored uses Smartphone capabilities to improve and facilitate both psychological and behavior assessment. As a consequence, it uses Smartphone's integrated sensors (GPS), a frontal camera and microphone to acquire location, photos of the subject's face and surrounding sounds respectively. Considering physiological acquisition, it relies on his wireless capabilities to acquire biomedical data from external wearable sensors. The challenge in BeMonitored was to be able to close monitoring an individual, while dealing with different factors like location, surrounding

context, presented stimuli, connectivity, mobility and detected abnormal events, which can be relevant for the individual monitoring and self-monitoring.

4.1 BeMonitored: A Smartphone Based Solution

The mobile phone, and more recently the Smartphone are interesting media devices for ambulatory psycho-physiological assessment since they are integrated in people's everyday lives [16]. Furthermore, current Smartphone capabilities and resources such as wireless connectivity (Wi-Fi, 3G, and Bluetooth), media capabilities (camera, media player, audio record) and GPS sensor and their availability and affordable price make it the natural device in order to fulfill this system's functional requirements. In addition, the growing use of communication technologies, namely the Internet and sensors modules, combined with data mining signal processing techniques and emerging support for cloud storage, give us the opportunity and the resources to create an ambulatory monitoring healthcare system.

BeMonitored explores the use of mobile to implement the conceptual architecture presented earlier to provide a solution for individual monitoring assessment and Study of Psychological Disorders system to be used outside of the lab environment (Figure 3). The end results has led to the BeMonitored architecture presented in Figure 5 .In this architecture, the Smartphone is the main logical block to accomplish both behavior and physiological data gathering while delivering a stimulus.

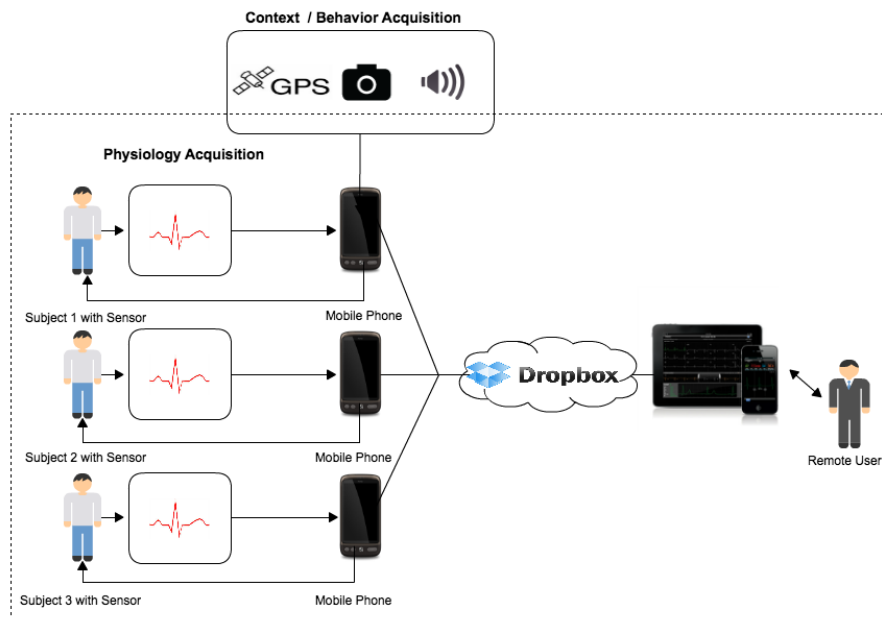


Figure 5- Smartphone based architecture.

A Smartphone based solution on the context presented, has several advantages:

- **Prevent/Diagnose health problems-** Frequent monitoring of people with certain diseases can avoid and early diagnoses severe health problems, and has a major value on the assessment of treatment plan progress (e.g. anxiety disorders).

- **Enhance patient-doctor communication:** Nowadays with the Internet, it is straightforward to send high quantities of information in a fast and cheap way (raw data, emails, chats, calls, SMS, photos, audio files, etc). As a result, information that was once only available through direct contact with the user can now be easily sent with a Smartphone, anytime, everywhere.

- **Reduced costs:** Both Smartphone and the Internet are becoming more and more accessible to the general population, in terms of costs and availability. Continuing advances in sensors and sensor-supporting technologies including pervasive computing and communications capabilities reduce the cost of introducing and using mobile phones to assist healthcare applications.

- **Portability:** Usually, monitoring systems are only accessible in hospitals. Even though those devices are accurate, they are costly and require regular visits to hospital. As a consequence, disturbances related to the hospital context such as nervousness or stress [2], can occur, which might affect the monitoring results, namely in psychological disorders. Therefore, a mobile monitoring system allows the patient to be monitored in a less disruptive and stressful context (e.g. at home). Such a system is an asset for the diagnosis, prevention, treatment plan and progress in many diseases, and in particularly in psychological ones (since context and environment has a major impact on patient psycho-physiological response).

Looking in detail at the system solution, it may be divided into four major components: the wearable sensor, the subject monitoring application, the server and the mobile remote user application depicted in Figure 5.

In following section the functional perspective of each component is described and what it represents for the global system proposed.

4.1.1 Smartphone as Data Gatherer and Deliver

In BeMonitored the Smartphone performs data gathering and stimulus presentation. The Smartphone's media capabilities ensure the video stimuli display on phone screen (Figure 6-(4)).

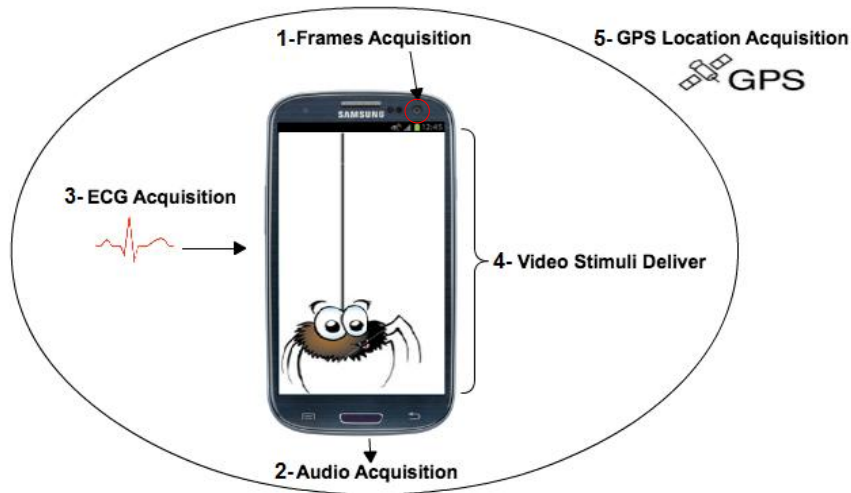


Figure 6- The Smartphone as a device used for behavioral (1,2) and physiological(3) data acquisition, stimuli deliver (4) and location context acquisition (5).

The front camera and audio recorder ensure the behavioral data acquisition, by acquiring several photos of subjects' face (Figure 6-(1)) and voice (Figure 6-(2)) respectively. The wireless connectivity (e.g. Bluetooth, Wi-Fi) enables to pair to an external biomedical sensor, acquires subject physiological data (Figure 6-(3)) and export information to a remote storage platform. Moreover, the integrated sensors, for instance GPS, allow to obtain information about location/context where the subject is being monitored (Figure 6-(5)).

4.1.2 The (Wearable) Sensor: RTABP Module

As it was previously mentioned, monitoring physiological data (e.g. heart activity) is very important in the early diagnosis and treatment follow-up of several diseases. As we mentioned on 2.4, with recent sensor technology improvements, there are many solutions that allow convenient, continuous and non-intrusive physiological monitoring [52-54]. Among several options available, we relied on an in-house built wearable device, called RTABP (Real Time Arterial Blood Pressure) module developed by the Ribeiro et al [17]. It acquires electrocardiogram (ECG) and photoplethysmography (PPG) at 500 Hz sampling frequency.

The RTABP has an acquisition box (Figure 7-1), which has itself several hardware components including a Bluetooth interface to transfer collected data via Bluetooth link to a remote paired device. The PPG is obtained by the pulse oximetry sensor, which is placed on the user right forefinger (Figure 7-2). Pulse oximetry is a non-invasive method that allows the monitoring of the oxygen saturation of a patient's hemoglobin (SpO₂), making use of the blood light absorption [39]. In order to acquire one ECG lead (lead II), the module uses three embedded electrodes, which are

placed in user the chest (Figure 7-3)). Besides this device obtains two biomedical indicators (ECG and PPG), the BeMonitored just relies on ECG, because in literature the most used biomedical indicator for physiological monitoring and assessment is the Heart Rate or its variation [2].

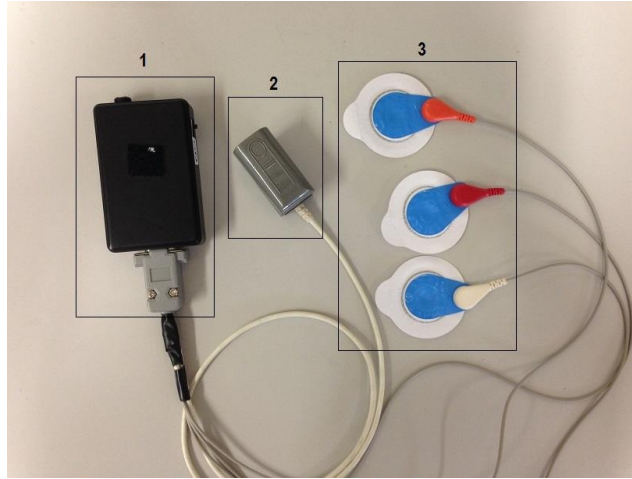


Figure 7- RTABP module components: 1- Acquisition box, 2- PPG sensor 3- Embedded electrodes.

4.1.3 Monitoring Subject Application

The monitoring subject application runs in their Smartphone and its aim is to monitor subject physiological and behavioral responses while delivering a stimulus, detecting abnormal related events, storing and exporting data to server component.

The application acquires both behavioral and physiological variables capturing several subjects' facial expressions, bio signals from wearable device (ECG) and records patient voice during a monitoring session. It also processes online the acquired data and extracts their relevant features, such as facial movement and heart rate values from ECG stream. All acquired information is stored locally and exported for remote session review. While monitoring, the application may also acts as a biofeedback system. The application might detect abnormal events and alert monitored user; this automatic intervention helps the user to clearly identify events that trigger physiological/behavioral responses. As an example, the application detects Tachycardia/Bradycardia episodes as abnormal events, and alert monitored subject to that events via a visual alarm (e.g. different color). Considering the user behavior, if severe face movements are detected, the system also gives an audio/visual feedback to the user, helping in the identification and possible self-correction of his/her physiological/behavioral response.

4.1.4 DropBox as a Cloud Storage/Communication Service

In order to achieve remote session review of all session's data, the system relies on the Dropbox cloud service for data exportation and storage through Dropbox API [29]. Therefore, the acquired and processed data from BeMonitored monitoring application is exported to a cloud storage service, which maintains all subjects session's data, and management files (i.e. several videos stimuli and video protocol files), making then accessible to remote user for later review.

4.1.5 Remote user application

The remote user application runs on therapist mobile device. It assists the therapist in the diagnosis process, treatment planning and outcome assessment. This application is able to manage session stimuli protocol and request new sessions. Furthermore, the remote user application is able to access the BeMonitored remote storage system (Dropbox), retrieve subject's sessions information, allowing the remote user visualizing and assessing data acquired. Since the function of therapist is to evaluate and conduct treatment plan, it may also allow the therapist to send a proper feedback to patients, manage patient's data and video stimuli protocol to be used in sessions.

5 BeMonitored in Detail: Processes and Implementations Options

This chapter, which presents the BeMonitored system in detail, is divided into 3 sections. The first section describes the programming environment used on the implementation of both BeMonitored applications. The second section provides an overview on the implementation of the system components, including applications architecture, features supported, processes involved and data workflow between monitored and remote user applications. The final section describes the system constraints and the implementation options.

5.1 Why Android?

From the start, it was established that the BeMonitored system applications would be supported in the Android OS (Operating System). Android is an open-source, Linux-based, software development platform, for mobile devices (e.g. Smartphone, tablets), developed by the Open Handset Alliance with the goal of allowing the easy development of new applications [78].

There are several features from Android OS that were considered important in the design and implementation of both BeMonitored system applications:

- **Support for multitasking and background services:** this allows maintaining several threads executing simultaneously. For instance it is possible to have dedicated services to manage connectivity and data acquisition processes while other deal with user interface interactions.
- **Supports data storage:** Android OS natively supports a SQLite engine [19] relational database, which can be used for data persistence and sharing within mobile device.
- **Abstracts hardware and network resources:** Android abstracts, through API's (Application Programming Interfaces), the access to hardware devices such as camera, GPS, embedded sensors (e.g. gyroscope, accelerometers), Audio, Wi-Fi, Bluetooth and Telephony. This access is of utmost importance for the implementation of BeMonitored Smartphone application since it needs capturing images, recording surrounding sounds and obtaining location. Using Core Location, Media Recorder framework [27], it is possible to easily access integrated sensors in the device and collect data (user location and recorded voice). Since Android framework supports full access to device cameras through the Camera API, it is possible to capture images, select their resolutions, etc. Android also supports access to Connectivity Manager, allowing the Smartphone to establish connections between other devices and exchange data wirelessly.

- **Has data sharing mechanisms:** The high level concepts of intents and Content Providers [19][20] allow abstracting interaction between Android OS running components using uniform APIs.

5.2 BeMonitored System

The BeMonitored system can be roughly divided into two main applications: subject monitoring application and remote user application.

The main use case of patient's monitoring application is to monitor their psycho-physiological responses. This process includes the communication between wearable sensor and user's Smartphone. The Smartphone should be able to seamlessly obtain the measurements from sensor module device, frames from camera, voice from audio recorder and location, requiring minimum interaction with the end-user while presenting a stimulus. This communication is integrated into the BeMonitored monitoring application (Figure 8), whose goal is to retrieve, process, stores and exports the collected data from patient session, to the remote user application.

The remote user application objective is performing remote session review, by accessing the patient's session data acquired, stimuli configuration and subject's management (Figure 8). The use case diagram Figure 8 explicit tasks that can be performed by both applications.

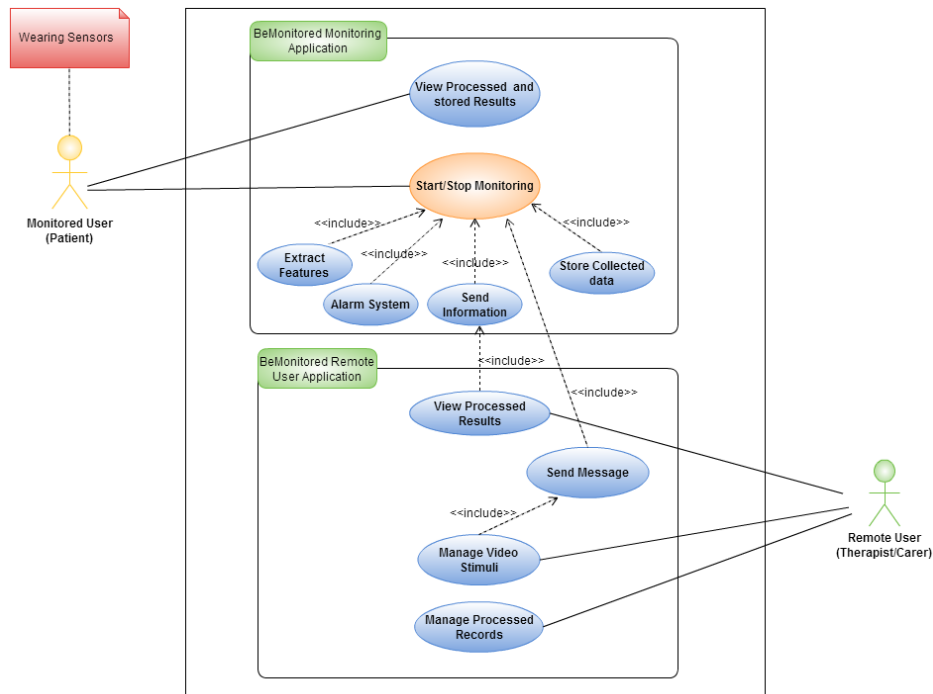


Figure 8- Use case diagram of BeMonitored system- Use cases for both monitored user and remote user application.

5.2.1 BeMonitored Data Management

The BeMonitored system supports patient/carer workflow, allowing customizable stimuli design, patient ambulatory monitoring and remote session review.

Although data export is possible using the Android file system and application database, the application also exports through DropBox via an application-shared folder, using Dropbox Core API [29]. This solution abstracts both the application and user from the data transfer process. By defining a common folder for BeMonitored and for the offline storage/analysis stations, all the data transfer and synchronization is taken care by DropBox.

The folder hierarchy used in order to ensure logical organization on Dropbox file system and the communication protocol between applications is described in Figure 9.

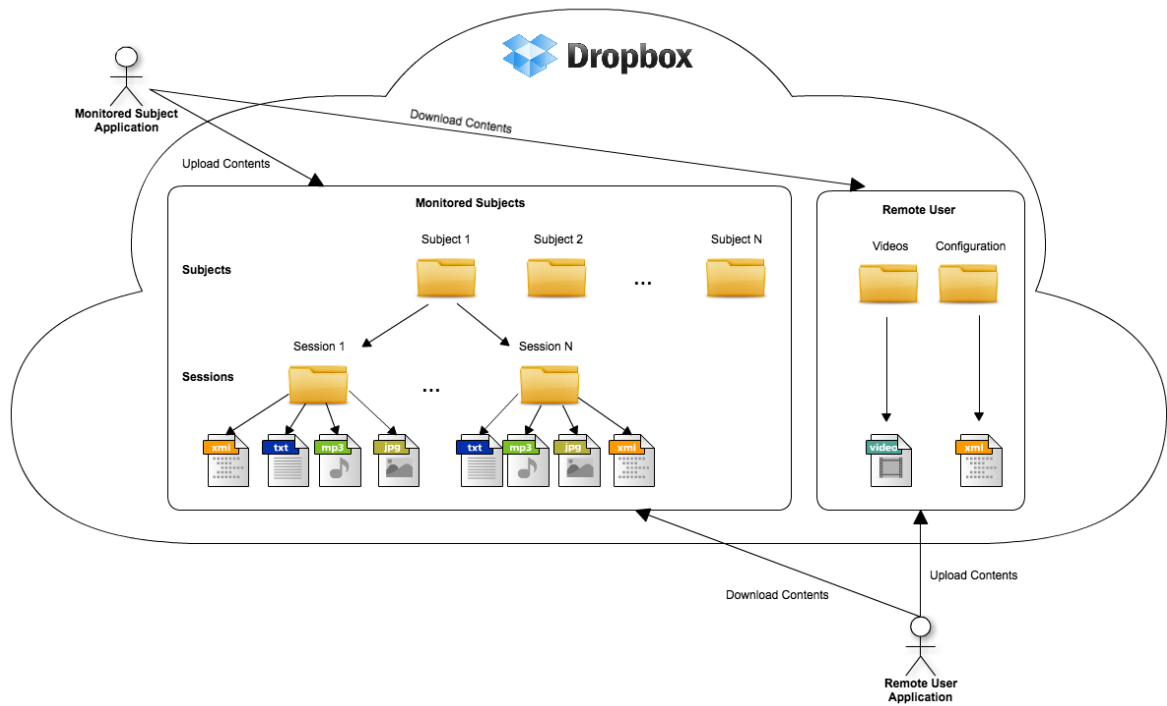


Figure 9 – Dropbox Server: File system Hierarchy.

On top level of Dropbox file system is a list of all shared folders from all BeMonitored subject's applications, a folder with all shared video-clips and a folder containing the configuration files of several videos stimuli. Within each subject folder is a list of folders containing all session's data acquired (i.e. photos, audio, calculated heart rate, eyes mid points coordinates and the video configuration file used).

Each BeMonitored monitoring application has a shared folder in DropBox with remote user, which is identified by the subject name, previously defined within application settings.

5.2.2 BeMonitored Workflow

The data flow sequence, involved on the supported functionalities, previously mentioned is presented on Figure 11.

The remote user is responsible for the configuration of the video stimuli protocol, that is presented to individuals (the monitored users), i.e tag relevant events, protocol transaction and video stimuli duration and sequence (Figure 11, step 1). Once this process is complete a XML file containing session protocol is created and exported to the Server through DropBox Core API [29] (Figure 11, step 2 and 3). Additionally, a SMS message is sent to the BeMonitored monitored application requesting a new test, through Android SMS Manager [80] (Figure 11, step 4).

The broadcast receiver [81] running on BeMonitored patient's application, which is listening to the incoming therapist's SMSs, triggers a Notification [82] (Figure 10-a)) when the new message is received.

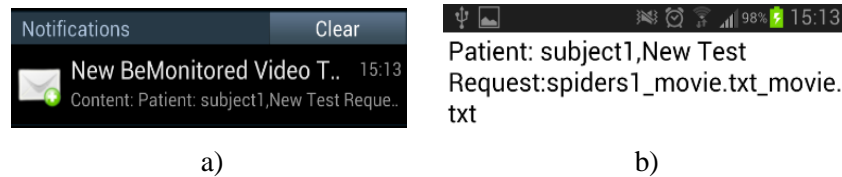


Figure 10- BeMonitored message protocol: a) The monitored user application broadcast receiver listen for therapist messages, generates a new test notification; b) SMS message content retrieved: patient name and video configuration file name to be used, sent by remote user application.

This notification contains the message content sent by therapist: patient name and the video test name (Figure 10-b)). The application retrieves this information, authenticates on Dropbox through Dropbox API [29], and downloads the new configuration file from the server (Figure 11, step 2 and step 5). The patient may perform the test using that session protocol (Figure 11, step 6).

When monitoring process ends, the BeMonitored monitoring application verifies Internet connection availability using Connectivity Manager [83]. If it is available, the application requests the user to authenticate in the server (Figure 11, step 2). The user will be sent to a screen, to allow or deny access to the shared Dropbox folder (Figure 12-a)).

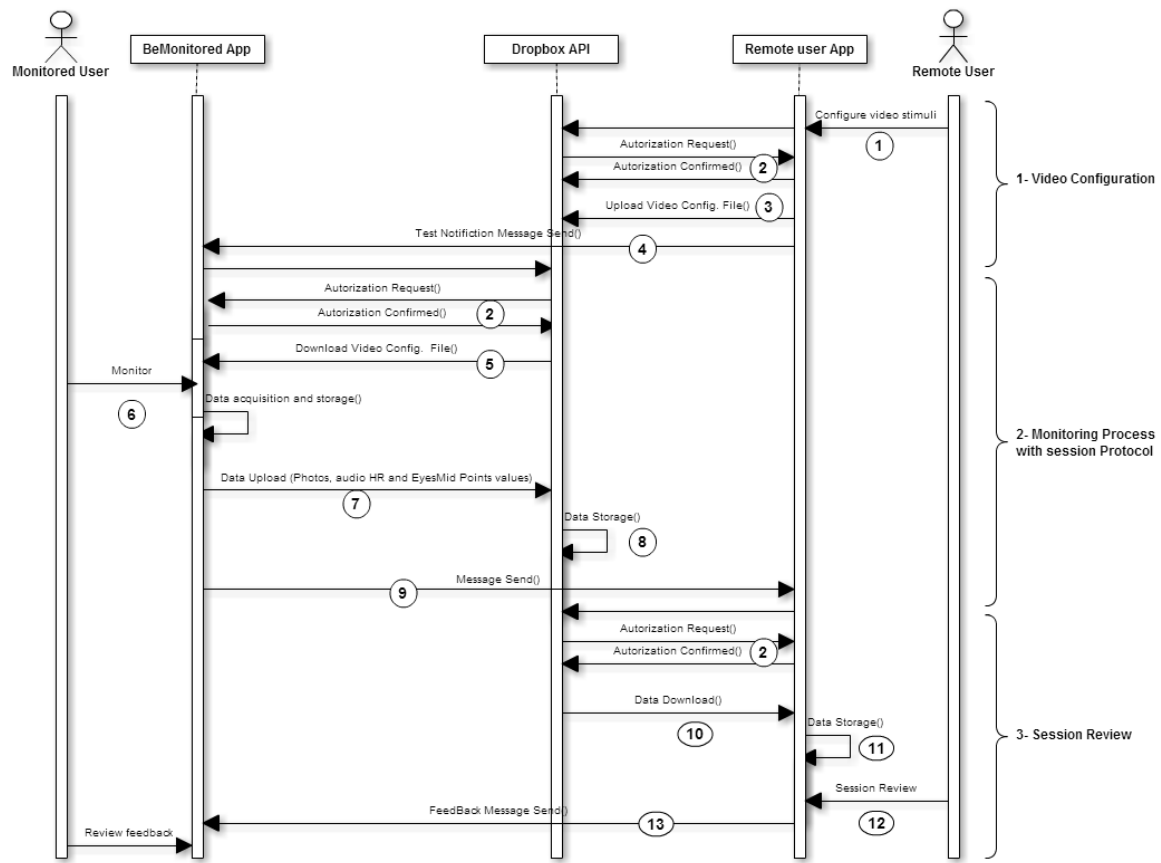


Figure 11 – Data flow sequence diagram.

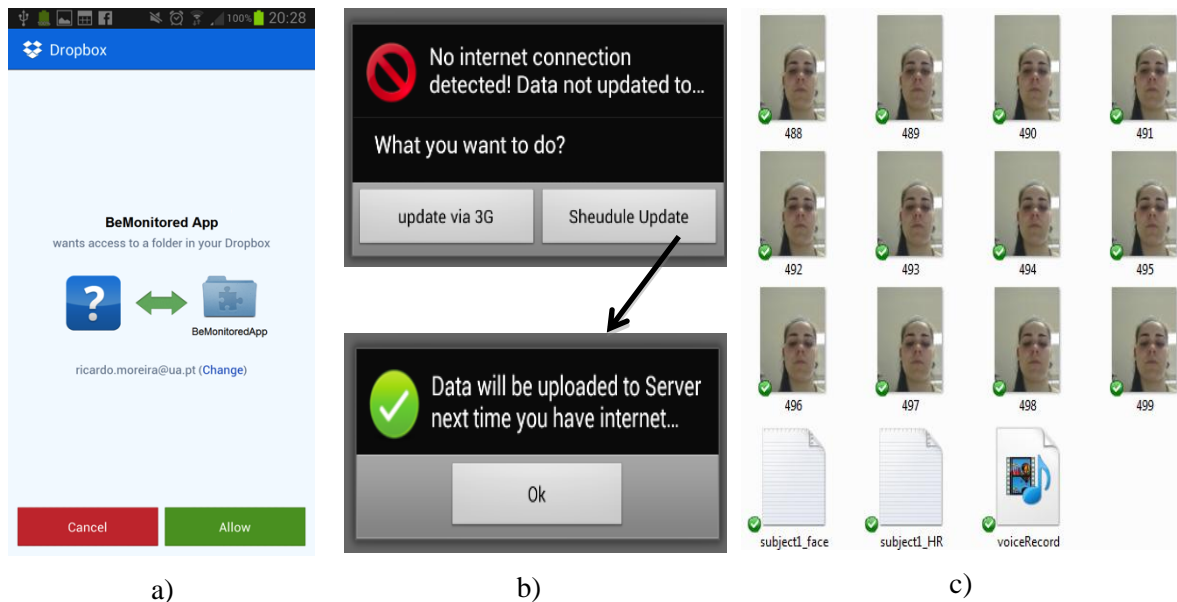


Figure 12- a) Dropbox Core API- server authentication; b) Check connection availability and manage data upload options if connection is unavailable; c) Dropbox file system: data stored within subject's session folder.

Upon authentication, user is returned to the previous activity and a background service starts sending all data acquired and processed to Dropbox (Figure 11, step 7). When updating data to server, the subject's name is used by the BeMonitored monitoring application, in order to select the correct path within Dropbox file system. Consequently, a folder is created inside Dropbox file system on the user folder with the previously defined session name and data (Figure 12- c) and Figure 11, step 8). If Internet connection is not available, the user will prompt with two options (Figure 12 - b)): user can turn on 3G-connection, i.e. update sessions' data or schedule update from next time application has an available Internet connection. If the last option is chosen, a global system flag will be activated, which indicates that specific test data were not uploaded to server. This flag is stored using android-shared preferences [21].

The BeMonitored application has a broadcast receiver [81] that is always listening from Internet connection availability. The next time the broadcast detects a connection available and if the global system variable is active, data is automatically uploaded to server in background. When system detect that all data was successfully sent to the server, the folder previously created on Smartphone's file system is deleted, in order to save space. Simultaneously, a message is sent by user's monitoring application to the remote user informing that there are new contents available on server (Figure 11, step 9).

The remote user application runs a broadcast receiver listening to incoming messages from patient's applications. When data from a session is available on server the application receives that message notification (Figure 13-a)), retrieves relevant information (Figure 13-b)), authenticates on dropbox server through Dropbox API [29], and stars downloading session data from server (Figure 11, step 2 and Figure 11, step 10). Once download is complete, data is stored on application database (Figure 11, step 11) and therapist may visualize session results (Figure 11, step 12), sends a feedback to patient or even requests new test (Figure 11, step 13).

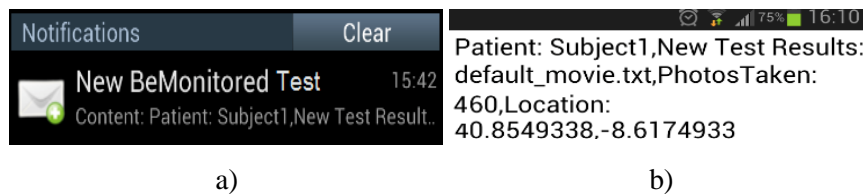


Figure 13- BeMonitored message protocol: a) The remote user application broadcast receiver listens to messages from monitored subjects and generates a notification; b) SMS message content retrieved: patient name and video configuration file name used, photos taken and location where the test was performed.

5.2.3 The BeMonitored Monitoring Application Architecture

The internal architecture of BeMonitored monitoring application (in Figure 14) reflects the multiple functions that the application must support: both **physiological** and **behavioral** data **acquisition**, data **process** (i.e. **event detection**), data **storage** and **export**

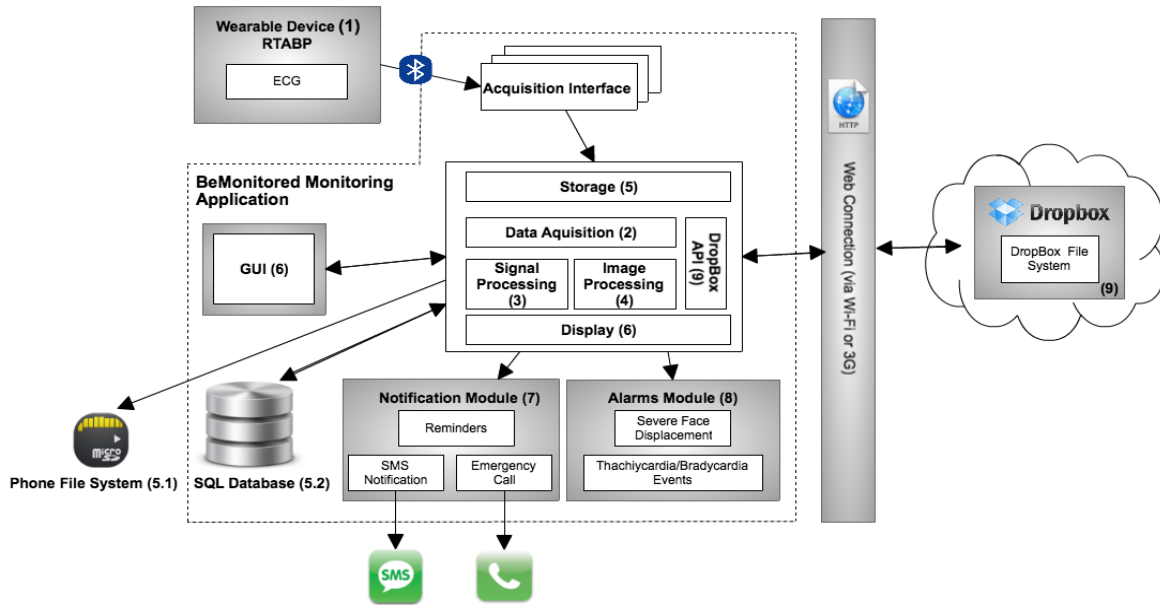


Figure 14- BeMonitored Monitoring Application Architecture: 1- Wearable device: responsible for acquiring ECG from individuals. 2- Data acquisition module: responsible for acquiring ECG data stream from wearable device, surrounding sounds, frames from camera and location. 3- Signal Processing: responsible for extracting features from ECG wave- HR estimation. 4- Image Processing: responsible for extracting features from frames captured- eyes position. 5- Storage: this module is responsible for storing data acquired and processed in both device file system and application internal database. 6- GUI: general user interface responsible for displaying several application screens. 7- Notification module: responsible for sending notification (SMS) to remote user application. 8- Alarms module responsible for detecting abnormal events and alert user. 9- Dropbox API- responsible for authenticating on Dropbox shared folder, updating and downloading contents to/from it.

The BeMonitored monitoring application must communicate with several external like the wearable device or internal resources of the Smartphone (e.g. camera, GPS, microphone). The **wearable device** is responsible for the acquisition of physiological information collected from the human subjects (1). The wearable device transmits acquired data (e.g. ECG) to the BeMonitored monitoring application through a Bluetooth connection. The application also receives frames from camera and audio from microphone recorder in the **Data acquisition module** (2). This module updates the data display and stores the raw data. The **Signal Processing module** (3) processes the

incoming signals (i.e. extract heart rate from ECG stream), and performs relevant events detection, namely detecting tachycardia/bradycardia episodes, in **Alarms module** (8). The **Image Processing module** (4) processes the video/images information collected by the Smartphone cameras and extracts relevant features (e.g. eyes position from bitmaps).

The visible **User interface** (6) is provided by the BeMonitored monitoring application. It coordinates the several modules during acquisitions, namely to ensure that all acquired measures are synchronized to the second and stored in (5) with timestamp in the file system (5.1) in *.txt* format, in order to simplify data exporting and human readability but also inside application internal storage using a **SQL Database** (5.2). During acquisitions, BeMonitored allows online monitoring (i.e. instantaneous heart rate calculation and face tracking.) of the main information in the Smartphone display (6), while presenting a audiovisual stimuli from a pre-established protocol. When not in session, it provides basic interfaces for session management, review and data exporting, through Dropbox API (9).

Monitoring Session Stages

During a BeMonitored monitoring session there are six main stages involved: **calibration, session protocol, data acquisition, processing, storage and event detection** (Figure 15-a)).

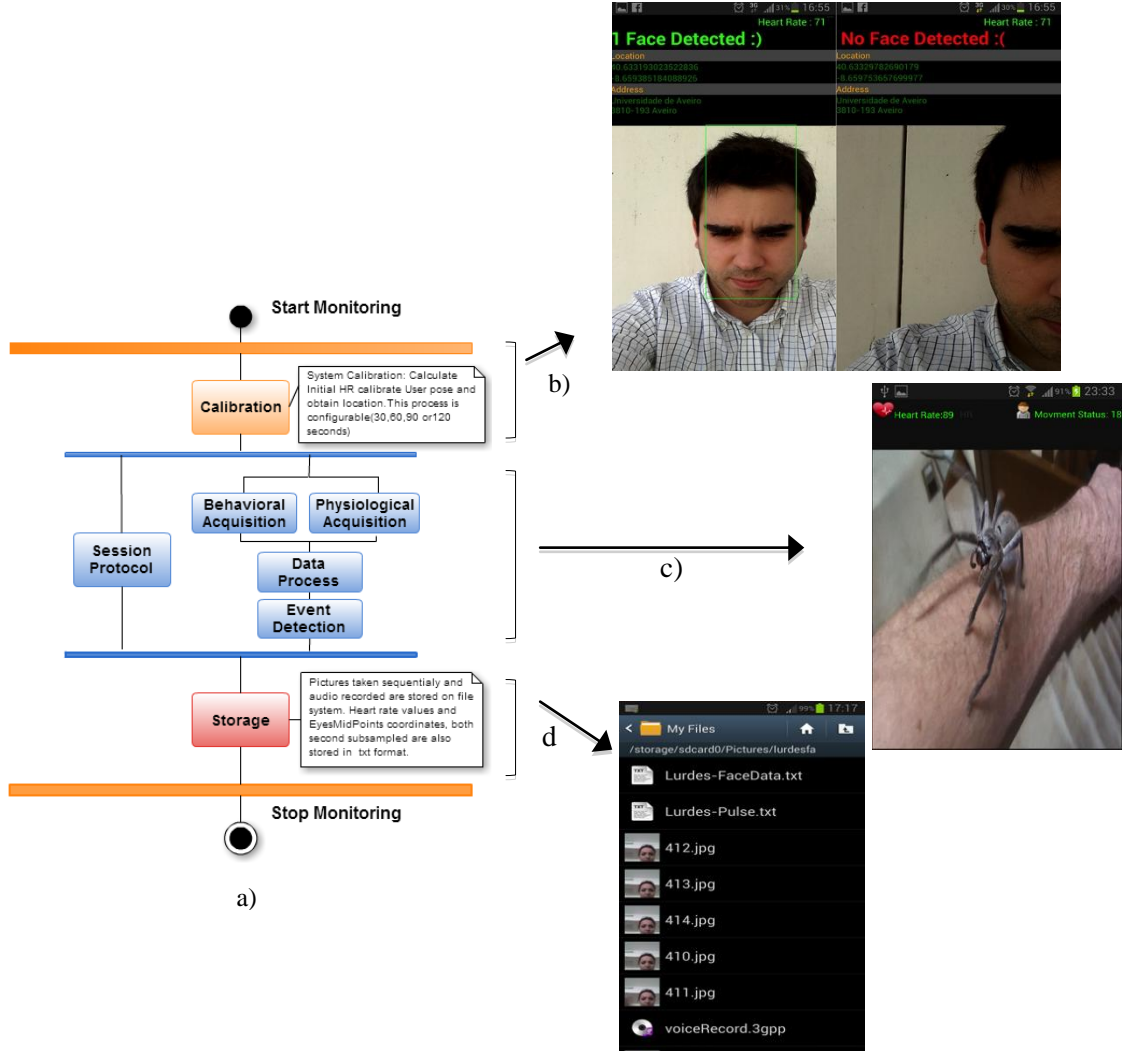


Figure 15- a) Activity Diagram that includes several stages involved in online monitoring; b) System calibration: HR baseline extraction and user head pose calibration and location acquisition; c) Video stimuli screen; d) Folder containing all acquired and processed information relative to a session: photos taken, voice recorded, HR and Eyes midpoints values.

The calibration process is performed in the start of every acquisition. At this stage, an online face tracking process starts, using phone's front camera (Figure 15-b)). The user see himself/herself on the screen, and with help of a feedback rectangle, he/she adjusts his/her head position. This procedure ensures that the system is able to capture the volunteer's face. During the calibration, the system starts the physiological (currently ECG) data collection. In this stage it is also obtained the user's location. Overall this protocol stage duration can be configured in the system settings. The

goal of this stage is to establish the baseline for the initial HR, calibrate the subject's head/eye position, and obtain the location where the test is performed.

After the calibration stage the video is displayed in parallel with the behavior and physiological data acquisition and processing processes (Figure 15-c)). During this stage the acquired data is used to extract the online signal features from ECG stream and video related parameters. Based on features extracted, the application detects online abnormal events (e.g. high/low HR values, faces not detected and severe facial movements). The test and the acquisition process end when the video also ends. Regarding session protocol, each monitoring session is defined by a specific video (the stimulus) and a set of video dependent time stamps to tag relevant events or protocol transitions. This description is contained on the video configuration file uploaded by the remote user application and customized according to the session protocol. The BeMonitored monitoring application downloads this XML file from Dropbox and parses it in order to display correct video sequence from the application shared video pool.

Application internal storage

All data acquired and processed are stored in a folder in phone's file system. The folder contains a *.txt* file with the calculated HR values, the coordinates of the eyes midpoints, and an audio file with the voice recorded during the session (Figure 15-d)). While the monitoring process is complete, all acquired (i.e. pictures taken and audio file recorded) and processed data (i.e. HR values and eyes mid points) are uploaded to Dropbox.

The acquired data is also stored locally inside an internal SQLite database. The database is primarily be used to:

- Store session records: photos, dates, strings, audio files, etc.
- Retrieve and review a session record.
- Delete a single session record.

Regarding these requirements, the database schema (Figure 16) was defined:

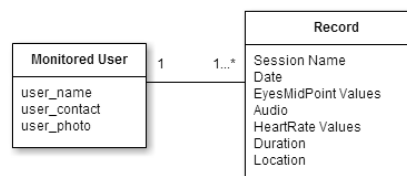


Figure 16- BeMonitored monitoring application database schema

The database consists of a monitored user record, which can have one or many session records.

The Monitored User table contains the following columns:

- user_name: The monitored user name.
- user_contact: Monitored user phone's number.
- user_photo: Monitor user photo.

The record table contains the following columns:

- Session Name: The session name chosen.
- Date: The session date.
- EyesMidPoint Values: The calculated eyes mid points coordinates extracted from each captured frame.
- Heart Rate Values: The heart rate values processed from ECG data stream.
- Audio: The audio file recorded during a session.
- Duration: The session duration in seconds.
- Location: The GPS location where the test was performed.

Since most of users not always have an available Internet connection, the system is capable of working both online and offline, by monitoring Internet connectivity to determine the right moment to upload session related information. For this reason, the application includes both local (SQL database and file system) and remote storage (Dropbox). Once data is stored locally (in application database), the monitored user can offline review his session's records.

Physiological Acquisition and Processing

In the BeMonitored monitored application, the physiological data acquisition, is made through the Acquisition Interface (Figure 14). The **Acquisition Interface** is a Bluetooth socket connection wrapper, initialized by the monitoring application, in order to receive raw data from the remote paired device. This relies on Android Bluetooth API [22] to perform the communication over Bluetooth link between the two devices.

In System settings, user can pair his phone to a specific module (Figure 17-b)). The application searches for available devices in the local area and user picks the one he wants to be paired.

As shown in Figure 17-c), when user starts monitoring, a dialog box will appear requesting user permission to enable Bluetooth. If user accepts request, a background service (*BioSignal*) creates a communication channel via Bluetooth socket to the device previously paired. This service is responsible for receive incoming data stream from wearable device, processes and stores it on a *.txt* file containing HR values second sampled to the second. The flow diagram of this process is shown in Figure 19-a).

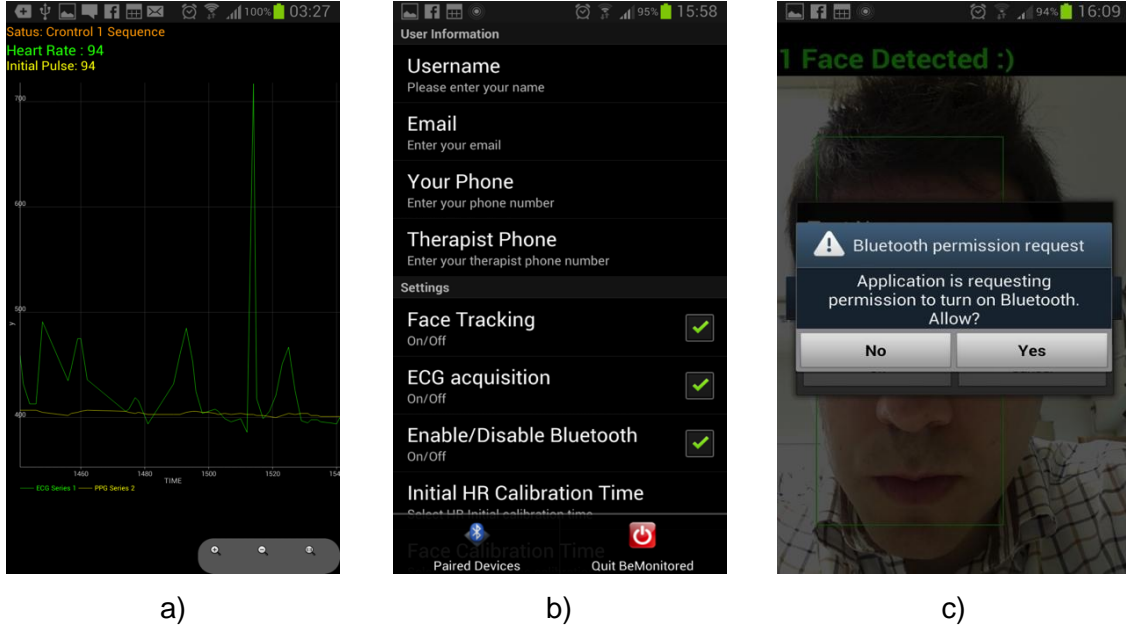


Figure 17- a) Physiological data acquisition (ECG and PPG data stream), instantaneous HR values and initial pulse.
b) Application settings; c) Request permission to enable Bluetooth and start physiological data acquisition.

The **Signal Processing module** (Figure 14- 3) and Figure 19-a)) is a driver, responsible for parsing the incoming stream from RTABP [17] sensor to acquire ECG and PPG and extract instantaneous Heart Rate values (Figure 17-a)). This procedure runs on a separate thread inside *BioSignal* background service. Within this thread, is performed a sequence of processes in order to extract features from ECG stream. The pipeline of this process is demonstrated in Figure 19-b). The *parser* is responsible for mounting PPG value into a single value and extracts ECG from incoming data stream. The extracted ECG Stream is processed in QRS Detector (Figure 18) in order to estimate instantaneous heart rate, using the implementation of the well-known QRS detection algorithm by Hamilton-Pan Tompkins [15] that was used in Droid Jacket [13].

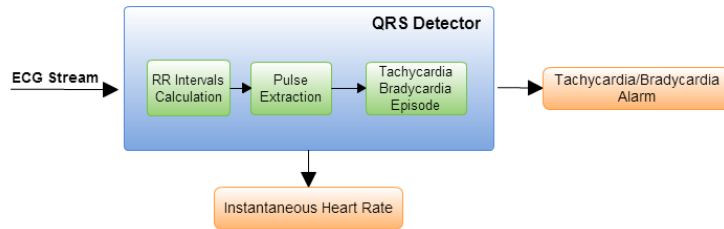


Figure 18- QRS Detector: Processes involved in the extraction of the instantaneous heart rate from the incoming ECG stream and Tachycardia/Bradycardia episode detection.

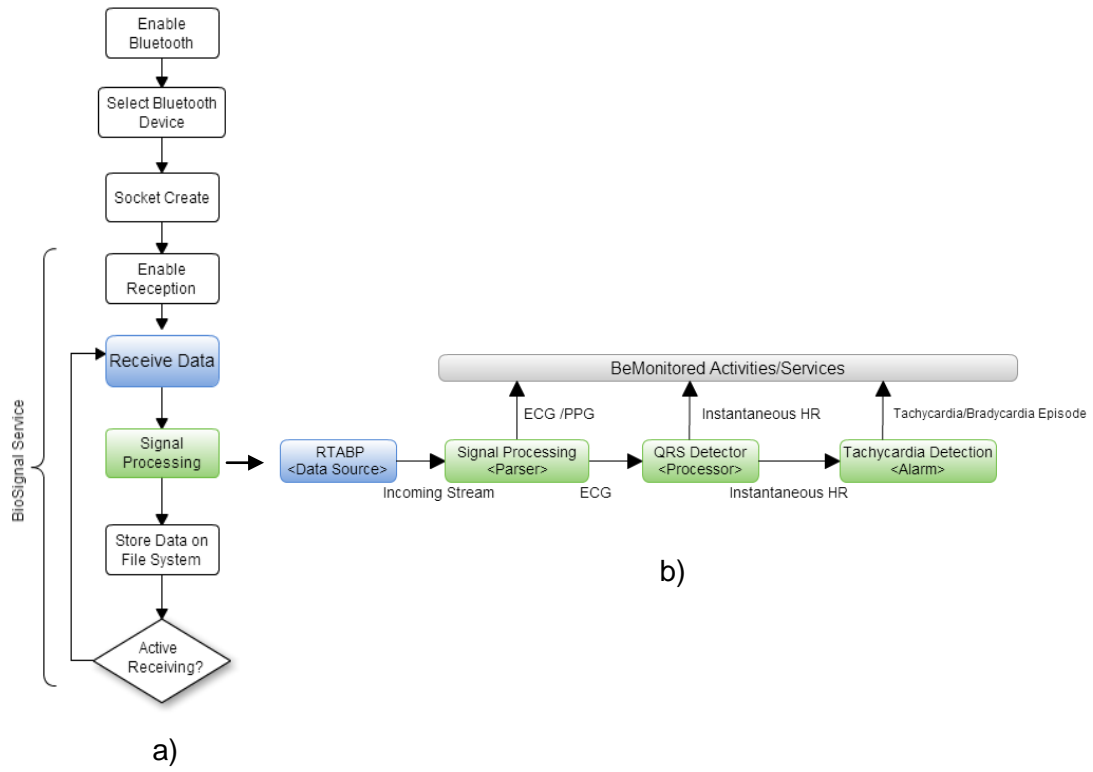


Figure 19- a) Physiological data acquisition flow diagram; b) Pipeline for instantaneous heart rate estimation and Tachycardia/Bradycardia event detection, supported in BeMonitored monitoring application.

The QRS component in ECG signal has been widely used to characterize patterns and extract features in ECG [40]. This complex can be used, though its specific characteristics, in automated determination of heart rate [40]. This implies knowing the distance between two consecutive QRS complexes, so with ECG sample rate (500 Hz), the duration of the RR interval is calculated using Equation 1 and the instantaneous heart rate is obtained using Equation 2. At each eight values of RR intervals an average is taken. The value obtained (*QRSdistance*), is used to perform the calculation of *RRDuration* (Equation1) and the corresponding *InstantaneousHeartRate* (Equation 2). The eight-position buffer is updated with new RR intervals values and the process repeats over time.

$$RRDuration = QRSdistance \div SampleRate \quad (\text{Equation 1})$$

$$InstantaneousHeartRate = 60 \div RRDuration \quad (\text{Equation 2})$$

Based on the online HR calculation an alarm was settled for Tachycardia and Bradycardia events. The alarm was established as a threshold to HR values above 100 bpm (beats per minute) or below 60 bpm [23]. In the monitored user level, the detection of an event triggers intent at Android OS level that generates an audio-visual alarm, translated in the device vibration with a distinct pattern and audio alarm (Figure 17-a) and c)). In the remote user level, if there are any abnormalities in the heart rate values, e.g. the HR decreases to values below 60 or increases to values above 100, the monitoring application automatically sends a SMS notification to remote user, notifying that something happened out of the ordinary with respective user GPS location at the moment.

The QRS detector detects the R peak in each heartbeat. However, the heart rate needs at least 8 heart beats to estimate instantaneous heart rate to minimize possible outliers impact. During this period, the algorithm does not calculate the heart rate values, returning -1 by default. The calibration of the system is used to synchronize all physiological and behavioral variables. During this stage, the system estimates the baseline from the initial heart rate values. After calibration, the new heart rate values are estimated in parallel and synchronized with the acquisition of the remaining variables.

Behavioral Acquisition and Processing

Regarding behavior monitoring, the system relied on video and audio capabilities of the Smartphone. In parallel with stimuli display and physiological data acquisition, images are captured using the phone front camera and audio is recorded using Smartphone microphone.

To accomplish the online video processing, we opted for acquiring sequences of individual frames instead of video stream. Although, the sampling frequency is lower (3 frames per second), it allows online processing and obtains a full face motion tracking, based on the extraction of the eyes position at each frame. Furthermore, this minimizes the processing cost, while allowing a number of frames per second that does not compromise the accuracy of the remaining monitoring processes. Besides that, having the frames sequence, it allows video monitoring by reassembling the video sequence of several subjects' facial expressions acquired during the test. This is possible by attributing a value to each frame, named the frame number, which starts at 1 and is incremented by 1 every time a new frame is captured.

When video stimuli are presented, *CameraService* starts his processes in data acquisition module (Figure 14-2). *CameraService* involves a sequence of processes: 1- frames acquisition, 2- image processing 3- features extraction 4- storage (Figure 20-a)). The first action performed is to accesses Smartphone's front facing camera and sets camera parameters (e.g. resolution). This is

possible, because Android Camera API [24] supports access to Smartphone camera features through *Camera.Parameters* object.

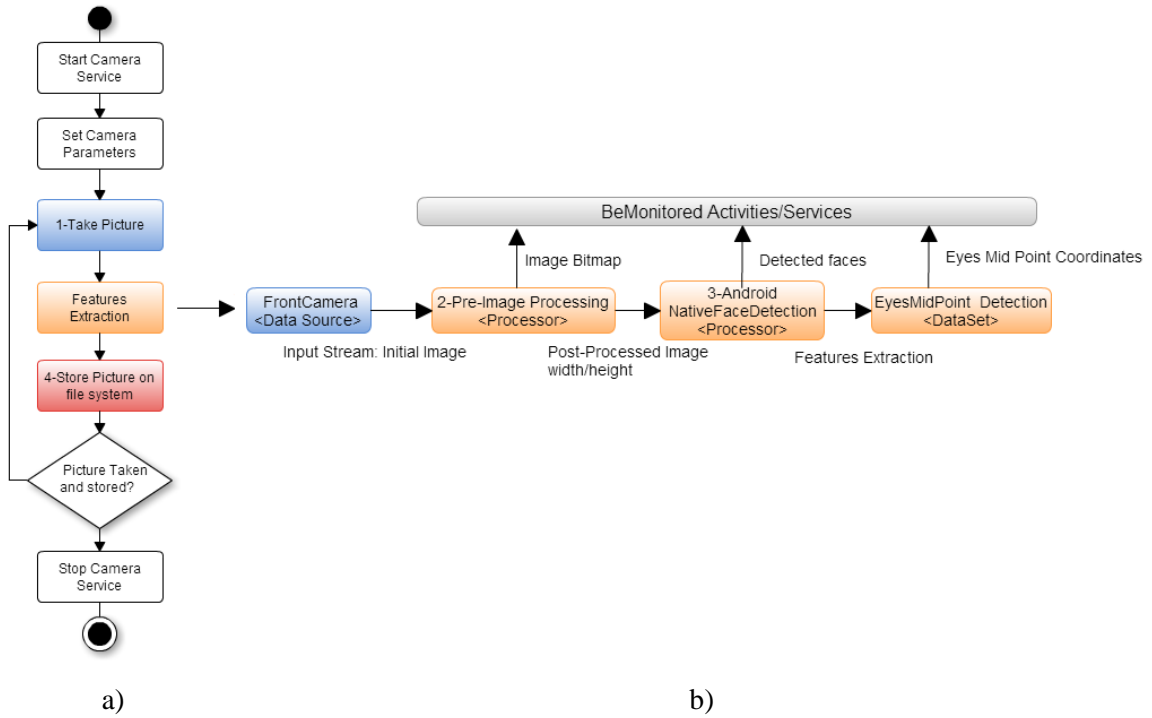


Figure 20 - a) Flow diagram of *Camera Service*: frames acquisition, processing and storage ; b) Pipeline for feature extraction from frames captured i.e eyes mid point calculation.

Reducing the images to a smaller size allows the Android Native Face Detection (ANFD)[25] to reduce the face detection time [26], since the ANFD is already optimized. By default, the image resolution for the device front camera is 1280*960. For that reason, the system relies on *Camera.Parameters* object in order to obtain all resolutions supported by the device front facing camera, and chooses the smallest (in our case 320*240). This option, guarantees that the feature extraction process is less demanding in terms of needed resources (memory and processing power).

After setting camera parameters, *Camera.takePicture* method is called which triggers an asynchronous image capture. When the raw data from picture taken is available, *onPictureTaken* method, the feature extraction process starts running on a separate thread (Figure 20- b)). Feature Extraction is a pipeline of processes in order to obtain Eyes Mid Points coordinates from bitmaps captured. In the first step of this pipeline is performed a Pre-Image Processing. Images taken by Smartphone front camera are flipped. Therefore, at this stage a rotation of 270 degrees in pixels matrix of raw bitmaps is performed, otherwise ANFD algorithm will not detect faces. Although the camera resolution was configured to the device smallest resolution supported (320*240), it is still

quite high. In this scenario, image quality is not very important since the objective is to extract simple relevant features (in this case eyes position) from frames captured and not the image quality itself. Therefore, this system performs a sub-sampling in the size of each bitmap by a power of two size (currently to 2^1), which returns an image that is 1/2 the width/height of the original, and 1/4 the number of pixels. This image processing optimizes the memory footprint and overall processing time (Figure 21(Final Image)).

With the assurance that the image bitmap captured is in the correct position, with a suitable size, the Android OS native face detection algorithm is run over the post-processed bitmaps. Faces are detected and the corresponding eye position and its midpoint are extracted from the array of pixels. The middle point between the two eyes is used to estimate eyes position, which is used as our face tracking solution, which will be explained later on this dissertation.

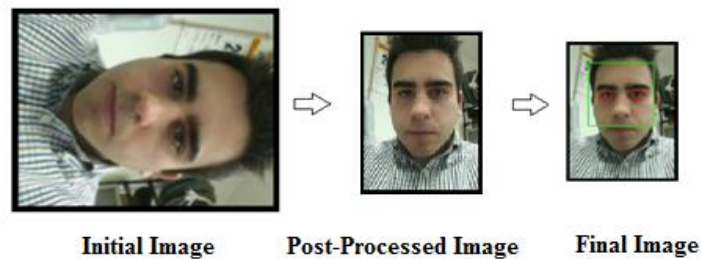


Figure 21 – Image processing steps: 1- Initial image: Image capture by smartphone camera; 2-Post- Processed Image: Initial Image rotation of 270 degrees and image sub-sample by 2 factor. 3- Final Image: ANFD runs over the post-processed image bitmap in order to detect face and eyes position and extracts eyes midpoint coordinates.

Once face features are extracted, the frame capture is stored on the device file system in the respective session folder. Each image frame acquired is converted to the JPEG format, with 50% compression. JPEG is an image file format that has associated small/medium sizes, when compared for instance with the TIFF [46].

Within the frame acquisition process, audio is recorded (voice/environment sounds) using MediaRecorder [27]. An audio file in .3GPP format is created on the device file system, in the same folder where pictures taken were stored and also within application internal database.

When video stimuli end or user forces to stop video, both services stop. The *BioSignal* service so stops the connection to the RTABP Module and Bluetooth is disabled. The *CameraService* stops frames acquisition process and audio recording terminates too.

User Location Tracker

The BeMonitored monitoring application includes a Location Tracking system. Most Android devices allow to determining the current geolocation. This can be done via a GPS (Global Positioning System) module, via cell tower triangulation or via Wi-Fi networks. Android contains the *android.location* package, which provides the API to determine user phone current geo position [28].

The BeMonitored monitoring application can use two different location providers:

- **Network:** This approach uses mobile network or Wi-Fi to determine the best location, which might have a higher precision in closed rooms than GPS.
- **GPSs:** uses the GPS receiver in the Android device to determine the best location via satellites, usually with better precision than network.

By default, BeMonitored monitoring application uses network provider to obtain subjects location. Besides that the user can also choose, in application settings, which location providers he wants to use (GPS or network).

For obtaining the user's location address the system relies on reverse geocoding [47]. The reverse geocoding, is the process of transforming a (latitude, longitude) coordinate into a partial address.

5.2.4 The Remote User Application

In this section, the available features on remote user application are explained.

In Figure 8, the following use cases were presented for remote user application:

- Manage Video Stimuli
- Manage Patients /Processed Records
- Review Subjects Sessions

Manage Video Stimuli

The remote user (therapist/carer) can configure the video stimuli to be presented to the monitored user. Both patient application and remote user applications, share a pool of video-clips containing several stimuli types (e.g. snakes, spiders,etc) (Figure 23-a)). The therapist has the responsibility to keep both pools updated. For instance if the therapist introduces a new video, he will have to upload this new media content to server and the user will download it. Regarding the video stimuli configuration process, the therapist can peek some videos from the shared pool and creates a new video sequence with a certain type of stimuli (e.g. containing spiders, neutral, snakes, rats, etc Figure 23-a),b)). Therapist can also manage the order of previous peeked videos

(Figure 23 -b)). Once the configuration process ends, a configuration file is created and is stored on application database. The therapist, can also choose a video configuration from the list (Figure 23-c)) and request a test to a certain patient (Figure 25-a)). Consequently, a *.txt* file containing all relevant video information on XML format is created (Figure 22), automatically uploaded to Server and a SMS notification is sent to the patient. It was decided to send a *.txt* file with video stimuli configuration instead of sending all video clips plus a configuration file with video sequence, since both video pools are updated with same content it is only needed to send the configuration file with the session protocol.

```
<?xml version='1.0' encoding='UTF-8' standalone='yes' ?>
<movie>
  <Author>Ricardo</Author>
  <MovieName>spiders2</MovieName>
  <Date>May 18, 2013 6:20:21 PM</Date>
  <Duration>192</Duration>
  <Sequence>[/storage/sdcard0/BeMonitoredVideos/Calibration/Calibra10.wmv,
    /storage/sdcard0/BeMonitoredVideos/Spiders/spider1.mp4,
    /storage/sdcard0/BeMonitoredVideos/Spiders/spider3.mp4,
    /storage/sdcard0/BeMonitoredVideos/Spiders/spider2.wmv]</Sequence>
  <Comment>This video contains several spiders </Comment></movie>
```

Figure 22- Configuration file of video created by remote user application in XML format. This file contains a set of parameters that are used on monitored user (patient) application to create the same video sequence proposed by therapist. The tag <Author> - contains the therapist name; <MovieName>- the name of the video; <Date> - the dateTime of the video creation; <Duration> - total video duration in seconds; <Sequence> - the path to the videos pool and the correspondent sequence (e.g. on this example , first video to be played is “Calibra 10” and the last is “spider2”); <Comment> - therapist comment/test instructions.

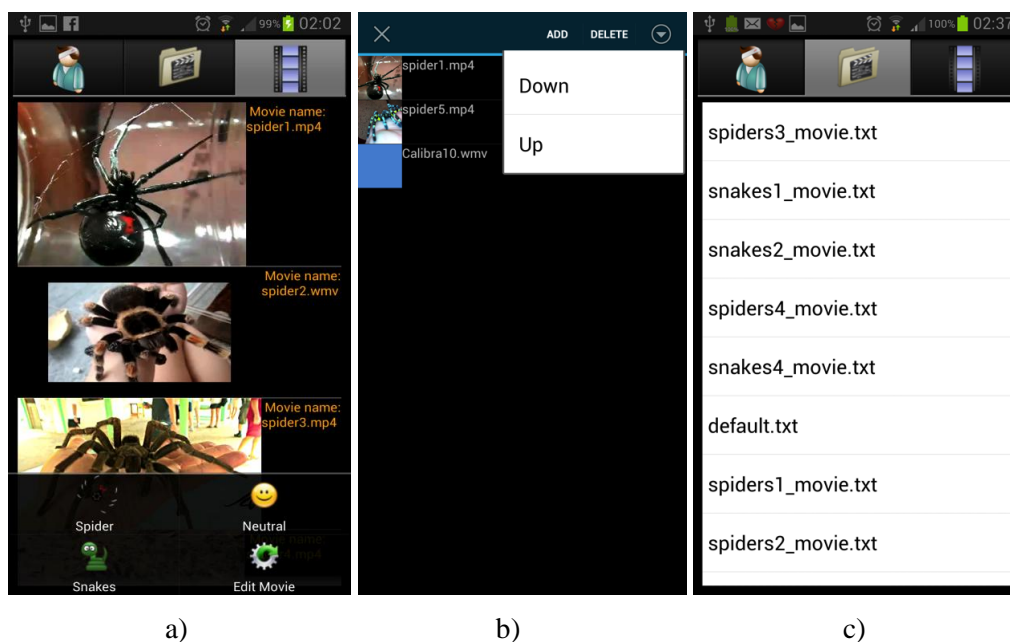


Figure 23- Video sequence management user interface: a); Videos pool with search by type feature(snakes, spider or netral videos). b) Setting the selected videos sequence; c) List of configured videos.

Manage Subjects/Processed Records.

Remote user application supports subjects and sessions management. Therefore, the remote user can add new Subject record within his application (Figure 24-a) and b)). This action will automatically create a folder on Dropbox with that subject's name and a record entry on application internal database.

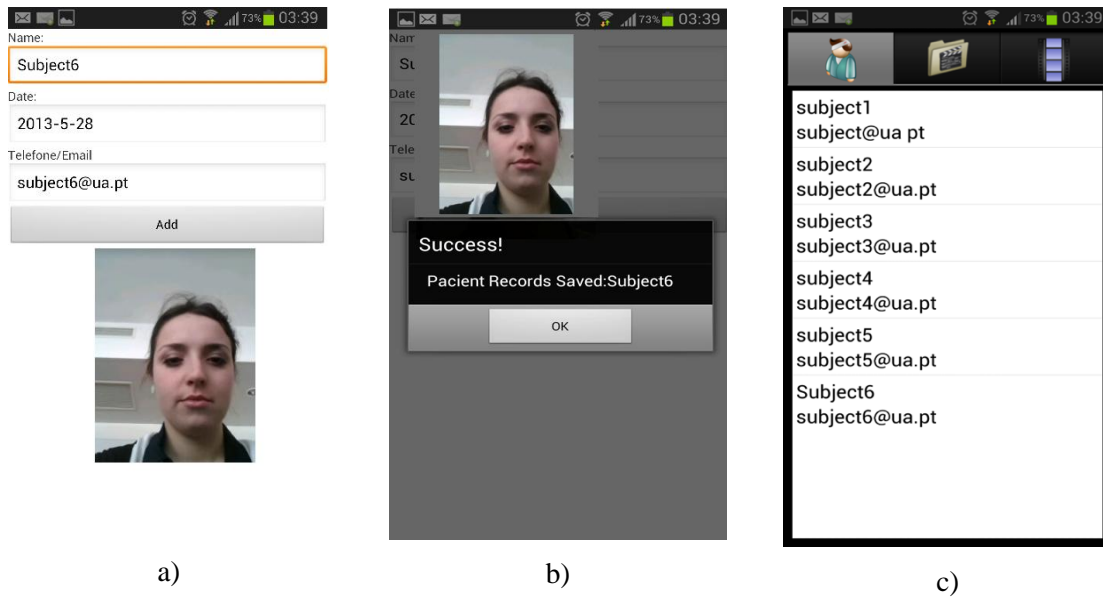


Figure 24- Subject management user interface: a) Insert new subject in system; b) New subject record stored on application DB and folder record created on server side; c) Review patient's data.

Review Subject Sessions

When received a SMS notification from patients monitoring application, the screen on Figure 25- a) appears. A remote user can link to Dropbox and download new content. This session data is stored inside the remote user application database referencing that specific subject. Therefore the remote user application maintains a record from each monitored subject and sessions performed.

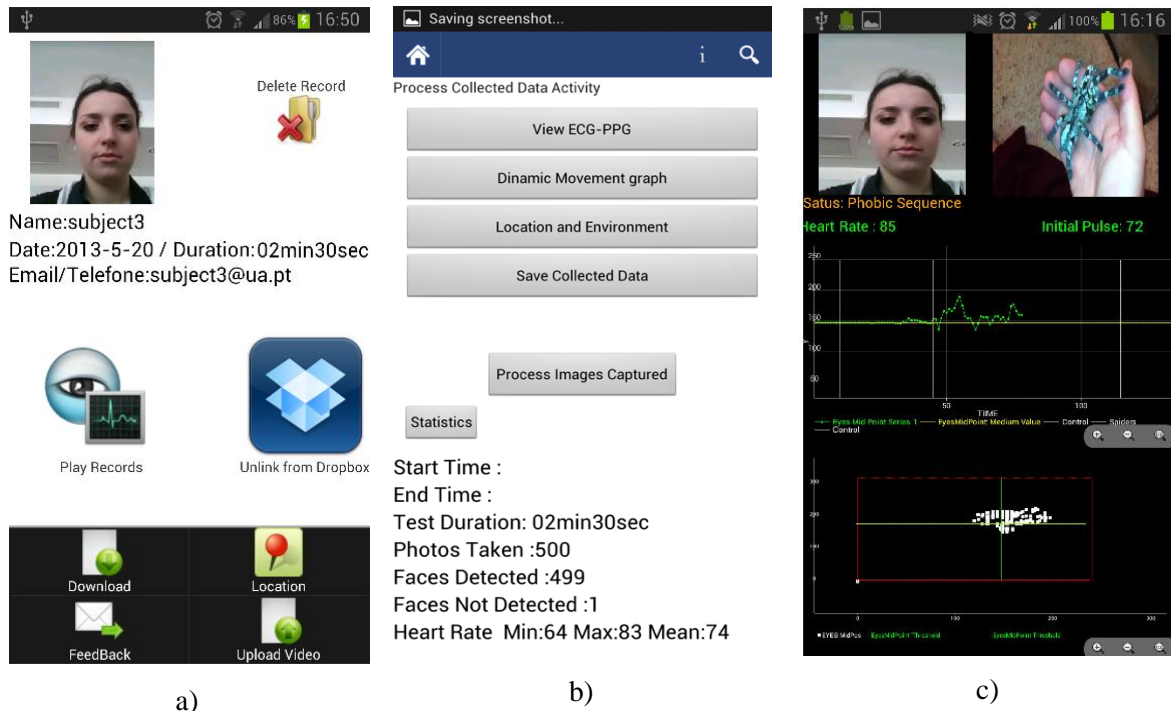


Figure 25- Sessions review user interface: a) Subject record: option to delete record, download session information from server, play session record, send a feedback to patient, view session test location and finally the option to request new test; b) Additional session information and session management; c) Online session review with protocol used.

Once data is downloaded remote user application processes data and performs some test statistics based on information retrieved from server (e.g. test duration photos taken faces detected minimum, maximum and average HR session values- Figure 25-b)). Remote user application can also retrieve subject location previously sent on message notification (Figure 13-a), b)) and allow to visualize the subject's location while performing the test (Figure 26-b)).

The remote user can review all data retrieved from session Figure 25-c) and send a feedback to a monitored user by sending a text message and/or updating new video test file, i.e. requesting new test (Figure 26-a)).

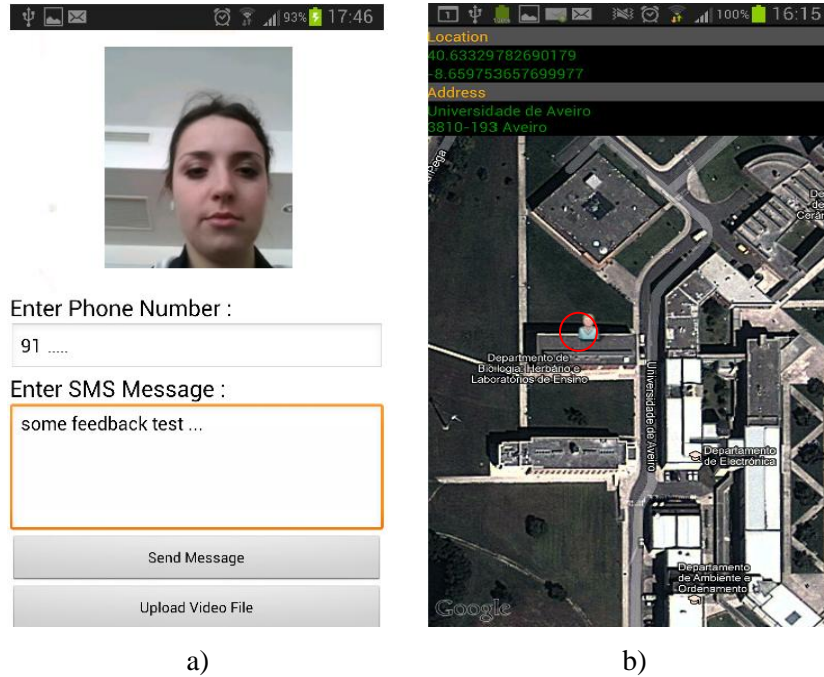


Figure 26- BeMonitored remote user application interface: a) Send feedback message to subject; b) Monitored Subject Location while performing a test.

Extracting Behavior from face tracking

The face tracking relies on Android Native Face Detection (ANFD). ANFD first detects the face position on a given image bitmap. Then it extracts features from detected face, i.e. eyes positions are obtained and the respective eyes midpoint coordinates are extracted, Figure 27-a). On Figure 27, from a) to b) a movement is observed in the face tracking system. The implemented face tracker system uses the difference between eyes midpoint coordinates to the initial baseline, both on xx and yy's axis to quantify the facial movement during a session, helping to identify which events cause discomfort in the subjects, making them to move. In this scenario, variations in xx-axis translate horizontal movement and changes in yy-axis on vertical movement (e.g. removal, avoidance).

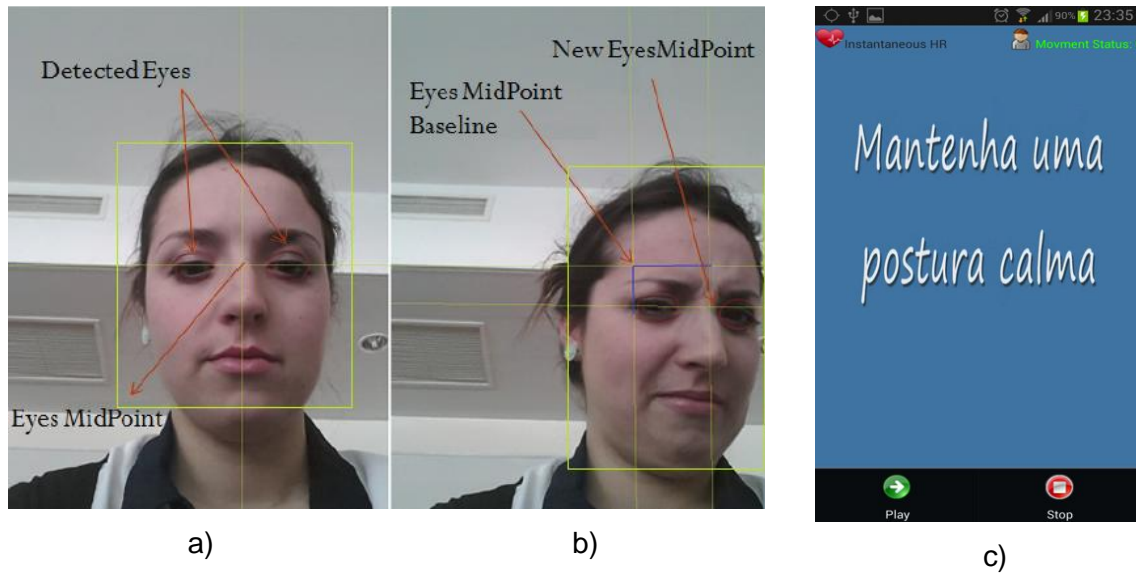
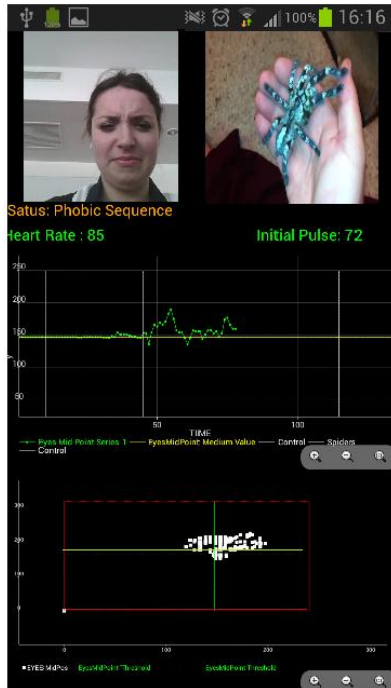


Figure 27- Face Detection and features extraction based on Android Native Face Detection; Using the initial baseline for face position a), the face tracker system estimates the face displacement along a session b); c) Video presented on mobile phone screen during the first 10 seconds of a session in order to obtain initial baseline for subject's face position.

In order to calculate eyes midpoint baseline, the first 10 seconds of video stimuli are presented to the user in a textual sequence, which tells him/her to stand in front of screen maintaining a comfortable position (Figure 27-c)). During this period, the system makes an average of the first 30 eyes mid points coordinates getting the baseline (since our camera frame rate is 3 frames per second i.e. 30 shots) for the initial subject's face position and corresponding eyes midpoints coordinates. Calculating the distance of each new eyes midpoints to the initial baseline (Figure 27-b)), is possible to quantify subject facial movement during the stimuli visualization, allowing to assess their behavior (face movement, and expressions) when confronted with the various video sequences.

On Figure 28-b), the green lines represents several eyes midpoints coordinates(xx coordinate), obtained from pictures taken during session. In this example (Figure 28-b)), it is observed that on controls sequences (control1 and control2) this subject does not present severe facial movement compared to initial baseline, since both lines are overlapping. However, in phobic sequence, there was facial movement relatively to the initial baseline. Moreover, subject facial expression and heart rate (initial heart rate = 72 bpm vs heart rate on spider segment= 85) translates the discomforted felt towards the stimulus presentation (Figure 28-a)).



a)



b)

Figure 28- a) Session Review of monitored variables and session protocol: on the top left, frames captured sequence; on the top right video stimuli used in session protocol; Status indicates the corresponding video sequence; Instantaneous HR values on the left, and Initial Pulse on the right; instantaneous eyes mid points: xx coordinates- horizontal movement (graph on the top), eyes coordinates (both xx and yy coordinates) dispersion around initial baseline, (graph on the bottom). In b). The orange line represents the time of the baseline video segment; blue line represents the controls segments, and finally red line the phobic segment. The green line represents the coordinates of eyes midpoint extracted from subject face during session and yellow line the baseline coordinate from the initial face position (both in xx coordinate). As we can see more movement on spiders segment comparing to others segments.

Session Review: A Synchronized Process

It is important to mention that all information presented in session review (Figure 28-a)) is synchronized, despite these variables are being acquired at different sampling frequencies (ECG at 500Hz, frames at 3 frames per second (fps)). As it was mentioned before, the QRS detector estimates instantaneous heart rate and the values are stored, sampled to the second. Regarding frames acquired, since the camera frame rate is 3 fps, the system performs an average at each 3 eyes midpoints values, obtaining a single value each second. When session review starts, audio recorder starts playing recorded voice, initial heart rate baseline is displayed and instantaneous heart rate and eyes midpoints values are updated at each second. Since frame rate of pictures taken is 3 fps, photos displayed on the top of the screen are updated each 1/3 seconds. Status value

(Figure 28-a)) represents which video sequence is being displayed at moment and the yellow line represents the initial eyes midpoint baseline (xx coordinate), previously calculated.

5.3 System Constrains and Implementation Options

During the BeMonitored system implementation several Smartphone's constrains conditioned the final solution.

Achieving a balance between the accuracy of the algorithm used for face detection and heart rate estimation, the time of processing and the required processing resources is a good example. Although recent models can have fast quad-core processors, they still have a constrained battery life, which is greatly affected by the amount of processing performed. The same kind of balance is also valid when dealing with online processing requirements needed for system alarms system.

Probably the more demanding balance was when addressing the face tracking solution. To achieve a reliable efficient online face tracking, the system calibrates the taken frames resolution to the smallest resolution available for the device camera, as it is not relevant the image quality but the several position of the user pose during the session. Furthermore, as the frames taken are stored on device file system, their low resolution also contributes to lower disk space required. Overall, the image compression contributes to the minimization of the required smartphone processing, resources being used and the duration to upload data to the server.

Another concert was limiting communications to strictly the acquisition periods (e.g., bluetooth acquisition interfaces,3G) and disable it right after the acquisition is complete.

The Smartphone Used

The Smartphone used to run BeMonitored applications were the Samsung Galaxy S3 GT-I9300.



Figure 29- The Smartphone used: Samsung Galaxy SIII.

Specification	Description
Processor	Quad-Core 1.4 GHz Cortex-A9
Memory (RAM)	1Gb
Connectivity	-Wi-Fi 802.11 a/b/g/n -Bluetooth v4.0 with A2DP,EDR
Primary camera	8 megapixels, 3264*2448 pixels Video Yes, 1080p@30fps
Secondary camera	1.9 megapixels, 720p@30fps
Battery	- Li-Ion 2100 mAh - Stand-by up to 590h (2G) or 790h (3G) - Talk time up to 21h40 (2G) or 11h40 (3G)
Sensors	Accelerometer, gyroscope, proximity, compass, barometer, light sensor.
GPS	Yes, with A-GPS support and GLONASS

OS (Operating System)	Android 4.1.1 Jelly Bean
------------------------------	--------------------------

Table 2- Samsung Galaxy S3 GT-I900 main specifications.

Why Dropbox

The selection of Dropbox was based on the good native support in both Android and major OS. The Dropbox Core API [29] service was therefore used to storage and maintains the BeMonitored applications state. Furthermore, the API supports the creation of shared folders that can be accessed by several users. Additionally, the API also supports authentication and encrypting methods, which ensures data integrity and methods to upload and download files via wireless connection.

Why Android Services

We choose to use android services [41] for both behavior and physiological data acquisition, because they provide a straightforward structure for running an operation on a single background thread. This allows handling long/intensive-running operations, ensuring the transparency of the process, without affecting user interface's responsiveness, maintaining user focus on UI events (e.g. stimulus display). In the BeMonitored applications, services are also used to upload and download data to/from Dropbox in background, which ensures the transparency of this process to the user.

Communication Technologies Used

To provide support for communication/information transmission, usually the wireless transmission technologies is considered but their details are clearly out of scope of the present dissertation. Nowadays, there are many solutions that have different trade-offs in factors such as range, bandwidth and power consumption, such as Bluetooth, GSM, GPRS, Wi-Fi 3G/4G, among others. The present work relies in 3 communication technologies: Bluetooth, Wi-Fi and GSM. In this scenario, some important topics were taken into consideration. Therefore, the system is able to check wireless connection availability. As managed data is sensitive, it ensures that the acquired data are sent to the server. Therefore, if at a given moment this data cannot be sent by a Wi-Fi connection, it is prompt to the user the option to send this data over 3G. Otherwise, the system schedules the data to be sent next time a network connection is available.

6 Spider Phobia as A Case Study

Specific phobias are the most common psychiatric disorders, thus causing a significant clinical burden [7]. Spider phobia (SP) is one of the most widespread forms of specific phobia. People with SP experience persistent and intense fear towards spiders and develop avoidance behavior of every context related to this animal [3]. Although animal phobia may be considered as having limited clinical relevance, this circumscribed anxiety disorder offers a valuable scientific model for investigating psycho-physiological reactions.

As a consequence, the spider phobia scenario was used as a proof of concept that BeMonitored can provide means to quantify the reaction to phobic stimuli in the assessment of the phobia level. As reported in the literature, the exposure to a phobic stimulus by a phobic person triggers a psycho-physiological response translated in avoidance behavior and increasing heart rate values and variability [2][8][18].

The BeMonitored was used to assess the spider phobias in a group of volunteers with different phobia levels. Since spider phobia has a very clear and specific ecological stimulus, it can be used in this scenario to prove the reliability of the proposed solution (BeMonitored), in the assessment of the phobia level or in the treatment follow-up-all in a more realistic and ecological context.

Based on the psycho-physiological measures from BeMonitored, we analyzed and compared statistically the performance of the volunteers when exposed to both phobic and neutral stimulus (in this case video segments).

6.1 Data and Methods

6.1.1 Subjects

The conducted study involved a group of 30 volunteer. All subjects answered the Fear of Spiders Questionnaire [30], and signed an informed consent. Based on the questionnaire results, we assumed that subjects with scores above the 75th percentile were considered potentially phobic and those below 25th percentile were considered as control group non-phobic. This has led to a group of a total 7 subjects – 4 potential phobics (f2, f5, f6 and f7) and 3 control (f1, f3 and f4).

6.1.2 Experimental Setup and protocol

During data collection, the Smartphone is placed in front of the user, in order to acquire video frames of the subject's face, with Smartphone's front facing camera, while presenting video stimuli

(Figure 30-a) and b)). To avoid the setup configuration problems and ensure that subject face is detected regardless of the subject's height, distance to device or even the context on which the device is used, BeMonitored application has a calibration process to ensure subjects correct position (Figure 30-b) and Figure 30-c)). The user wears RTABP embedded Electrodes and a PPG sensor in order to acquire physiological data as it is depicted in Figure 30-d). During the calibration phase, the system also extracts initial heart rate (Figure 30-c)).

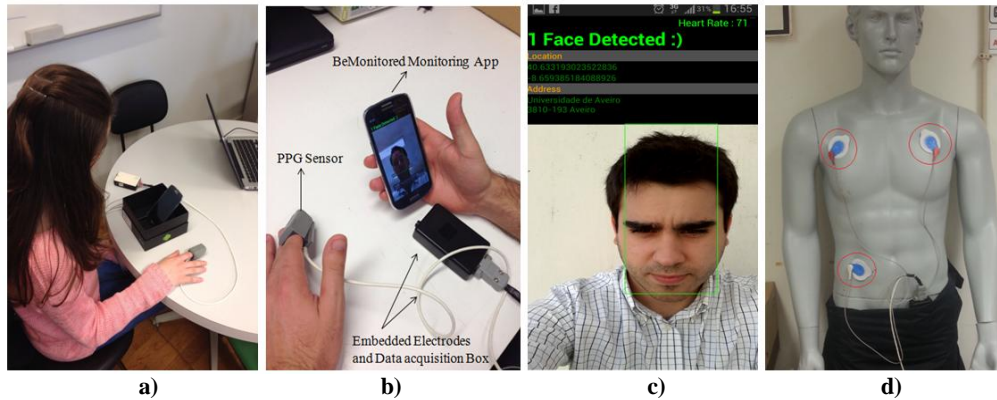


Figure 30 - Experimental setup: a) and b) BeMonitored components and sample usage during a session a spider phobia study. Note that on a) the subject faced the Smartphone not holding it to avoid damage on the equipment due to extreme manifestations of phobic subject; c) Subject face position calibration; d) RTABP module sensors position in monitored user's body.

Each session consisted in a video with sequences of neutral and spider segments (actual order: neutral, with spiders, neutral-Figure 31), where the face position and the heart rate were monitored. The volunteers were exposed to a total of 150 seconds of video (10 seconds with textual sequence, 35 seconds with control1 segment, 70 seconds with spiders and the last 35 with control2 segment).

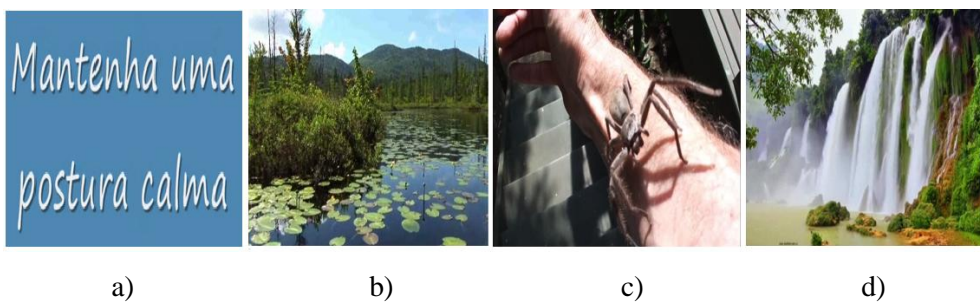


Figure 31- Example of video stimuli sequence: a) Textual segment (10 seconds); b) Control 1 segment (35 seconds); c) Spiders segment (70 seconds); d) Control 2 segment (35 seconds).

For each volunteer dataset, the data were split into three groups: control 1 (first neutral video), spider (video containing spiders - active), and control 2 (second neutral video). The studied variables were the heart rate, face movement in the xx and yy axis and its power (Figure 32). The last variable was calculated as

$$P(t) = x_{dist}(t)^2 + y_{dist}(t)^2, t = 1, \dots, N \quad (1)$$

where x_{dist} (y_{dist}) is the distance from the current midpoint eyes position in the xx (yy) axis to the baseline eyes position, and N is the length of the record.

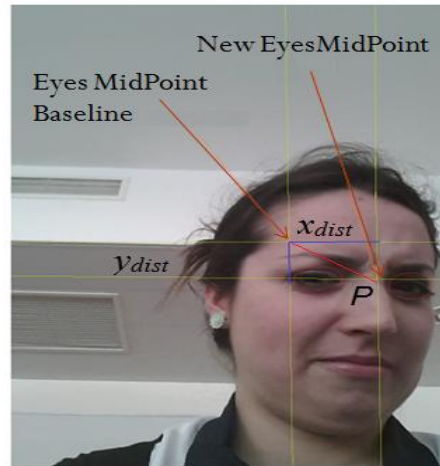


Figure 32- Facial movement power (P): P is calculated based on $P(t) = x_{dist}(t)^2 + y_{dist}(t)^2, t = 1, \dots, N$ where x_{dist} (y_{dist}) is the distance from the current midpoint eyes position in the xx (yy) axis to the baseline eyes position, and N is the length of the record.

The segments were compared inside each volunteer data (paired statistical analysis), using a Wilcoxon signed rank test (comparing the segments median), and also using a F-test (comparing the segments variance). It was considered a $p < 0.05$, for the significance level. A Bonferroni correction was implemented for multi-comparison analysis.

6.2 Results

The data acquired and processed by the monitoring application reveals an alteration on the behavior of all volunteers when the spiders appear, indicating that the phobic element has an impact that is present no matter how small it is.

The power of the face movement is significantly different between control1 and control2 segments ($p < 0.05$), except in one non-phobic volunteer (f1). When comparing the spider with the

control1 segment, a similar result was obtained – significant differences ($p < 0.05$) for all volunteers except in one non-phobic subject (f1), indicating that there was a behavioral response change when the spider appears. A significant difference ($p < 0.05$) is also observed between the spider and the control2 segment, in all except two (f1, non-phobic and f6 and f7, phobic) volunteers.

It was also found that the variance of face movement power in the spider segment is higher than the variance in the control2 segment ($p < 0.05$), except in the non-phobic volunteers (f1, f3 and f4) and f7 (the boxplots in Figure 33 allow a similar interpretation).

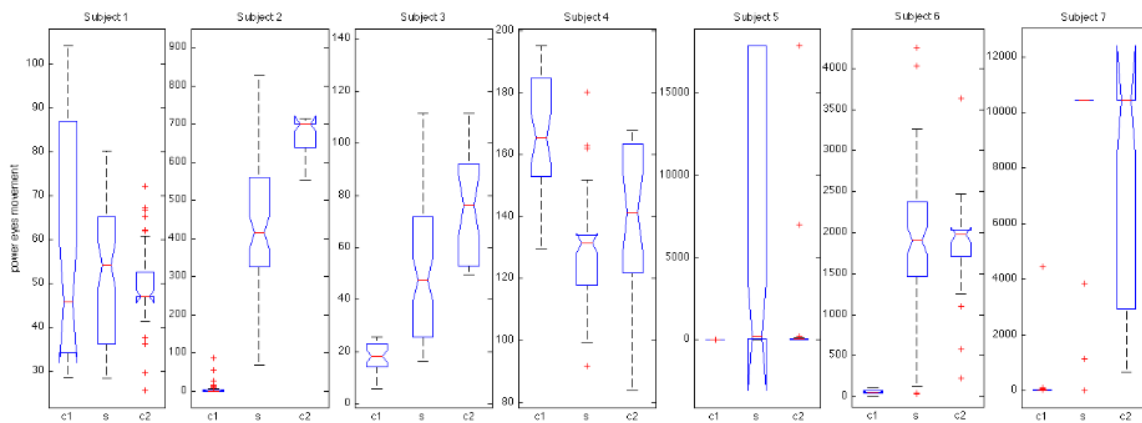


Figure 33 - Dispersion of face tracking movement (as power displacement in relation to initial position) for the seven volunteers considering the control1 (c1), spider (s) exposure and control2 (c2) segments. The phobic subjects are subjects 2, 5, 6 and 7. Subject 6 is an extreme example; during the session he felt a high discomfort and tried to not focus the video in the spider segment, being translated in the high variability of face movement. Each boxplot represents the 75% percentile, median and 25% percentile for the face tracking movement.

In relation to the heart rate, it was found a significant difference between both control segments except in two phobic volunteers (f2 and f5, $p < 0.05$) that appeared to be extremely nervous since the start of the session. There is a significant difference between almost all volunteers ($p < 0.05$, except for f5 and f7 - phobic) when comparing the control1 and spider segments. This may be motivated by the fact that the subjects know, a priori, that they would be confronted with spiders, which may alter their anxiety (e.g. heart rate values). The observed variance in the spider segment is higher than the variance in control1 segment (there was an activation, $p < 0.05$), in all except two phobic element (subject 2 and 7), Figure 34.

The increase of variance in Heart rate (Figure 34) and in face movement power (Figure 33) suggest that subjects have a reaction either psychological and behavioral after spider exposure.

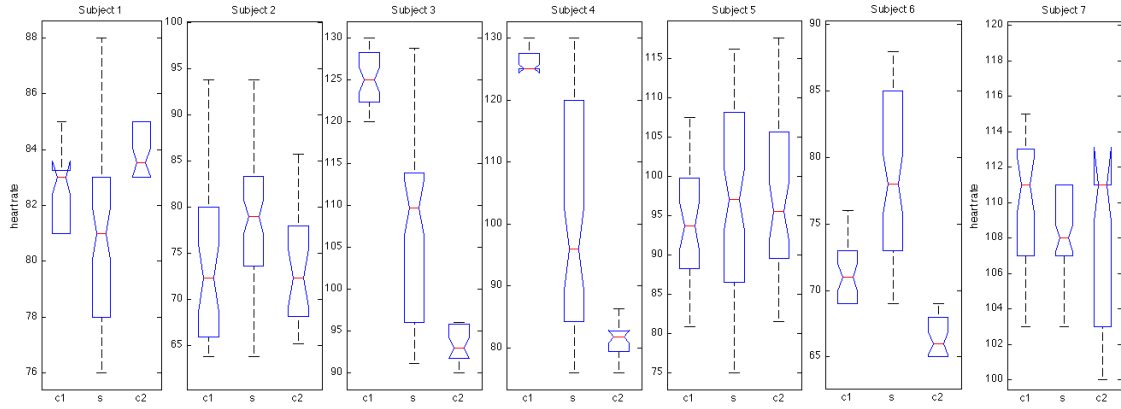


Figure 34 - Dispersion of heart rate values for the seven volunteers considering the control1 (c1), spider (s) exposure and control2 (c2) segments. Each boxplot represents the 75% percentile, median and 25% percentile for the heart rate values.

The clustering algorithm K-Means was used to study the relation between segments data, dispersion diagrams. Initially we analyzed obtained data using a configuration with two clusters ($K = 2$) in order to identify two groups (non-phobic and phobic). However, by using this configuration, a subject was a group by himself, because he/she had an extreme reaction to the stimulus. Therefore, as it is intended to separate at least the non-phobic subjects, it was included an extra cluster, in the attempt to group subjects with the same characteristics. Consequently, we used a configuration with three clusters ($K = 3$), trying to group non-phobic, probable phobic and extreme reactions. The three cluster identified (cluster 1, cluster 2 and cluster 3) are represented in the Figure 35-a), Figure 36-a) and Figure 37-a).

From the analysis of the cluster there is a possible discrimination between phobic and non-phobic groups. Considering control1 vs spider (Figure 35-a) and b)), the cluster 2 contains data from f6 (phobic), the cluster 1 data from f2 and f5 (both phobic), and the cluster 3 contains the remaining data (phobic and non-phobic).

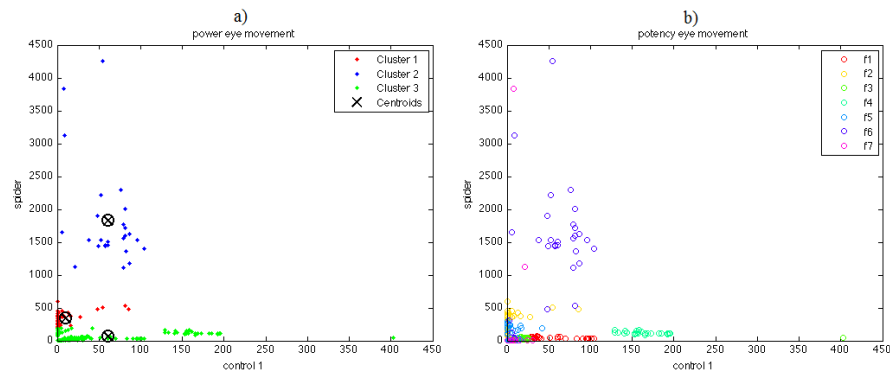


Figure 35- a) Clustering using K-Means method, relating: control1 and spider segments; b) dispersion diagram of data of each subject.

In relation to control 1 vs control 2 (Figure 36-a) and b)), the cluster 3 contains data from f7 and f6 (both phobic); cluster 2 contains data from f2 and f6 (both phobic); and finally cluster 1 contains the remaining data (mixing phobic and non-phobic data).

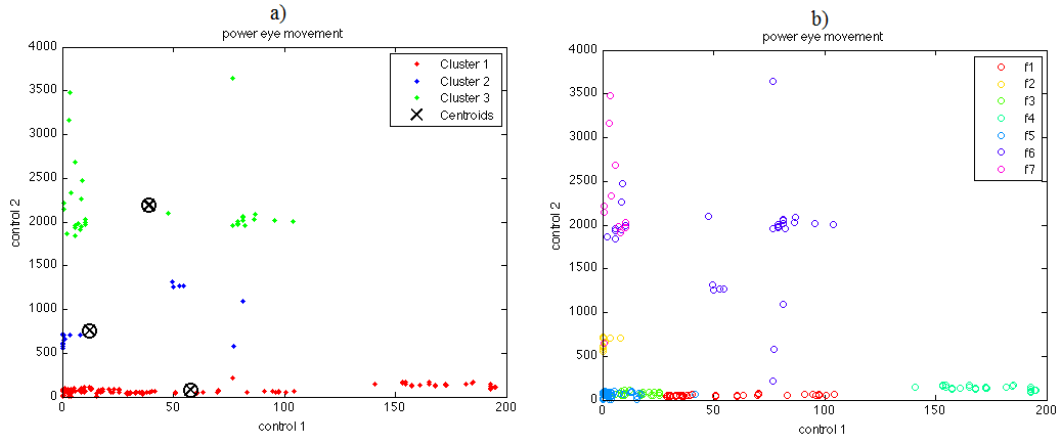


Figure 36- a) Clustering using K-Means method, relating: control 1 and control 2; b) dispersion diagram of data of each subject.

Lastly, in control 2 vs spider (Figure 37-a) and b)), the cluster 2 contains data from f2 and f6 (phobic); cluster 1 contains data from f6 (phobic); and cluster 3 is composed by the remaining subjects' data (mixing phobic and non-phobic).

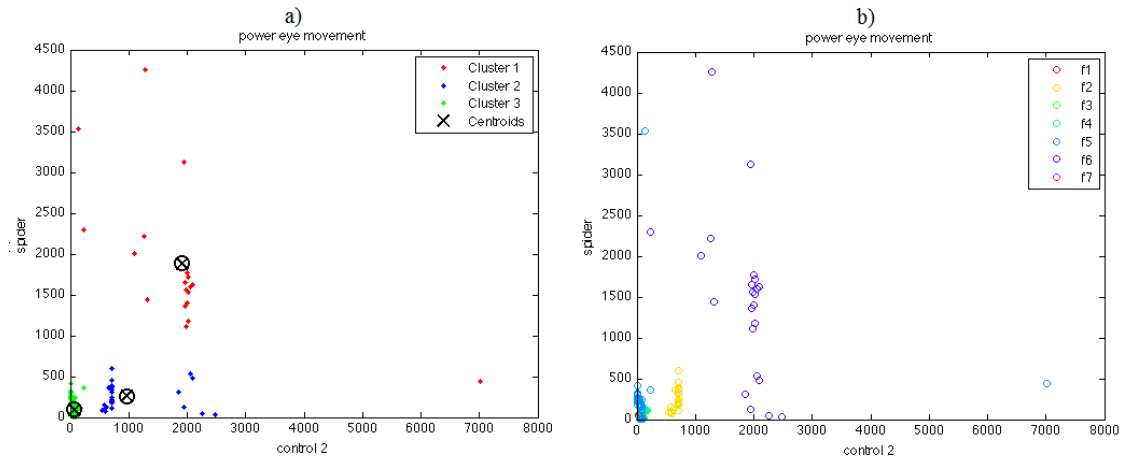


Figure 37- a) Clustering using K-Means method, relating: control2 and spider segments; b) dispersion diagram of data of each subject.

Analyzing Figure 35-a), Figure 36-a) and Figure 37-a), it is noticeable that subject f6 is always differentiated from other volunteers, constituting in some cases by himself a cluster (Figure 35-a) and b)). The other phobic subjects (f2, f5 and f7), are also distinguished from the

rest, however they are not all in the same cluster, and at the same time they belong to the same cluster as non-phobic subjects.

Overall, even considering the limited number of subjects, non-phobic are always in the same group which suggests that using these clusters it might be possible to distinguish spider phobic from control subjects, using only the face movement power captured by the Smartphone's camera. One possible justification for the obtained results may be related to the fact that control subjects feel indifferent to the stimuli presented, which does not significantly influence their behavioral response. On the other hand, the phobic subjects showed a distinct behavioral response. In fact, the fear, the disgust, or the discomfort experienced by those individuals when confronted with the stimuli, were translated into a removal / avoidance response, as mentioned in the literature [2][8][18].

A similar methodology was implemented in the physiological variable (heart rate) but the results do not suggest a reliable separation groups when using absolute HR values. The absolute values are dependent on each person, not capturing individual induced changes. Therefore, although not tested using a relative measure of heart rate, or its variability may provide better results.

7 Conclusion and Future Work

In this dissertation it is proposed the BeMonitored, a high level conceptual architecture based on Smartphones to support more ecological monitoring of psychological experiments. BeMonitored relies on Smartphones both as the solution to deliver audio-visual stimuli and to gather psycho-physiological and context (e.g. external resources connected via Bluetooth or Smartphone own resources like camera and GPS) i.e. to capture the subject's behavior, physiology and environment.

The current BeMonitored instance is able to deliver customizable specific context dependent audio-visual stimuli as sequence of videos (e.g. video with spiders) and to capture subject's behavior (tracking face movement and voice), physiology (heart rate) and environment context (Smartphone camera, microphone and GPS) The current system provides basic session management namely on demographics and supports offline review on both user's Smartphones applications. BeMonitored produces synchronous data for each session in accessible and readable format (e.g. photos, text files, audio) that can be exported and saved using DropBox (e.g. research folder on desktop or mobile application), allowing further analysis by the therapist/carer.

This BeMonitored implementation was tested on a spider phobia study, where it was found that spider phobic was separated from control subjects using solely the face motion captured with the Smartphone camera. Also, there were heart rate differences between spider and neutral stimuli. Although current study focused only on spider phobia, the results support the validity and the potential of using BeMonitored in other phobias, especially in cognitive behavioral therapy (CBT) [31] and biofeedback scenarios, either for assessment of the phobia "stage" or to deliver a stepwise sequence of video stimuli according to accepted psychology guidelines.

The capturing and quantification of physiology and behavior in realistic environments is very relevant in psychological science [1]. However, due to technical difficulties, namely lack of mobile setups and logistic, most of studies and assessment have been conducted in highly controlled settings, regardless of the relevance of the context and environment in the studied phenomena [2]. The BeMonitored conceptual architecture addresses some of these issues by:

1. Improving the assessment and diagnosis of anxiety disorders: BeMonitored relies on mobile systems, namely in Smartphones and sensors devices to monitor distressers' heart activity, facial movement, and to record video and sound, while delivering synchronously customized stimuli.

2. By supporting experiments in more ecological context (i.e. outside laboratory environment): Unlike to the commonly used treatments, which are conducted in lab [2][8] and rely on the directly observation of the individuals' reactions, BeMonitored, based on mobile devices, allows a quantified and qualitative assessment of patient's psycho-physiological responses, outside the lab context, which contributes to a greater validity of data acquired.

Although further tests are needed the BeMonitored proved to be a reliable and viable system in the assessment and treatment follow-up of this kind of disorders that by design can be further extended to provide other physiological and behavioral parameters.

7.1 Future Work

BeMonitored clearly opens several directions that can be roughly categorized in system validation and technical improvements:

- Extending the system validation and usage
- Improving facial tracking and adding eye tracking.
- Moving BeMonitored from the lab to the outdoor.
- Exploring the Biofeedback in BeMonitored.

7.1.1 Extending the system validation and usage

Due to the limited number of subjects that participated in the validation experiments, increase the number of subjects is crucial to support or dismiss the usability of BeMonitored namely as screening solution for phobia detection and as follow-up solution to access the evolution of phobic in CBT. Also the potential of BeMonitored to other phobic stimuli, although not addressed, still have a high relevance not only from the phobic therapy [31] but also from a basic psychological science [7].

The current information system back office implemented is quite simplistic, and several technical enhancements are clear:

- implement a back office support not only to manage the Dropbox information but to allow more complex and efficient query and visualization solutions namely a web or desktop application.
- multi user support and implement/improve the user interface for treatment follow-up either the subject (e.g. place information, enhanced data upload) or the therapist (e.g. enable metadata tagging, define scopes based on subject, therapies, stimuli among several other possible options).

7.1.2 Improve Facial tracking and add eye tracking

Although the subject's facial movement tracking solution has shown potential, BeMonitored does not detect eyes movement. For that reason the system is prone to be tricked once subject consciously or not, adopt strategies like fixing their face position, and looking away, avoiding direct confrontation with the stimulus – these are not distinguishable from non-phobic by only using the current face tracking solution.

As future work, it would be interesting to develop an eye tracking mechanism that allows quantifying the eye movement. Besides the fact that fine eye movements by themselves are already used of cues in video in behavior assessment [50], such a solution would also allow the current system to automatically inform the therapist, whether or not the patient tries to trick the system.

7.1.3 Move BeMonitored from the lab to the outdoor

Although the solution proposed in this work allows to quantify subject's psycho-physiological response outside the laboratory (the devices involved are portable) the study was conducted in closed environment. Consequently it was not possible to assess the impact of environmental factors and associated variables in individual's responses. Therefore, an aspect that began being developed, however not tested, was monitoring the psycho-physiological response of individuals in an outdoor environment. In this scenario, the therapist is able to set certain strategic points on a map, which correspond to areas where the stimulus will be activated (Figure 38-a)).

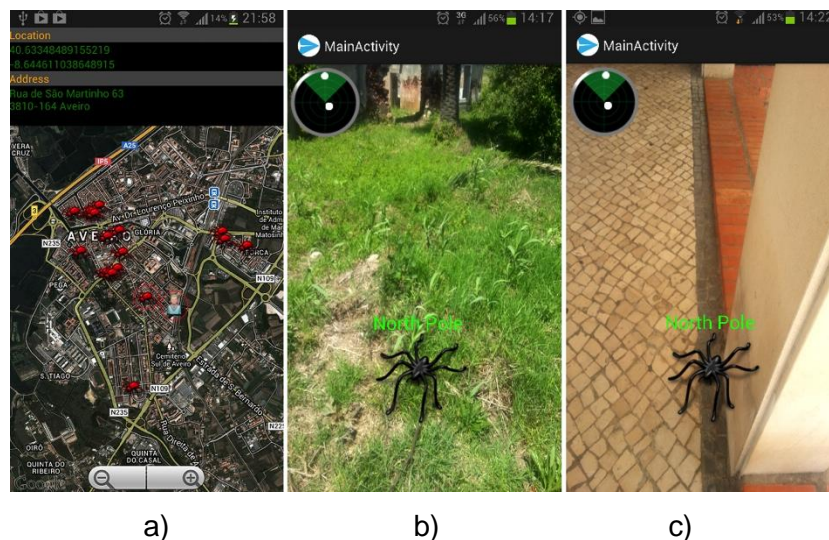


Figure 38- a) Location of the stimulus activation and monitored subject location; b) and c) camera preview of the surrounding environment and stimulus display when user is near the area where the stimulus was defined.

Additionally, it may also make sense monitoring environment variables (e.g. location, temperature, luminosity, environment sounds, etc), in an attempt to understand how these factors, may or may not influence the individuals' responses.

7.1.4 Exploring the biofeedback in BeMonitored

As initially mentioned, BeMonitored supports abnormal event detection, namely tachycardia/bradycardia detection, based on instantaneous heart rate and severe facial movements based on the online variation of the eyes midpoint position to the initial baseline.

Regarding biofeedback-based therapies, although not fully tested and integrated, BeMonitored already implements some feedback mechanism. BeMonitored has a prototype alarm system which feedbacks user with his/her instantaneous heart rate and online face movement, while displaying stimulus on the phone screen Figure 39-a) and b). Although this feedback may not be reasonable in a pure CBT strategy – avoid bias of the subject towards the stimuli induced by the feedback – the potential for using these biofeedback mechanism remains to be explored.

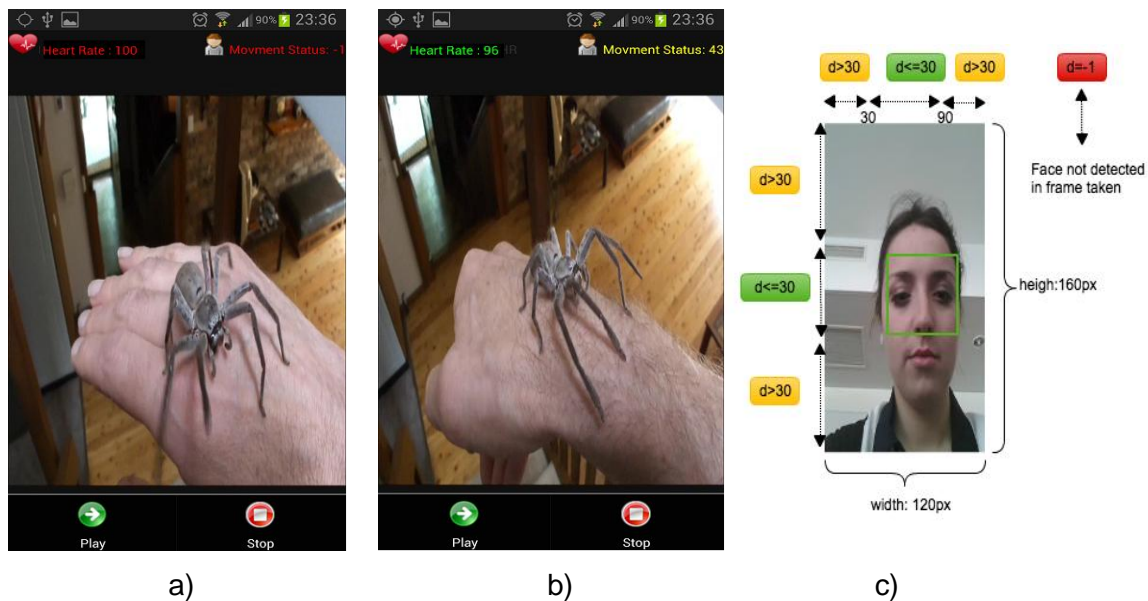


Figure 39 – a) and b) Biofeedback application: alarm system based on colors and vibration to alert online detection of tachycardia /bradycardia events and severe facial movements while presenting a stimuli for the user who is being monitored; c) alarm color based on the distance (d) of each new eyes midpoint coordinate to initial eyes midpoint baseline: color green- distance ≤ 30 px; color yellow- distance > 30 ; color red- face not detected($d = -1$ maximum distance by default).

In our biofeedback proof of concept solution, the user interface displays information that is altered based on the behavior and measured HR. For instance, user interface (as in Figure 39-a)), presents on the top of the screen the instantaneous heart rate value, which gives information to the monitored subject about his/her HR variations during stimulus display, i.e. his/her anxiety levels. When the instantaneous HR value is over 100 bpm (beats per minute), or below 60 bpm the color is set to red (Figure 39-a)), indicating an abnormal event (i.e. tachycardia and bradycardia respectively), otherwise the color is set to green (Figure 39-b)). However, the instantaneous heart rate might not reflect anxiety levels, because volunteers can be all times over or above the defined threshold. Therefore, we intend to study the heart rate variability as an indicator of anxiety instead of the absolute heart rate values.

A similar mechanism is implemented but now based on the face movement inferred from the distance between eyes midpoint to an initial position (the baseline). Based on this distance an alarm was set to quantify user facial movement during the monitoring session and feedbacks that information to user. Since the dimension of frames captured is 120*160, we assume that distances to initial baseline below 30px (i.e. within green square Figure 39-c)), translates an insignificant face movement, and for that reason color is set to green. Distances above 30px (i.e. outside green square), reveal a higher movement in relation to initial position and the alarm color is set to yellow. When the system does not detect a face on the bitmap captured, the eyes midpoint coordinate is 0 (by default), and the distance to initial baseline is maximum (-1 by default, Figure 39-a) and c)). This event triggers the device vibration and the movement status color becomes red with the distance value of -1 (Figure 39-a)). In this scenario, the measurement of facial movement becomes an unreliable measure for evaluating phobic and non-phobic, which makes it even more important the integration of an eye tracking solution in the system.

Currently, this biofeedback BeMonitored extension is still not fully tested but already has the potential on the therapy of this kind of disorders, since can help subjects to clearly identify which events trigger or not their psycho-physiological responses and teach them how to control their body and emotional responses while being confronted with the stimulus [51].

8 References

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