Universidade de Aveiro Departamento de Electrónica, Telecomunicações e Informática,
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Droid Jacket: Sistema de Monitorização Móvel de uma Equipa

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"É fazendo que se aprende a fazer aquilo que se deve aprender a fazer."

Aristóteles

Universidade de Aveiro 2010
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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 (M.I.E.C.T.), realizada sob a orientação científica do Professor Doutor José Maria Amaral Fernandes, Professor Auxiliar do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro e do Mestre Ilídio Fernando de Castro Oliveira, Professor Assistente Convidado do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro

Dedico este trabalho aos meus pais e ao meu irmão.

I dedicate this work to my parents and brother.

o júri / the jury

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Palavras-chave Sistemas de Monitorização, Detecção de Alarmes, Computação Móvel, Arquitectura de Software

Resumo

Os profissionais de emergência lidam no seu quotidiano com situações de perigo, agindo muitas vezes sob pressão, expondo-se a níveis de stress e fadiga por períodos extensos, causando um impacto negativo nas suas vidas e saúde. Neste contexto, a utilização de novas soluções a partir de tecnologias vestíveis, redes de sensores e dispositivos móveis cria a oportunidade de oferecer um acompanhamento mais próximo, com o objectivo de detectar situações de perigo e dar suporte a equipas de profissionais de emergência médica em campo. No entanto, existem muito poucas soluções voltadas para a utilização sinérgica destas tecnologias emergentes que dêem suporte integrado à monitorização de uma equipa.

Nesta dissertação propomos uma arquitectura conceptual de software (TeamMonitor) para agregação, análise e disseminação de informação direccionada para a monitorização de equipas na acção. Team Monitor é sustentada na noção de nós de coordenação centrais, que são responsáveis pela recolha de dados de diferentes fontes (ex.: vários profissionais de emergência) e subsequente fluxos de trabalho para análise, incluindo processamento básico de dados (ex.: execução de detectores de alarmes de sinal biológico) e troca eficiente de dados com clientes externos. O nó central dissocia a rede de tecnologias de informação da rede de fornecimento de dados. O suporte é dado pela camada de aquisição de sinal biológico e de análise que nós desenvolvemos, o módulo BIOSal.

De modo a ilustrar a viabilidade do TeamMonitor, nós implementámos um sistema como prova do conceito, o Droid Jacket, onde o nó central da TeamMonitor é instanciado num dispositivo móvel com Android. Droid Jacket permite monitorizar até quatro Vital Jacket® (uma tecnologia vestível para a monitorização de uma pessoa), fornecendo tanto o suporte para a troca eficiente dos sinais agregados para clientes externos, como a detecção precoce de potenciais alarmes a partir do processamento em tempo real dos dados adquiridos. Ao contrário de outras abordagens comuns, nós considerámos as capacidades de processamento do dispositivo móvel para estação base. Nós implementámos um algoritmo simples de detecção do complexo QRS da onda cardíaca e de arritmias no Droid Jacket, a partir do electrocardiograma adquirido pelas unidades com o Vital Jacket® vestido.

Droid Jacket demonstra que a incorporação de dispositivos móveis num cenário de monitorização de uma equipa é uma opção razoável, e o conceito pode ser estendido e adaptado a cenários mais realistas como a monitorização de bombeiros.

Keywords Monitoring Systems, Alarms Detection, Mobile Computing, Software Architecture

Abstract

First responders deal in their daily lives with danger, working under pressure, exposing themselves to stress and fatigue for extended periods, which has a negative impact on their lives and health. In this context, using new solutions based on wearable technologies, sensor networks and mobile devices raises the opportunity to provide closer monitoring, aiming at detecting hazard conditions and supporting first responder teams in the field. However, very few solutions exist addressing such synergistic use of these emergent technologies to support integrated team monitoring.

In this dissertation we propose a conceptual software architecture (TeamMonitor) for information aggregation, analysis and dissemination towards field-action teams monitoring. TeamMonitor is supported in the notion of central coordination nodes that are responsible for data aggregation from multiple sources (e.g.: several first responders professionals) and subsequent analysis workflows, including basic data processing (e.g.: running biosignal alarms detectors) and data stream relay to external clients. The central node decouples the IT network from the data providers network. This support is provided by a biosignal acquisition and analysis framework we developed, the BIOSal module.

To illustrate TeamMonitor feasibility, we implemented a proof-of-concept application, the DroidJacket, in which the TeamMonitor central node is instantiated in an Android mobile device. DroidJacket is able to monitor up to four VitalJacket® devices (a wearable garment for individual monitoring) providing both the support to relay the aggregated signals data to remote clients and an early detection of potential alarms based on real-time processing of the acquired data. Unlike other common approaches, we rely on the mobile device processing capabilities for the base-station. We implemented a basic algorithm for heart wave QRS complex and arrhythmia detection in DroidJacket, using the electrocardiogram acquired from the VitalJacket® units.

DroidJacket demonstrates that incorporating mobile devices in the team monitoring scenario is a reasonable option nowadays and the concept can be extended and adapted to more realistic scenarios like firefighter monitoring.

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List of Abbreviations and Acronyms

ANS Autonomic Nervous System

API Application Programming Interface

AV Atrio Ventricular

BIOSal Biological Signal Aquisiction Layer

BP Blood Pressure

BPM Beats Per Minute

CDC Centers for Disease Control and Prevention

CRUD Create, Read, Update and Delete

ECG Electrocardiogram

EPA Environmental Protection Agency

FTP File Transfer Protocol

GSM Global System for Mobile Communications

GPRS General Packet Radio Service

GPS Global Positioning System

GSR Galvanic Skin Response

HR Heart Rate

HRV Heart Rate Variability

HTTP Hypertext Transfer Protocol

ICT Information and Communications Technologies

IDE Integrated Development Environment

IEETA Instituto Engenharia Electrónica e Telemática de Aveiro

IT Information Techonology

IP Internet Protocol

JAR Java Archive

J2EE Java 2 Enterprise Edition

J2ME Java 2 Platform MicroEdition

MIT Massachusetts Institute of Technology

MBU Mobile Base Unit

NOAA National Oceanic Atmospheric Administration

OOP Object-Oriented Programming

OS Operating System

PC Personal Computer

PDA Personal Digital Assistant

PNS Parasympathetic Nervous System

PPG Photopletismography

RF Radio Frequency

SA Sinoatrial

SDK Software Development Kit

SIAS Sistemas de Informação na Área da Saúde

SNS Sympathetic Nervous System

SPO2 Oxygen Saturation

SSRL Smart Systems Research Tool

TAN Team Area Network

TCP Transmission Control Protocol

UDP User Datagram Protocol

UI User Interface

UML Unified Modeling Language

UMTS Universal Mobile Telecommunication System

USARIEM U.S. Army Research Institute of Environmental Medicine

USAMMRC U.S. Army Medical Research and Materiel Command

USCG U.S. Coast Guard

VJ Vital Jacket®

VR Vital Responder

WIFI Wireless Fidelity

WPSM Warfigther Physiological Status Monitoring

Chapter 1

Introduction

1.1 Motivation and context

Professionals such as first responders (firemen, emergency vehicle crews, policemen and paramedics), have many stress situations on their daily work, focused on physical and emotional exhaustion, where they are typically monitored through medical visits [1]. First responders must have an exemplar performance, as they and other individuals are depending of their reactions and decisions, which are essential to the operational success of critical situations. In this context, it is clear that the evaluation of first responder conditions is critical, namely to evaluate their health status and identify specific needs or factors that may or may not trigger decisions like keeping them in the missions front line. In an operational scenario, the extreme conditions may be a blow on the physiological and physical wellbeing of an individual, and these can be perceived through symptoms such as trauma, exhaustion, fatigue and panic disorders [2] [3] [4]. Every human being, feels, once in a while negative effects of stress exposure for dealing with adverse situations, which increases their vulnerability to stress risk factors. Both stress and fatigue are related to changes in the autoimmune system [5] [6] and the evaluation of these phenomena is still a great challenge for scientific community, especially in an operational scenario. Monitoring physiologic signals such as ECG, respiration, SPO2, galvanic skin response (GSR) and body temperature are good options since they have been widely used in areas such as psychophysiology as important indicator of stress levels [1] [7]. In physiological signal monitoring, it is important to provide a secure, efficient and reliable solution [8] [9] [10]. This data can be used to support either online decision making system [11] [12] or to better understand the effect of extreme conditions on first responders, to explicitly identify diseases related to the mental and cardiovascular system [3] [5] [13]. Achieving this involves different knowledge areas such as sensor networks, wearable technologies, location systems and biomedical signal processing, which will emerge to create a platform for professionals monitoring such as first responders (Figure 1.1).

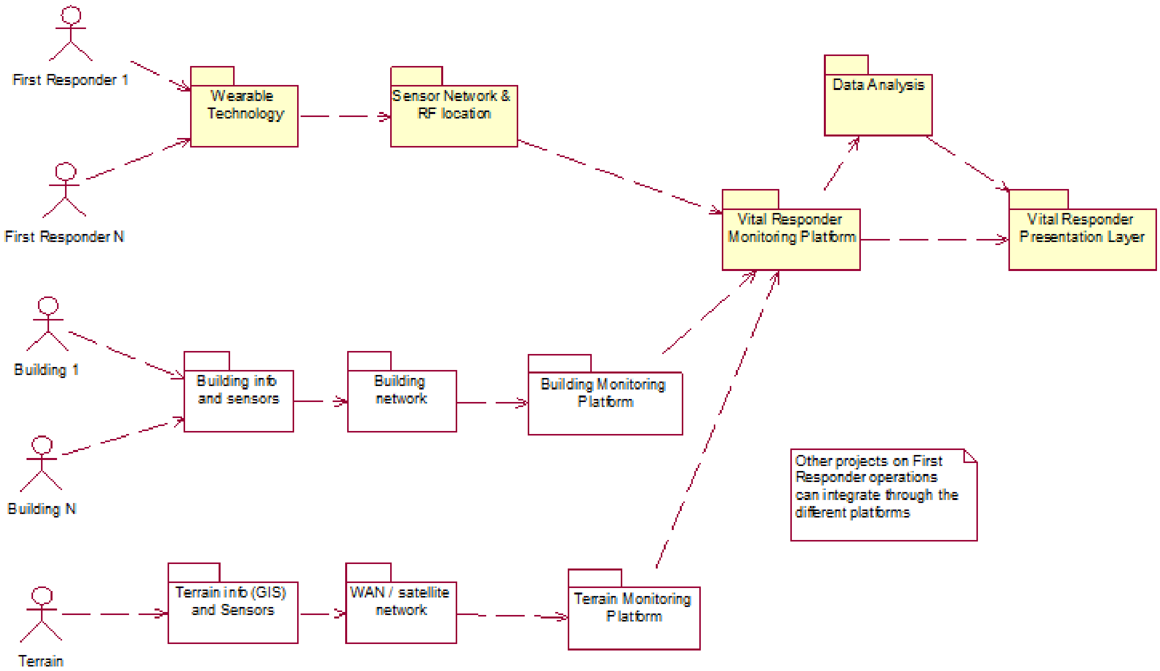


Figure 1.1: Vital Responder project focus [14].

Another important theme that is addressed by monitoring such group of professionals is mobility. Over the last years, new technological advances in mobile devices and wireless communications provide a novel approach for development of monitoring systems. Nowadays mobile devices are actively part of our lives, and scientific areas such as medicine are investing in new solutions for using mobile devices as components of their architecture. Furthermore, in the last few years, physiological signals have been subject of research in human health monitoring and diagnosis. Several studies [15] [16] [17] of physiological signal monitoring systems use, as detection and analysis device, a PC or a PDA. Mobile devices like a smartphones have a compelling computational power that can be applied in a mobile monitoring system architecture for processing some biological signals [18] [19].

Nevertheless, due to the multidisciplinary areas that a project of this scale presents, there are several technical issues to consider for designing the infrastructure in a wireless monitoring system. The wearable garments collect real time data from individuals, and both sensors networks and location systems are mandatory to provide location and reliable data dissemination in a critical scenario. The study of the collected data brings us two new research areas, biomedical processing and data analysis, used to extract pertinent information and apply pattern recognition features to detect abnormalities.

There are a few active research and commercial projects, developing new methods for intelligent medical and critical scenario monitoring such as WPSM led by USARIEM and USAMMR, a system that collects vital signs and other event information [1], and SMART developed by USCG, NOAA, EPA and CDC, for whose the main purpose is to design a monitoring program for dispersant operations in a place burning [20]. The Vital Responder project is another example. VitalResponder (CMU/PT/CPS/0046/2008) that is led by IEETA / University of Aveiro and has various partners from academia/research (IT/Porto and IT/Aveiro, Carnegie Mellon University), commercial (BioDevices S.A., Petratex) and firemen associations (Companhia de Sapadores de Vila Nova de Gaia and B. Voluntários de Amarante). The main goal of the VitalResponder project is to provide an effective first-response system in critical emergency scenarios to evaluate (online and offline) the nature of physiological stress processes of first responders in operational scenarios and develop adequate response mechanisms to handle them [14] [21].

1.2 Objectives

The objective of this work is to propose a system (architecture and software application) that allows monitoring teams of first responders, in the context of the project VitalResponder. As a proof of concept we limited the scope of the envisaged system to fulfill the following requirements:

- gather the vital signs information (focus on electrocardiogram - ECG) and location from first responders in the operational field.
- provide visualization for first responders information.
- Disseminate that information to operational coordination.

- provide basic early signal processing over ECG for detecting stress related features (heart rate and arrhythmias).

As an additional requirement, the option for open standards led us to choose Android OS for the mobile devices. To achieve these objectives we propose to articulate several solution components:

- **TeamMonitor:** a system architecture for a team monitoring solution. TeamMonitor defines generic coordination modules and roles for a solution that will provide a template to support online monitoring for a team member, including review of vital signs, location information and some online processing specifically to support alarm detection.

- **Bio**logical **S**ignal Acquisition **L**ayer **(BIOSal)**: a modular framework for a Bio-Signal Stream Session that can either be deployed in a mobile or on a standard PC. The BIOSal enables the data gathering of several first responders and supports the development of plugins that can be used to implement simple processing algorithms namely alarm detections based on data input.

- **DroidJacket:** An Android based solution that is an instance of the TeamMonitor. DroidJacket enables the user to monitor the ECG online and simulated location of the first responders team that is being acquired using the VitalJacket®. DroidJacket relies on Biological Signal Acquisition Layer (BIOSal) for most of the reception, gathering and processing of the team acquired information.

- Three detectors were developed as a part of DroidJacket scenario to illustrate the online processing abilities supported on a mobile device.

The core of the framework should present a modular approach, with high level programming abstractions, based on a plugin architecture, obliterating the complexity of using heterogeneous network protocols (Figure 3.3).

1.3 Dissertation structure

This dissertation is divided into the following chapters:

In **Chapter 1** (the current one) we present the main motivation for this dissertation (solution to monitor teams) and enumerate the dissertation objectives and main contributions.

In **Chapter 2** entitled "Monitoring team's stress", we will do a short review on stress related physiology concepts and address the state of the art on how to infer to stress from vital signs. Our focus will be on the electrocardiogram (ECG) role in this context. We also review existing solutions for vital signs team monitoring to identify major issues in this scenario.

In **Chapter 3 and 4** we propose a modular architecture (TeamMonitor) intended for signal data acquisition and processing for our team monitoring solution. As component of TeamMonitor, we have a framework called BIOSal, and illustrate its applicability in a application DroidJacket, a mobile team monitor application. DroidJacket is applied in a case study for firefighters team monitoring and we integrated some plugins for ECG signal filtering, specifically QRS complex detector - to perform heart rate, and arrhythmia detector an abnormal ECG event that can be a relevant alarm signal. Also some tests and results, in specific scenarios are showed.

Chapter 5, "Conclusions and future work", discusses the accomplishments during the development of this work.

Chapter 2

Monitoring team's stress

For any team monitoring solution to be able to provide a valuable support, it must address two main issues: (1) clearly identify the vital signs used to measure (or infer) stress (the building block for any critical situation detection solution), and (2) understand the technical constraints of the specific scenario the team is in. In this chapter we will focus on the basic human physiology markers related with heart rhythm variations that can be associated with stress.

Next, we will focus on the technical details related to team monitor issues and some solutions described in the literature.

2.1 Physiology of human Stress

Stress is the body's response mechanism to any situation that represents action, or is judged like so. It is a *"response that describes the condition caused by a person's reaction to physical, chemical, emotional or environmental factors"* [22], and each person reacts in a different way to stress. Hans Selye, a scientist who studied stress, introduced the term stress, where he observed stress response mechanisms were present, like secretion of hormones, such cortisol by the pituitary gland, a small gland at the base of the brain [23]. It is also known, that *"excess stress can manifest itself in a variety of emotional, behavioral, and even physical symptoms"* [23]. Physical symptoms such as sleeping disturbances, fatigue, gastrointestinal disturbances and headache are examples of stress phenomena. Regarding emotional symptoms and behaviors, we have anxiety, overeating, depression, and other psychiatric disorders [3] [23] [24]. One good example of extreme body stress is heat stroke, which has serious effects on health but extremely difficult to detect through medical examinations [21]. To be able to address stress one must first address the basic mechanisms that is susceptible to be altered by it. That is the case of the autonomic nervous system and by consequence the heart function.

2.1.1 The human heart

The human heart is essential to human life and naturally both stress and fatigue interfere with its normal condition. The human heart (Figure 2.1) is an organ mostly composed by muscle that is responsible for pumping blood throughout the body. It is composed by four chambers, two at the top (atriums), and two at the bottom (ventricles). Heart pumps blood with oxygen and nutrients throughout vessels in order to reach all body cells and obtain it back, through the veins. To fulfill its function, the heart has two main actions that are related with contraction and relaxation of its chambers. The contraction when the blood is expelled out is called systole, and relaxation, called diastole, is when the blood enters to the chamber and remains there for a stationary period.

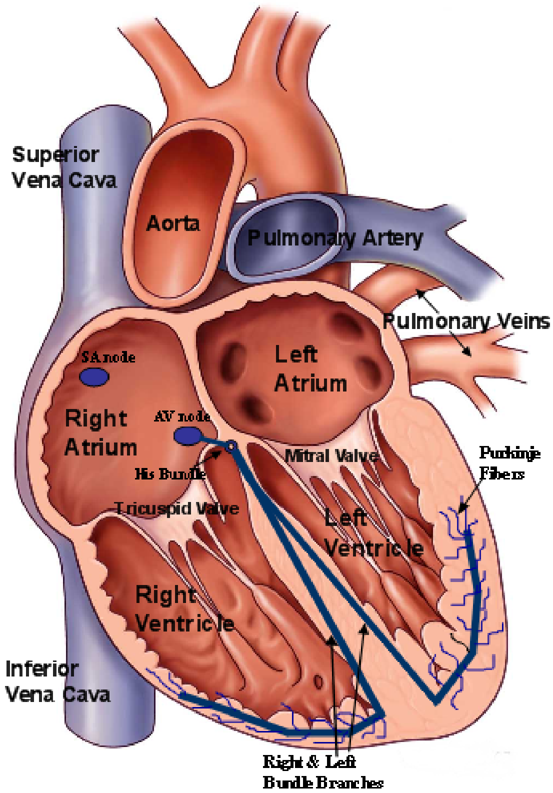


Figure 2.1: Anatomical view of the normal heart and conduction system [25].

The heart is mostly composed by muscle and the most important one is the myocardium. Different kinds of muscle cells are related to different functions: there are cells associated with the actual heart's contraction, and those that are bonded to conduction system, which disseminates electrical impulses [26] . The heart beat is a result of polarization and depolarization of these cells that provokes the contraction and relaxation periods. Initially, cardiac cells are polarized, and when electrically excited, they depolarize and then contract. This polarization and depolarization can be measured through the recorded electrocardiogram signal. In electrocardiogram analysis, clinicians study wave characteristics (P,Q,R,S,T), where the cardiac cycle initiates in sinoatrial (SA) node, as illustrated on (Figure 2.1), intended for heart rhythm pacemaker, which stimulates the atrium. Therefore the P wave describes the mutually atriums depolarization. Following the atriums contraction, the preliminary impulse reaches delayed into the atrioventricular (AV) node, accordingly to (Figure 2.1), this pause has the purpose of enhancing blood volume at ventricles. Subsequent QRS complex describe the ventricles depolarization and finally, the T wave represents ventricles repolarization, in order to be stimulated again (Figure 2.2) [26].

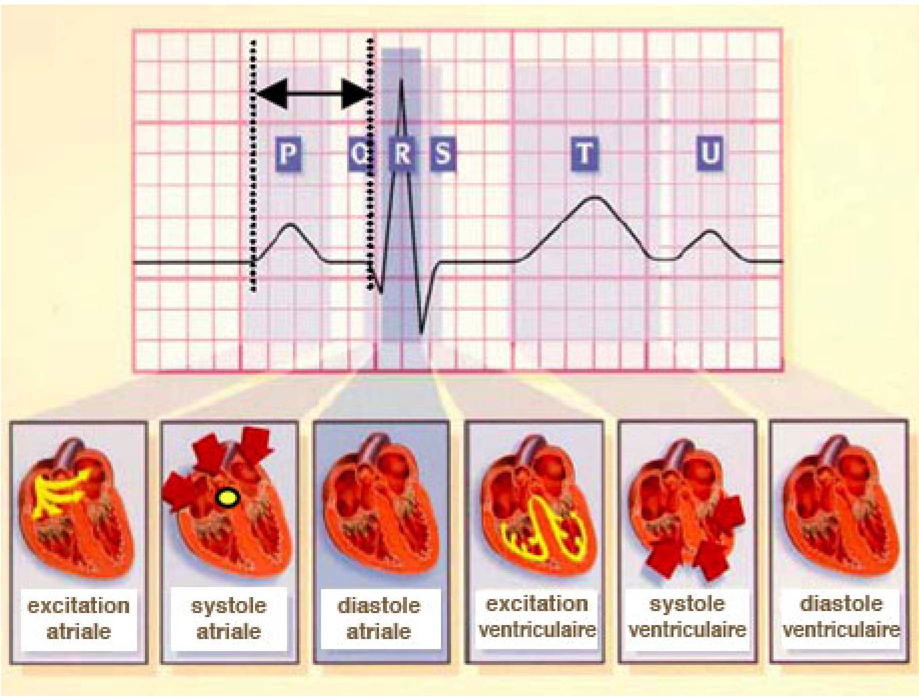


Figure 2.2: Normal ECG waveform [27].

2.1.2 Autonomic nervous system

The nervous system is responsible for processing and communicating information through the body, and assuring that changes are rapidly handled [26]. In the context of the nervous system, the autonomic nervous system (ANS) plays a relevant role in stress scenarios. The autonomic nervous system (ANS) is responsible for unconsciously and autonomously balancing body activities, such as regulating cardiac activity, and by other hand somatic nervous system handles with muscle activity in conscious activities such as moving an arm. The ANS is composed by two main systems: the parasympathetic nervous system (PNS) and the sympathetic nervous system (SNS). PNS is mainly related to operating overall resting or relaxation, while the SNS operates when physical activity is required. Thus, these two systems are related with the balance of our body internal organs environment [26]. Autonomic nervous system (ANS) is responsible for normalizing the heart beat, through nerve cells (neurons) that are among the brain and the heart. The balance amongst parasympathetic and sympathetic parts of the autonomic nervous system coordinates the heart rate, so when a person feels fear, they find themselves in an unsafe circumstance or performing some physical activity, the PNS increases heart rate. However in a rest state, relaxation, heart rate is decreased by SNS (Figure 2.3). Measuring the ANS activity can be used to infer the stress levels on humans. For example, the ANS can adjust temperature levels, blood glucose levels and cardiac output through regulation of muscle contraction and glandular secretion [28] that can be related with specific physiological status. It is possible to have measures on the balance between the SNS and ANS namely in normal or stressful conditions. Good examples are heart rhythms, blood pressure, and body temperature.

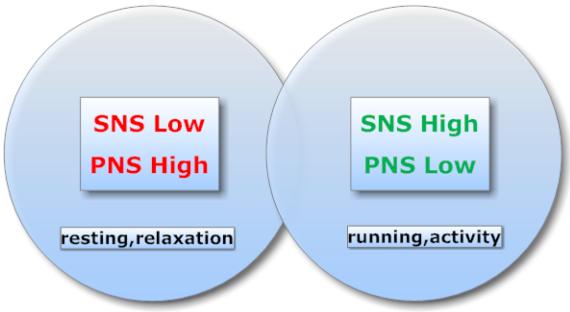


Figure 2.3: Autonomic response system diagram.

2.1.3 Blood pressure

Blood pressure (BP), is the pressure strived by blood against artery walls, and is highly related with changes in the heart rate, as well as presents a variation that can be coupled to changes from beat to beat and minute to minute in response to innumerous influences both external and internal to an individual [29]. During the cardiac cycle (**Human Heart section** 2.1.1), two pressure values characterize blood pressure. In systole (systolic blood pressure) the pressure is maximum, whereas in diastole (diastolic blood pressure) the pressure achieves a minimal value. Some studies relate the increase in arterial blood pressure with stress incidents [13]] [30] [31].

2.1.4 Body temperature

The body temperature can offer relevant cues on the stress and fatigue state of a human subject. Body temperature can be characterized as being the capacity of our body to controll the heat, generating it or just dispelling it. Even though temperature fluctuations are meaningful in an external environment, our body is capable to sustain the internal temperature stable [32]. A normal temperature is near 37 °C, and it is influenced by issues such as time of day, eating, metabolic rate or even psychological factors [33]. At normal conditions the human body has the ability to conserve its own temperature through a thermoregulation mechanism. If the body is not able to regulate its own temperature, the body may enter in extreme conditions like hyperthermia that can lead to heat exhaustion and heat stroke. Hyperthermia is an event generated by failed thermoregulation. With thermoregulation failure, an episode can possibly arise. Generally, an occurrence is considered whilst the body temperature is greater than 37.5 °C - 38.2 °C. Heat exhaustion is an example of Hyperthermia when an individual can not sweat enough to cool body temperature. Significant physical exertion may cause heat, and due to humidity and heat, the proficiency of cooling mechanisms is diminished [34]. Typically, this events occurs in circumstances such as high temperatures and body dehydration. Symptoms may appear including headache, fatigue, vertigo, weakness, nausea, which many times lead to fainting. Another case of hypherthermia is heat stroke, which is extreme, caused by a heightened exposure to heat, that can cause organ failure, or even death [21].

2.2 Monitoring the human stress

To be able to track the heart function in order to infer the physiological status of a human being, most common methods are:

- Electrocardiogram.
- Photoplethysmography.
- Galvanic Skin Response.

2.2.1 Electrocardiogram

The changes of polarization in the heart can be measured through electrocardiograms. Heart exerts similar to an electrical impulses generator, which propagates electrical impulses through the hearts conduction system. Therefore, an electrocardiogram measures voltage variations amid electrodes attached over the body surface [26]. The ECG history begins in the 1880's through the first ECG recording performed by Waller [26]. Nowadays, the use of ECG is widespread throughout clinical applications, namely to observe pathologies from rhythm pattern analysis or electrocardiogram wave morphology using signal processing advanced techniques [26]. An ECG recording is the major diagnostic method worn for heart diseases diagnosis, for being a non invasive, secure and low cost technique [35], hence it is valuable information to predict cardiovascular diseases related to unmanageable stressful and risk factor situations.

2.2.2 Photoplethysmography

Photoplethysmography (PPG) is a simple and low-cost method that can be applied to identify blood volume changes. It measures small variations in light intensity associated with blood volume modifications by cardiac activity, typically placed in the extremities like fingers or ears [36]. PPG is known to supply valuable information about cardiovascular system such as heart rate, cardiac output, autonomic function and arterial blood oxygen saturation [36], that can be used to detect respiration events such as hypoxemia, which represents an abnormal concentration of oxygen in the arterial blood. According to [1] and to the reasons described before, PPG may help evaluating persons stress.

2.2.3 Galvanic skin response

Another way to monitor the ANS is through galvanic skin response, also designated skin conductance. The sympathetic nervous system induces changes in the electrical resistance of the skin, through sweat glands that can be considered as an electrodermal response of the autonomic nervous system. This technique may be used to evaluate the physiological and mental stress [37] on an human being. As soon as stress is exhilarated to unmanageable levels, alterations in skin resistance are detected by GSR detectors. Although there are no well-defined levels in order to quantify stress, galvanic skin response is a fine stress indicator [37].

2.2.4 Arrhythmias and stress

Given the number of existing markers of stress, in this dissertation we narrow our focus on arrhythmias. Arrhythmias are changes of heart rate in relation to the normal rhythm (heart rate fluctuates amid 50 and 100 beats per minute) [26]. Arrhythmias can be defined as irregular single heartbeat, or as an irregular group of heartbeats [38]. The designation of an arrhythmia is associated with the origin, and/or otherwise related with heart rate. A slow rhythm, below 60 beats per minutes is designed bradycardia, whereas tachycardia is an expeditious rate above 100 beats per minute. For example, a ventricular tachycardia defines an arrhythmia located at ventricles, where rate exceeds the established threshold for a normal rhythm. Arrhythmias can be benign, life threatening, or even fatal [21], depending on heart morphology changes [26]. According to [24], the heart rate variability can be associated with factors (e.g. psychological) that the autonomous nervous system behavior, namely stress [1] [24]. Palpitations and Premature Beats are examples of heart rhythm irregularities. Palpitations, normally considered a benign arrhythmia, whilst may causes discomfort, by anxiety and mental stress meanwhile premature beats arises when sometimes normal sinus rhythm is interrupted by a beat that arises before expected, called a premature beat. Its designation may be supraventricular or ventricular, dependent of its origin. For instance, a study showed that physicians during night shifts, display a higher rate of ventricular premature beats [39], and it was inferred that situations such as stress were closely related to the occurrence of these arrhythmic beats. Various studies on animals relate ventricular arrhythmias with psychological stress [40] [41]. Another article reference, points to ischemic episodes and ventricular arrhythmias at patients related with stress events [42]. Being able to detect arrhythmias in extreme conditions and hazardous environments can improve the detection of possible critical situations. In our specific case we will centre our attention on ventricular arrhythmias that can be detected by using simple signal processing methods over ECG [38], appropriate for our mobile device based solution that we will describe in the next chapter.

In this context, some arrhythmias and diseases related with the ventricular function, will be described, as illustrated at Figure 2.4.

- Ventricular tachycardia (Figure 2.4a): occurs when rate exceeds 120 beats/minute, with a similar morphology to premature beats. A ventricular tachycardia episode is detected only when at least three consecutive beats occur [26].

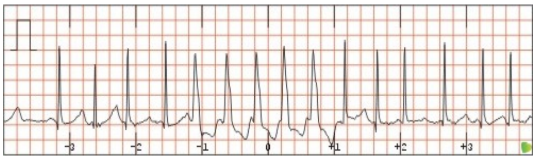
- Ventricular flutter (Figure 2.4b): has a rapid rate, usually around 300 beats/minute, but regular, which is difficult to discern P, QRS complexes and T waves [26].

- Ventricular fibrillation (Figure 2.4c): unlike ventricular flutter, the rhythm impulse by ventricles is unsystematic. Ventricular fibrillation leads to *"cardiac arrest, cessation of respiration, loss of consciousness, even to the death"* [26].

- Ventricular ectopic beats: the most common ventricular ectopic is premature beat, causing ventricular contraction and may be related with heart disease, natural causes or even stress or other stimulations [43]. Regarding ventricular ectopic beats, we may have some arrhythmia patterns: Bigeminy: (Figure 2.4d) is an arrhythmic episode composed by a sequence between normal beats and premature beats of PVC (Premature Ventricular Contraction) - N (Normal) - PVC. Trigeminy: (Figure 2.4e) the same as Bigeminy, with an exception, the occurrence of a premature beat, however is among two normal beats. Ventricular Couplet is a sequence of two consecutive premature beats.

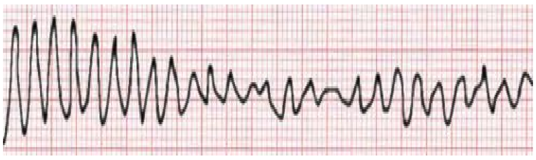
- Myocardial ischemia (Figure 2.4f): results of a low blood flow to the heart cells, causing them to have a lack of oxygen [26]. In an exercise or mental stress scenario, heart cells demand more oxygen, so if an heart artery narrows [26], an episode may arise. Further symptoms such as chest pain or discomfort may occur, and consequently even an arrhythmic episode as ventricular fibrillation.

  A good review on arrhythmias can be found in [26].

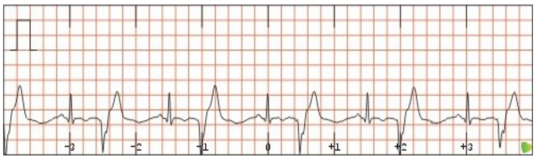


(a) Ventricular tachycardia episode [43].

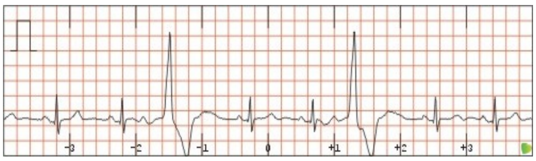
(b) Ventricular flutter episode [35].



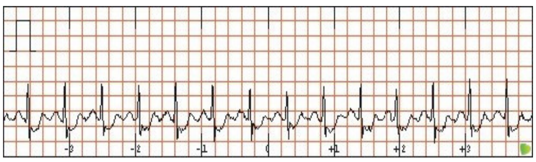
(c) Ventricular fibrillation episode [35].



(d) Bigeminy episode [43].



(e) Trigeminy episode [43].



(f) Myocardial ischemia episode [43].

Figure 2.4: Ventricular arrhythmias and diseases.

2.3 Information and Communications Technology for team monitoring

In this dissertation, we are interested in providing a solution to prove that mobile devices can support team monitoring at both at individual and team level, in the specific case of firemen to identify or predict critical events that may endanger their life, namely alterations in the heart function. The relevance of this specific scenario is clearly demonstrated in a comparative study of Los Angeles firefighters and insurance writers [21]. The study showed a close association among ischemic heart disease and their profession, concluding that the incidence was higher in firefighters. The challenge is to be able to do close monitoring of an individual or a team while dealing with different factors, like the extreme operational conditions, limited communication scenarios, mobility and detected alarms that can be relevant for the individual and for the team. In these kind of operational conditions there are several crucial factors affecting the design of ICT solutions:

- **Communication** (range, bandwidth).
- **Monitoring vital signs** (scalability, computational power, wearability, reliability, security, persistence, synchronization).
- **Mobility** (size, weight, power consumption).
- **Location** (outdoor, indoor, relative or absolute).
- **User interface** (simplicity, usability, fault tolerance).

We will now go through these topics to further explore the underlying requirements.

2.3.1 Communication

For instance, to provide support for communication/information transmission we usually consider in this context wireless transmission technologies but their details are clearly out of the scope of the present dissertation. There are many solutions that have different trade-offs in factors such as range, bandwidth and power consumption, like Bluetooth, GSM, GPRS, WIFI, 3G, UMTS and Zigbee [44]. Some important topics should be taken into consideration: The system should be able to predict disconnections, by, for example, periodically checking on the signal strength, and as it is decreasing, a disconnection might happen. The same can be considered for when there are handovers [45]. A mesh is better than a centralized system, because if a node shuts down, there is still a network connection, since the network can regroup again, and if possible without manual intervention. When designing a network, one should consider creating their own structure, because using the public network can lead to network congestion. For example, in a critical scenario, the infrastructure should be able to assure the network availability [45].

2.3.2 Monitoring vital signs

Using a sensor placed on each individual requires solutions that are closely related with other requirements, namely:

- **Wearability:** allow non-invasive close monitoring that do not affect the performance. This can be achieved for instance by using light and easy to place sensors.

- **Reliable communication:** each sensor must have enough communication bandwidth, so that it can provide meaningful information. This implies being able to transmit the data in a given sample rate and, for efficiency, some pre-processing so that only relevant data is actually transmitted, reducing both the communication traffic and bandwidth use (e.g. transmit pulse rate instead of complete ECG waveform) [44].

- **Security:** the system should support data integrity. Another issue is confining private access to personal data. Using authentication services and proper certificates such as X.509, are a requirement of an secure system [46].

- **Persistence:** having a persistence infrastructure, in order to provide storage and search services [47].

- **Scalability:** design a solution that allows users/devices with different modus operandis and requirements, communicating and exchanging information [48].

- **Temporal synchronization:** when collecting information from different sources, another aspect to consider is the temporal synchronization of data [44], in order to associate events, or notes to the various signals.

- Other issues such as legal, liability and ethical issues should be considered [45].

2.3.3 Mobility

Regarding mobility, some aspects ought to be considered:

- **Size and weight:** the devices have to be small and light enough to be carried and not be troublesome.

- **Power consumption:** the devices should minimize battery consumption trying to remain active without having the need to be charged.

2.3.4 User Interface

Requirements related to user interface in these scenarios:

- Usability: the application should have a usable and intuitive interface that is easy to access, and providing feedback to the user along his actions and minimizing false alarms.

- Simplicity: the application ought to be clean, simple and not impose hard and long tasks to the user [48].

- Fault Tolerance: this system should be fail-safe, namely by minimize user errors.

2.3.5 Location

Having an accurate location service is an important feature, being a requirement for a system as ours. Locating team members in real scenarios, either in outdoor or indoor [49], like in a building is very important. Depending on the used solutions this location can either be absolute, GPS, or relative, like the distance from a given reference (sensor networks inside a building).

At the table below, we can see a comparison between different research/commercial projects, with some solutions for monitoring vital signs taking in consideration a series of factors (Table 2.1):

	MobiHealth [8]	Proetex [50]	Wealthy [51]	Zephyr [52]	SSRL Tool [49]	VitalVest [53]	AID-IN [48]
Sensors/Measures	ECG, surface EMG, pulse oximeter, respiration sensor, temperature sensor, accelerometer	Heart rate, respiration rate, internal and external temperature, gas sensor	ECG, core and skin temperature, accelerometer	temperature, respiration rate, heart rate, blood pressure, SPO2 as well environmental sensors.	none	heart rate, brain waves, body temperature, respiration, pulse wave	pulse oximeter, ECG, temperature
Location	GPS	GPS	GPS	none	nd	GPS	none
Int.Communications	Bluetooth	Bluetooth	wired	Bluetooth	Bluetooth	WIFI, RF, Bluetooth, 802.15 (ZigBee)	802.15.4
Ext.Communications	GPRS, UMTS (future 2.5G and 3G)	nd	GSM, GPRS	802.11(Wi-Fi), RF	GPRS, 802.11(WIFI)	nd	802.11 (WIFI)
Mobile Base Unit	PDA	nd	laptop, desktop	smartphone, laptop	PDA, smartphone, tablet PC	pocket PC, laptop	tablet PC
Platforms	Windows CE, EPOC (Symbian), Palm OS	nd	nd	nd	J2EE,J2ME,.NET	nd	nd

Table 2.1: Commercial/research projects of monitoring systems (vital signs and other sensors).

[1]

[1]nd = not discriminated. Consider internal communications as the communication between the device and sensors from the monitoring unit, and external communications as the communication among the monitoring unit and external entities.

Numerous approaches and solutions have been tested throughout the years as described in (Table 2.1). Most projects have chosen destop/laptop as device for monitoring, although some also use mobile devices (SSRL Tool, MobiHealth, Zephyr). In most cases these devices are used to acquire/monitor ECG, temperature, respiration and some accelerometers. However some projects that are more concerned with the field monitoring, have environmental sensors. (Zephyr, Proetex). In terms of location, GPS is the most popular solution but, since it only works outdoors, there is a need for a solution that works indoors. In terms of communication the solutions vary according to the scenario. In forest scenario some projects (Zephyr, Proetex) use GPRS/GSM UMTS or 3G technologies, but this solution implies an added cost for using a telecommunications operator. A drawback of this solution is the need to have towers installed that ensure a good coverage. Using other technologies for external communications is also a solution to avoid added operator costs but it may imply developing and supporting their own infrastructure, namely supported in WIFI and/or Zigbee. This is the case of the projects VitalVest, Zephyr and AID-IN. Regarding development frameworks, most of the projects use Windows solutions, whether they are mobile or desktop, and some already use open source solutions such as JavaME (SSRL Tool) [49].

Chapter 3

A framework for team monitoring

Our approach will address the problem monitoring firemen team from an high level more focused on a specific scenario based on the scenarios identified in the project Vital-Responder. We will propose an IT framework (TeamMonitor) to support team monitoring using mobile devices in the data acquisition, processing and relay processes. We assume that details related with communication, power, and hardware among are not an issue although is a complete scenario they must be addressed and considered.

3.1 Vital Responder scenario

In a possible Vital Responder scenario (Figure 3.1) each Vital Jacket® (see 4.1.1) is associated with a field unit. It transmits vital signs and other sensor values relevant to first responders' coordinator. The local team coordinator acquires data using a mobile device, which processes the data in real time while giving visual feedback to the commander on his team's physical and health status. The local coordinator, through the mobile device, is able to disseminate the data through the communication links to a central operator system. The Control Operator system is responsible for storing the data within the internal network (TAN - Team Area Network). This system may provide other services such as audio communication between operators and teams involved in an operation. The Control Center supports the back-end operation. It provides a front-end system for the users (e.g. external medical specialists) to access the acquired data from the operational field and support the data analysis through specialized tools. At the same time, the control center is also responsible for communications management and data storage services.

In this scenario (Figure 3.2) the main actor is the Commander, which is responsible for

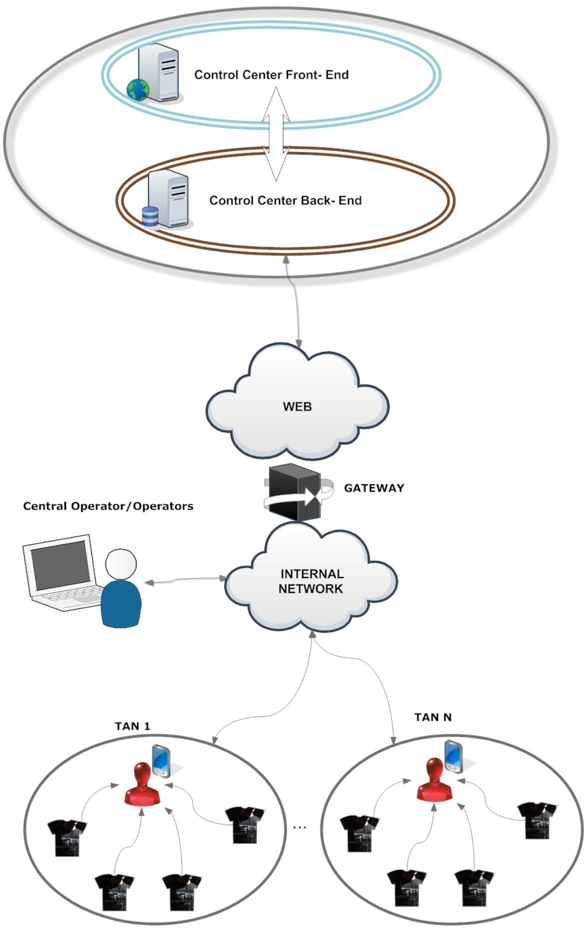


Figure 3.1: A possible approach to the Vital Responder Network.

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coordinating a team. Each team member has wearable technology [9] that gathers data and sends it through the system. In this data, there is information relative to location, ECG, SPO2, and temperature. After processing the data, the system should be able to send notifications to the presentation layer.

3.2 The TeamMonitor system architecture

At the Vital Responder we are waiting for a ICT solution that can focus mainly on the following aspects:

- an infrastructure that allows real time monitoring of multiple firefighers at the same time, subjected to work induced stress, and in real time be able to fire alarms that

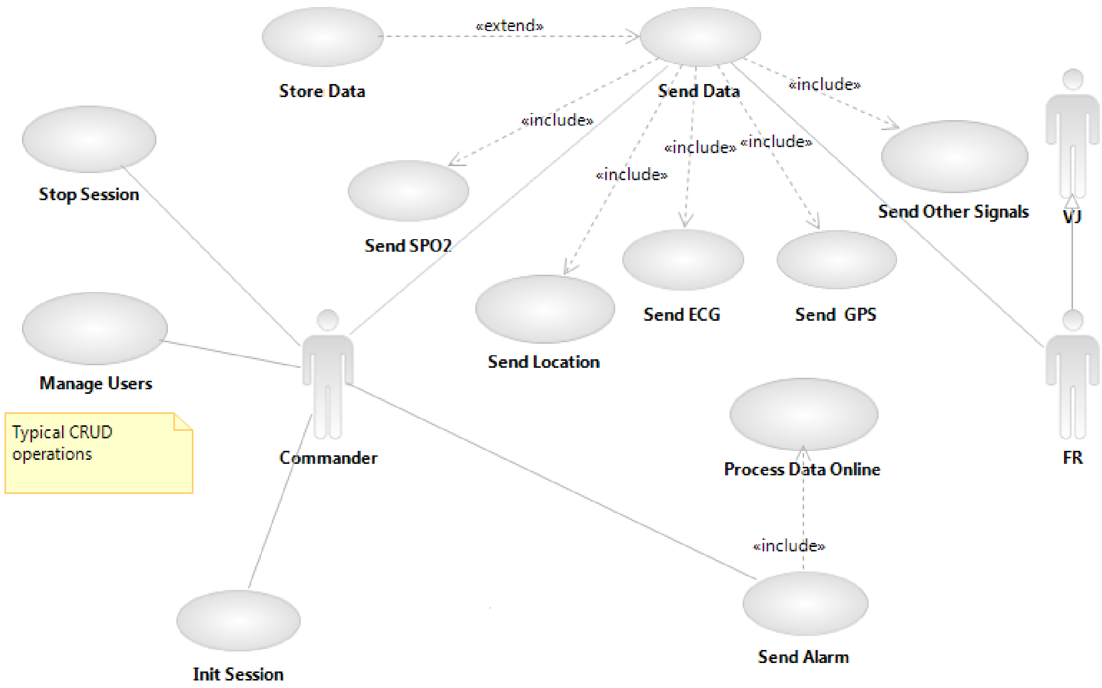


Figure 3.2: The system use cases.

can notify other actors of a dangerous situation to an agent.

- a system that can follow the actors in a mission, despite their mobility.
- a fail-safe and robust structure.
- from this projects multidisciplinarity, where several investigation teams are involved, comes the need for the development to be modular, so that each contribute can be more easily integrated.
- providing data access for other systems.
- allowing the system to work as a node in the network.

To address the issues we identified earlier we propose an high level architecture that we called TeamMonitor. TeamMonitor is architecture based on generic devices as central coordination nodes that are responsible for providing and relying data and supporting basic data processing and storage. As architecture (Figure 3.3), TeamMonitor is modular and is composed by:

- **Application:** responsible for the interaction between the user and the system. It is liable for displaying the relevant information from processed/gathered data and triggered alarms from BIOSal (explained below).

- **BIOSal framework:** a framework incorporated into this architecture with the purpose of transforming data and making it available to the interface layer, from the communication details with biological data sources, to processing and alarms detection, explained in the next chapter.

- **Storage Provider:** This architecture block is comprised by services, which deal with storage access from the layer interface, so it is responsible for typical database operations (insert, update and delete).

Although the presented architecture was designed by us, some other previous works were taken in consideration. In [54], concepts such as stream parsing and service processing are used to gather useful information, and database for storage. In another project [47], data is collected from multiple sensors, supported by data streaming from multiple devices. In [55] a plugin architecture was described in order to integrate new modules for data streaming.

3.3 BIOSal

TeamMonitor architecture stresses the relevance of providing a modular architecture that:

- allows extensibility - we achieve this by proposing and implementing an plugin solution.
- allows gathering and providing data services to the external observer - this comprises both the actual monitoring stream, filtering data, data post processing and alarms detection.

As a component of TeamMonitor, BIOSal includes bio signal acquisition and processing. BIOSal is implemented in Java (so may be used in other Java oriented systems such as J2ME, or J2EE) and is supported on a simple plugin solution - the Light Java Plugin Framework. It was based on [56] and using the definition of specific Java interfaces and relying on Java dynamic binding and classpath mechanism, it is possible to integrate new functionalities during runtime through plugins, by providing only a handle to the

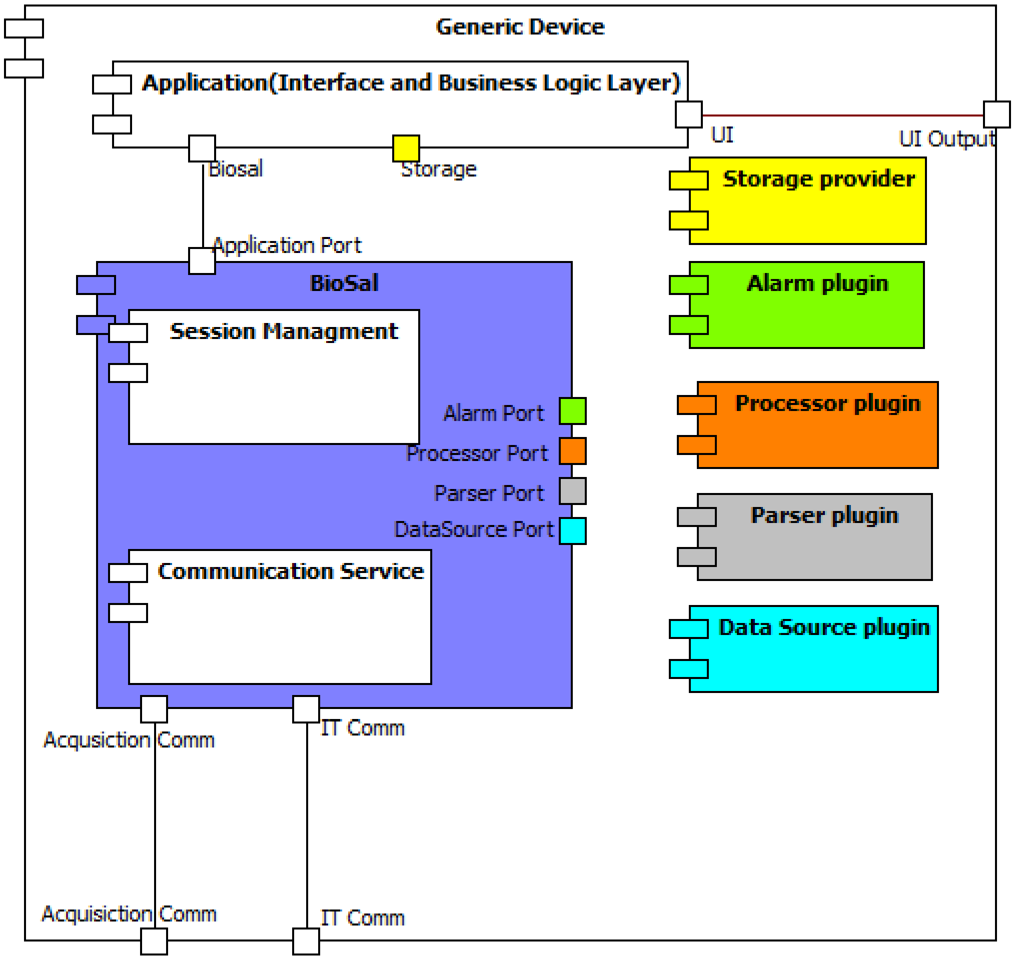


Figure 3.3: The TeamMonitor architecture.

plugin (as a java object implementing the given interface). The BIOSal system has the following mechanism to load plugins inherited from Light Java Plugin Framework: locally via classpath, existent classes, directory or a JAR File, and remotely from a specific source using standard HTTP connection (Figure 3.4). Details on the actual implementation can be found in appendix A - The Light Java Plugin Framework.

BIOSal has four logical packages/functionalities with very specific task:

- **DataSources:** responsible for abstracting and supporting simple connections with a data provider, encapsulating the complexity of the connection to the outside of the system.

- **Parser:** used to perform data parsing, each parser just has to input the data type

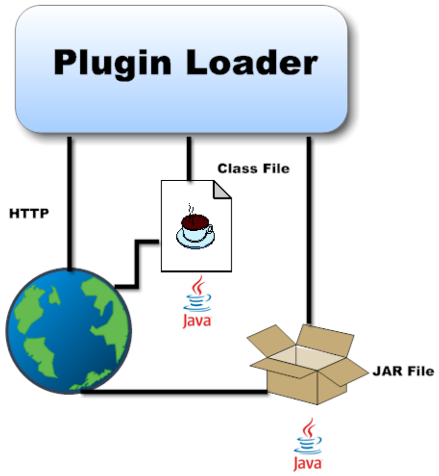


Figure 3.4: Plugin loader system.

generic inputstream.

- **Processors:** responsible for handling and performing the signal processing algorithms. They can be specialized depending on the input data type.
- **Alarms:** responsible for analyzing collected or processed data, and through well defined rules for event recognition, for detecting specific events occurrent and notify the user or interested observers.

As functional units BIOSal has:

- a **SessionManager** which deals with created sessions from DataSources.
- a **Supervisor** which provides the interface between external entities such as observers, listeners and BIOSal framework. The Supervisor is responsible to perform all updates to his observers. Moreover, this entity controls the dynamics among the different modules as described below (3.3.2).
- a **Parser Manager**, responsible for loading plugins that implements the interface IParser using the Light Java Plugin Framework.
- a **ProcessorManager** and **AlarmsDetectionManager**, as ParserManager execute the same functionality, however for Processors and Alarms plugins, which implement repectively the interface IProcessor and IAlarmsDetection.

3.3.1 Session management

The Session Manager is responsible for managing all running sessions and providing an interface between entities who want to create, start or close a session. For the Session manager, the main concepts are DataSource and Locator. A Data Source is an entity that encapsulates the way you estabilish a connection with a particular source (e.g file or TCP/IP stream, Bluetooth stream). A DataSource class hides the way the connection details. Therefore Parser Plugins use the inputstream abstraction from DataSource for parsing. To deal with the DataSources there is an interface (DataSource) that defines the services to connect, disconnect, or send commands in order to get data. Each DataSource possesses a Locator. A Locator is an entity that holds an uniform resource identifier (URI). The URI is a name that identifies a resource on the Internet, and possesses flexibility to deal with different network protocols (eg. HTTP, FTP). In this context a simple way was achieved to identify each DataSource, by the flexibility to deal with different network protocols, in the possibility of using other protocols. For example, as described below (Figure 3.5) it is possible to init a session and afterward to obtain the sessions identifier, that will serve to initiate streaming from a given DataSource, a instance that implements the interface DataSource.

$ds \leftarrow newDataSourceImplementation()$
$sessionID \leftarrow SessionManager.initSession(ds)$
$session \leftarrow SessionManager.startSession(sessionID)$

Figure 3.5: Pseudo - Code explaining how to create a session.

3.3.2 BIOSal dynamics

The logic dynamics of BIOSal follows the Publish/Subscribe or Observer/Observable pattern, which basically allows entities, that wish to receive notifications/updates to register as observers/listeners of a particular observable. When it want to send an update, notifies its observers/listeners [57]. In our system, the listeners are any entity that implements Observer interface, and the observable entities must extend Observable class.

Each plugin module (Processor, Parser, AlarmsDetection) has a respective manager, which handles with plugins loading associated with a specific Interface, using the Light Java Plugin Framework. The show flow is controlled by an entity called Supervisor, and it is important to refer that there is one Supervisor for each connection with DataSource,

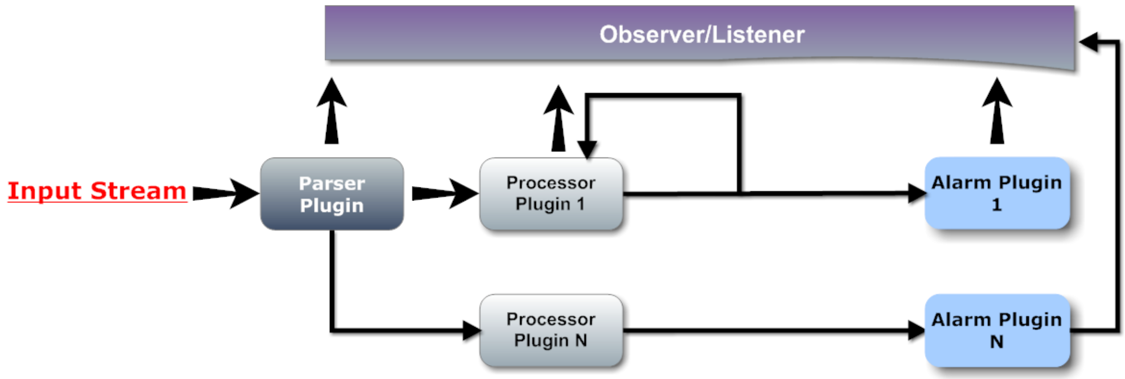


Figure 3.6: BIOSal dynamics.

this means that we may have multiple processing streams for the same DataSource, and consequentelly allow you to have multiple streams for different DataSources. Supervisor mediates the updates among BIOSal plugins and observers. Initially this entity has a service to start the data flow from an InputStream. When a session is started a reference of the InputStream is passed to ParserManager, corresponding to this session, therefore the ParserManager, contains a map of plugins that extends IParser interface. It selects all the plugins who may parse that Inputstream, and send to Supervisor, where it executes data parsing from a new thread. After filtering the data, the Plugin Parser sends the result to the Supervisor, which in turn, makes sure that the Processor plugins from the Processor-Manager will accept the result as an input. At this moment, a new thread is created to deal with the processing and transformation of the received data (this permits to Supervisor, stay availalbe for other updates). Finally, when Processor plugin generates a result, the supervisor is updated again. The Supervisor will ask again the ProcessorManager if there is another plugin processor that uses the received result as an input. This operating logic allows a chain processing betwen multiple processor plugins. Once all transformations are completed, the Supervisor, asks the AlarmsDetectionManager for alarms plugins that accepts the result data as input (like Processors and Parsers) . If Alarms plugins detect some abnormality, they notifiy the observers of BIOSal 3.6. In each step of the cycle, the Observers are updated, which discard the data if they do not need them. This process does not bring overhead since only an object reference is sent, and not a copy. For example, the ECG only needs to be filtered in order to be visualized, as opposed to the QRS Detector, which needs to process the calculation of the heart rate. After this, the heart rate can be used as an input of an alarm plugin to detect events such as tachycardia.

3.3.3 Internal data format

To answer the need of using several biological data types with different formats, we proposed a generic solution for the internal BIOSal data format among the components Parser, Processor and Alarms. Each DataFrame can have multiple DataTypes (Figure 3.7). Each DataType has an identifying tag to differentiate it from others (e.g ECG, pulse), and can have a series of values or a simple value. In the case of the pulse, there is only one value, and in the case of the ECG there can be multiple samples, depending on the ECGs sample rate (e.g. 500Hz). Because the DataFrame has several DataTypes, we can have multiple data types in the same structure (Figure 3.7).

Figure 3.7: BIOSal internal data format.

Chapter 4

DroidJacket: our TeamMonitor instance

To illustrate the TeamMonitor feasibility, we implemented an application - Droid Jacket - where we instantiated a TeamMonitor central node into an Android mobile device. Droid Jacket relies on BIOSal for accessing and managing the data flows to provide both the user interface and the processing facilities, which has several features (Figure 4.1):

- has a modular plugin structure based on a developed framework called BIOSal. BIOSal enables the implementation of plugins to process or relay the acquired data. For illustrating this feature we implemented a simple arrhythmia detector that processes incoming ECG streams.
- is able to gather information and monitor up to 4 operational firefigthers.
- provides the UI to visualize both vital signs and location information to track the first responders in the operational field.

4.1 Droid Jacket scenario

The Droid Jacket scenario has a more limited scope that the overall Vital Responder project as it is a proof of concept. Our focus will be more on the mobile device and its role as both data gatherer, processor and provider (Figure 4.1).

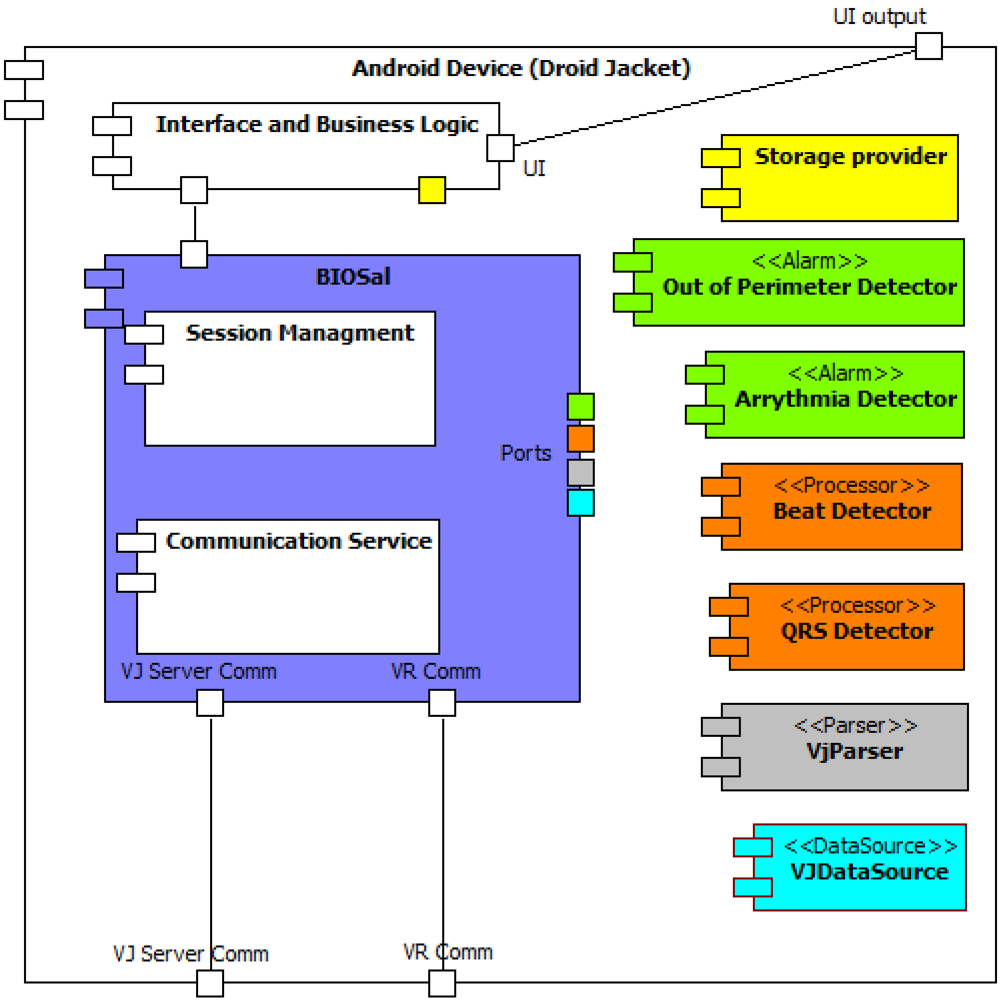


Figure 4.1: DroidJacket as TeamMonitor instance.

Our focus will be in providing a solution for the mobile base station (Figure 4.2), where the main components are:

- the Vital Jacket®.
- the VJ Server.
- the Mobile Base Station.

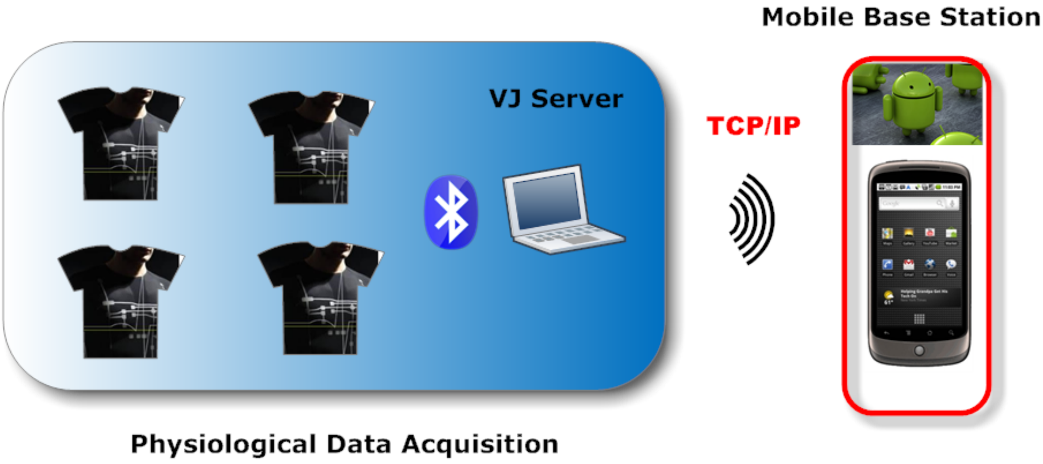


Figure 4.2: Droid Jacket monitoring overview.

4.1.1 The Vital Jacket®

The Vital Jacket® (Figure 4.3) is a wearable vital signs monitoring system and is compliant with EU directive 42/93/CE and produced with a ISO9001 and ISO13485 certified manufacturing process. It combines textiles with microelectronics providing a reliable physiological data for sports, clinical scenarios and emergency situations [9]. It is a system able to acquire, store and analyze offline data with its own proprietary software.

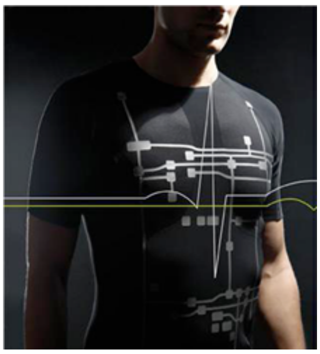


Figure 4.3: The Vital Jacket® [9].

4.1.2 The VJ Server

The VJ Server (Figure 4.4) is a framework developed by Biodevices S.A. that is responsible for combining the output of several Vital Jacket® boxes [9] (at the moment a maximum of 4 four devices connected simultaneously). It allows access to the acquired physiological data to external applications. This can be in real time connected boxes or offline by providing previously acquired/recorded/stored data on a SD card, suitable for simulation and development [9]. The connections to the Vital Jackets® are made via Bluetooth, where the access point handles at most seven slaves, while VJ Server provides its services through standard TCP/IP socket based API. Consequently, TCP has a mechanism to detect transmission errors and failures, as opposed to UDP, which has a quicker data exchange than TCP. Nonetheless, to ensure a datagram delivery service, a reliable mechanism should be implemented [58]. Considering data transmission over TCP/IP, using sockets is recommended, since it abstracts the physical and control protocols. Sockets are endpoints that permit bidirectional communications among processes across an IP oriented protocol.

Due to the commercial nature of VitalJacket® and VJServer (property of BioDevices S.A.) some details on the actual services available in both products are confidential (e.g. data message structure and communication event sequences) but accessible through a set of high level services which enable the listing of the existing devices, or start and stop the data streaming. VJ Server currently provides ECG (1 lead at 200 Hz), battery level and a set of observable events from low battery warnings to communication related notifications (e.g. lost connection, restarted connection). Details on the services and events are described in appendix B VJ Server Services and Events.

4.2 Why Android

From the beginning, it was established that the Droid Jacket application would be supported in the Android OS. Android OS is an open source mobile operating system and is currently supported by the Open Handset Alliance [59]. In spite of the fact that using Android was not an option but a requirement, there are several features from Android OS that were considered from the beginning and that were very relevant in the design and implementation of the Droid Jacket mobile application:

- support for multitasking and background services: this allows maintaining several threads executing simultaneously. For instance it is possible to have dedicated services to manage the connection while other deal with user interface interactions.

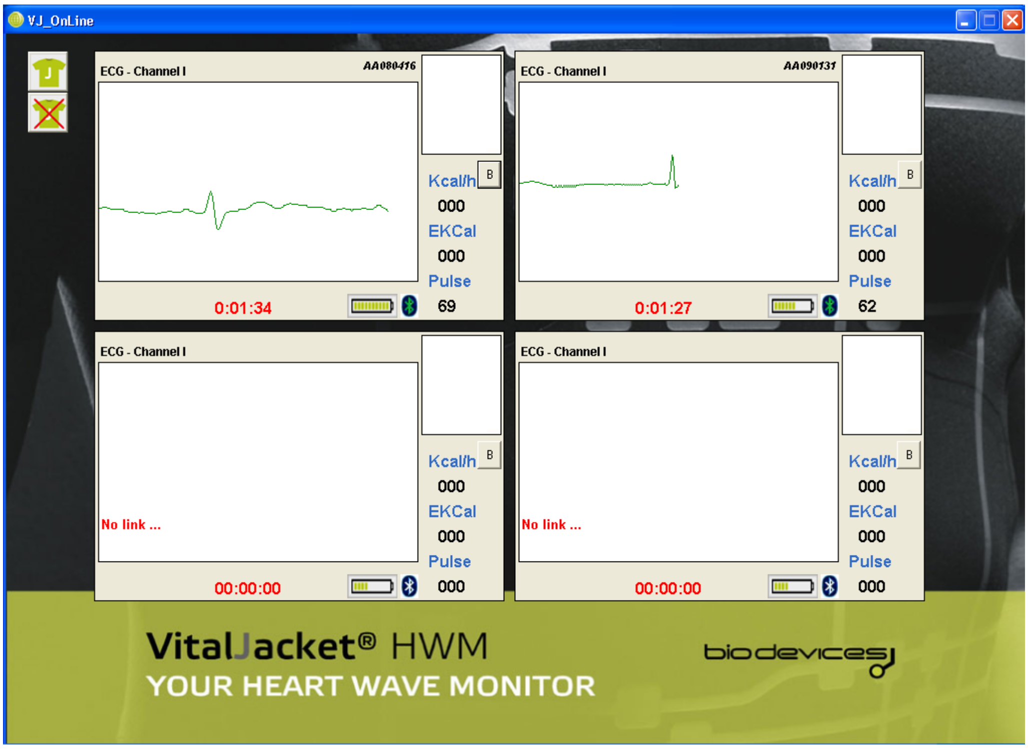


Figure 4.4: The VJ Server application.

- support for data storage: it natively supports a SQLite engine [60] relational database that can be used for data persistence and for data sharing within the mobile device.

- abstracts hardware and network resources: Android abstracts, through API's, the access to hardware devices such as camera, GPS, accelerometers, gyroscope and digital compass. Other services such as Audio, WIFI, Bluetooth and Telephony, also provide specific APIs for access.

- has data sharing mechanisms. The high level concepts of intents and Content Providers [61] [60] allow abstracting interaction between Android OS running components using uniform APIs. This is especially useful to decouple the data client from the data provider details at the Android OS level.

- is an open source framework. Android OS possesses a specific SDK (Software Development Kit).

4.3 DroidJacket: the application

Following the Android computational model [61] [60], Droid Jacket is structured in several activities that support user interface, and also in services, which handle BIOSal access.

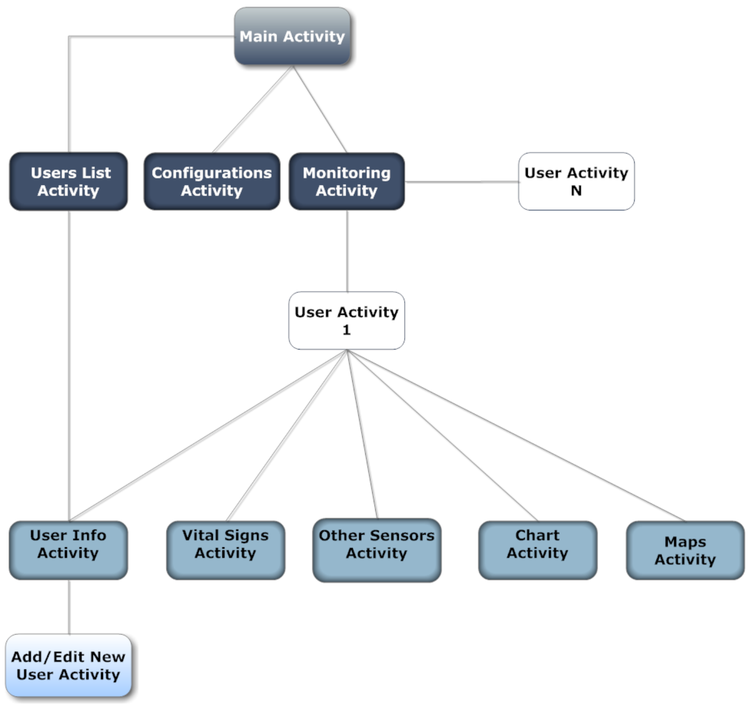


Figure 4.5: Droid Jacket actitivities.

The main Droid Jacket activities (Figure 4.5) are:

- **Main:** responsible for creating the others activities and used to perform operations such as to create a server socket TCP to act as a gateway between a data provider and an external application, in this case is the VJ Server.
- **Monitoring:** used to access the main functionalities of Droid Jacket using a tab based user interface. Each monitored user has an associated tab and maps location that is used for relative spatial positions between other field units.
- **Users List/User Info:** used to deal with users personal data, listing all users at the database (Users List), or typical users CRUD operations, such as insert (Users List), update (Users Info), and delete (Users List) user information.

In Droid Jacket there are also other components hidden from the user:

- **Storage services:** these are content providers, and are responsible for database management, namely to support data insertion/edition and removal from the database.
- **Main Controller:** this controller provides access to the BIOSal plugin framework to support adding new plugins to Droid Jacket.
- **SignalsService**: this service uses the BIOSal framework, that requires continuous processing, and accordingly to [61] [60] is a good choice. SignalsService uses the MainController to load a plugin implementation of the DataSource, the VjDataSource. Thereafter, a session is started with the previously loaded DataSource. BIOSal dynamics is started from a dedicated supervisor. Note that the service is registered as an observer of that supervisor, in order to receive updates of new alarms. When these alarms are received, the Notification Manager is used to warn the user.

4.3.1 Integration of BIOSal plugins in Droid Jacket

The connection to BIOSal is ensured by the Android service SignalsService (Figure 4.5). Activities that use this service are registered as observers/listeners for updates from parsers and processors plugins. In Droid Jacket any monitoring user interface activity can be bound with the SignalsService that supports the BIOSal main services. The services are responsible for communicating with BIOSal and, for example, start a session with our data provider by each activity.

4.3.2 The Droid Jacket user interface

A typical Droid Jacket user starts the application and a screen (Figure 4.6) appears. In order to access options, the menu button has to be pressed, where main options are shown.

Users

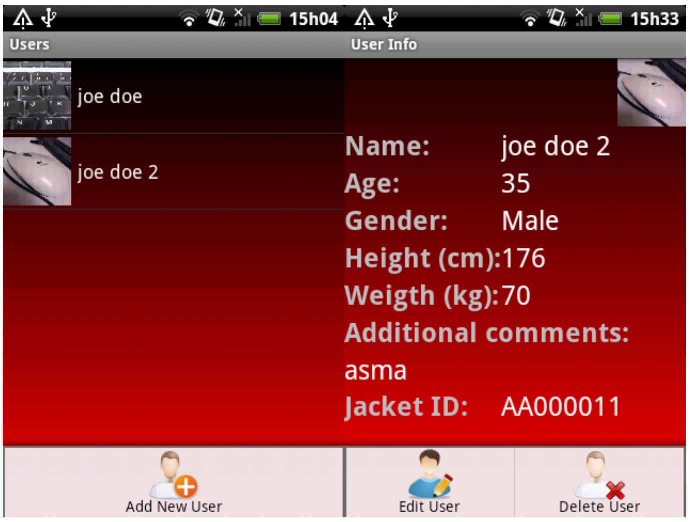
This previously mentioned option is responsible for users management. Initially, a list of all users appears, (Figure 4.7a). By pressing the menu button, we can add a new user, and the system shows a form. Once we entered all the information in the required fields, in our case the name and the Vital Jacket® device, we just click the Save option, the

Figure 4.6: Droid Jacket start screen (with menu button pressed).

information is stored in the database and consequently the users list is updated. Back to the users list, when we click on an user, his personal information is presented. To update or delete the user information, it is necessary press the menu button, and the update process is similar to insertion.

Monitoring

The Monitoring option allows data visualization by user, acquired from VJ Server, individually. The tabs at the top represent field units and their location (Figure 4.8). The tabs at the bottom are the main activities for the currently selected field unit from the top tabs. At the first bottom tab appears the user information (Figure 4.8), i.e. personal data, which permits edition. The second tab is prepared to receive and provide sensors updates such as the temperature sensor (internal and external), and also environmental values such as carbon monoxide, which, physically Vital Jackets® do not yet support. The next tab (Figure 4.8) was created to display vital signs as real time ECG and heart rate, performed by VitalSignsActivity. Finally, the last tab will show the evolution of the heart rate over time in a chart, using Chart Activity, but it is not implemented. One important aspect is how to implement the tabs mechanism. If each tab is represented by an activity, for



(a) Users list (b) User personal information

Figure 4.7: Droid Jacket users.

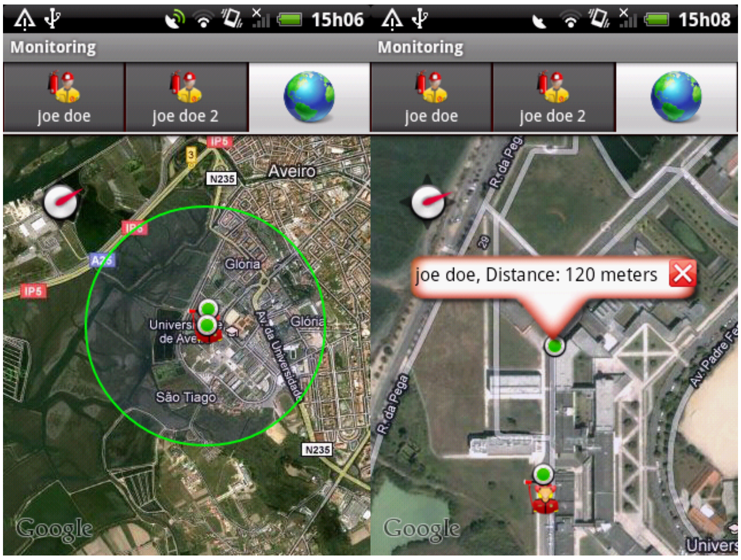
example monitoring four field units; we have 4 * 4 = 16 activities at once, which creates a noteworthy overhead on the application. To minimize this, instead of using activities, views was the option [60], thereby reducing the applications overhead.

(a) ECG display. (b) Others sensors values such as temperature and environment.

Figure 4.8: Monitoring view (vital and others signs).

Location visualization

One of the features that this system supports showing GPS locations of each unit currently being monitored (Figure 4.9a). Also the distance between the mobile device and the firefighter, as well as his name, can be shown. The mobile device is represented by the firefighter commander, since the units are represented by green pins. Another important aspect is the operational range, where the green circle (Figure 4.9a) defines the perimeter among the field units and the mobile device.

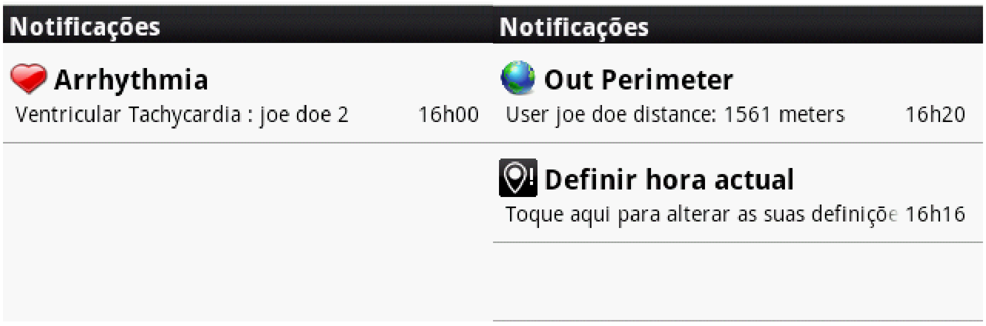


(a) Firefighters maps location (b) Distance between the field unit and the mobile device (represented by firefighter icon).

Figure 4.9: DroidJacket location view (vital and others signs).

DroidJacket notifications

The SignalsService receives alarms and triggers Notifications, using the Notification Manager from the Android platform (Figure 4.10a). An example of an arrhythmia event is shown, describing the type of an arrhythmia and the field unit name (Figure 4.10b). Another type of notifications is "Out of Perimeter" that sends an event when a field unit is out of range for a defined threshold, as explained above; in this example the raznge is one kilometre. Finally, a simple alarm notification related to the internal temperature is triggered, as explained below.



(a) Arrhythmia notifcation (b) Out of Perimeter notification

Figure 4.10: Droid Jacket notifications.

4.3.3 Plugins implemented in Droid Jacket

The BIOSAL modular architecture we implemented different plugins/modules:

- an arrhythmia detector that will be describe in more detail.
- a perimeter Plugin, defining if a team unit is out of that perimeter. This plugin was only was simulated, using static coordinates. A next version of our data source VJ Jacket® will possess GPS, so we only need to readapt the plugin for VJDataSource.
- a hyperthermia Plugin: this is a very simple plugin that detects if the internal temperature is greater than a pre-established threshold, typically 38.2 °C.

The role of the arrhythmia detector is to demonstrate that by using BIOSal in an Android mobile device it was possible to process the ECG while gathering incoming data from several sources and to provide alarms in critical situations in critical situations like arrhythmias episodes. There are several algorithms of arrhythmia detection that have been studied over the scientific community supported in methods like artificial neural networks, fuzzy networks, wavelet analysis, decision trees, nearest neighbor and others [38]. Some of these arrhythmia algorithms have been applied to mobile devices [58] [15] [62] [63] [12]. We selected the algorithm proposed by M. G. Tsipouras et al. [38]. The selection was based on some facts. It offers a satisfactory accuracy (around 95%), for a specific type of arrhythmias, and handles noisy environments because it only needs QRS complex detections as input. The algorithm is based on a knowledge based system [38] being able to provide fast response, enabling its use in an online processing solution. Nevertheless, this arrhythmia detector has some limitations as it is based only on the RR interval (distance between consecutive QRS complexes, that represent the ventricular contraction)(see section

2.1.1) as a result, the detection system just distinguishes among ventricular arrhythmias [38].

The arrhythmia detector is supported on several modules implemented as plugins that were also integrated in DroidJacket. The implemented implemented are:

- a QRS detector
- a beat detector.
- an arrhythmia episode detector.

Beat detector

The beat detector uses RR interval obtained from the QRS complex detector. The classification algorithm uses a sequence of rules as depicted in [38], in order to classify a type of beat between N (Normal), PVC (Premature Ventricular Contraction) and VF (Ventricular Flutter/Fibrillation). Basically the algorithm rules uses the previous, the current and the next RR intervals to classify the beat.

QRS detector

The QRS component in ECG signal has been widely used to characterize patterns and features in ECG [64]. This complex (Figure 2.2) can be used to characterize the ventricular contraction (see 2.1.1) of the heart and to be used, through its specific characteristics, in automated determination of heart rate [64]. This implies knowing the distance between two consecutive QRS complexes, so with ECG sample rate, the duration of the RR interval (Equation 4.1) and the instantaneous heart rate are easily calculated (Equation 4.2).

$$RRduration = QRSdistance \div SampleRate \tag{4.1}$$

$$instantaneousHeartRate = 60 \div RRDuration \tag{4.2}$$

Over the years several algorithms to perform QRS detection where presented using multiple approaches like artificial neural networks, wavelet transforms [65], filter banks and genetic algorithms. A good review can be found in [64]. One of the most common solutions is the Pan Tompkins algorithm [66] [67], which is extensively employed, well-known for satisfactory sensitivities and specificities near 99.5%. This was the method that we

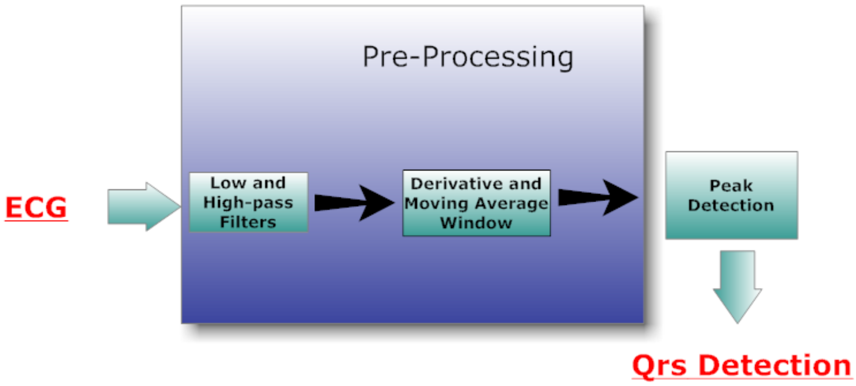


Figure 4.11: Qrs detector

selected to implement in our system. From this method output we also perform heart rate estimation.

The QRS complex has a frequency spectrum betwen 10Hz and 25Hz [64]. The algorithm in [67] applies two digital-filters to remove particular components such as P or T waves and some noise artifacts. It then uses a combination of slope information extracted from the derivative, a square transformation and a moving average, being that the last one helps removing larger signal oscillations. The peak detection is accomplished with decision rules (pseudo code below) using adaptive threshold estimation (Equation 4.3). A detailed description is provided in the original proposal [67] [68].

$$NEWTHRESHOLD = NOISEMEAN + COEFICCIENT \times (NOISEMEAN - QRSMEAN) \quad (4.3)$$

for $eachECGSample$ **do**
  $newPeak \leftarrow detectLocalMaxPeak(sample)$
  if $newPeak > 0$ **then**
    if $newPeak > threshold$ **then**
      $saveAsnewQrsComplex()$
      $updateQrsMean()$
    else
      $saveAsNoise()$
      $updateNoiseMean()$
    end if

$threshold \leftarrow thresholdestimation(qrsMean, noiseMean)$

end if

end for

An arrhythmia episode detector

In the waveform classifier, each beat is classified and used in the arrhythmia episode detection using (Figure 4.12) a deterministic automaton, which analyzes the sequence of beats, determining if an arrhythmia occurs, the beginning and the end of an episode as well as their designation.

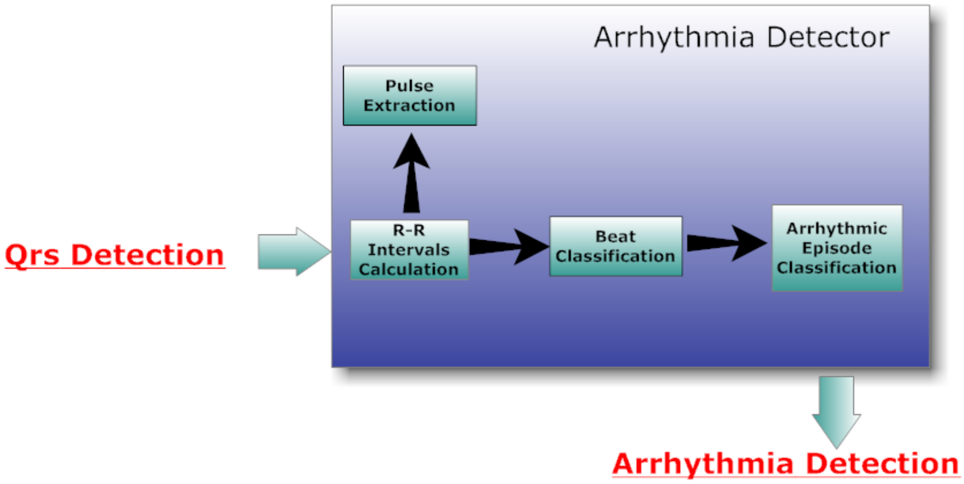


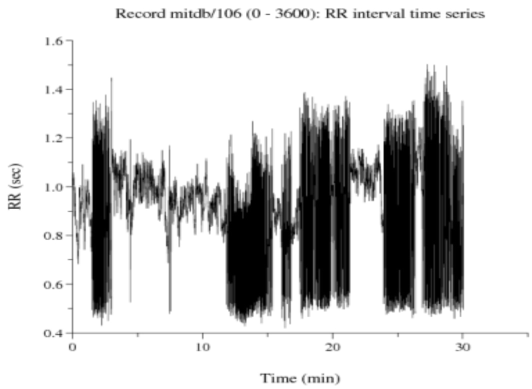
Figure 4.12: Arrhythmia detector based on RR interval duration.

QRS detector validator

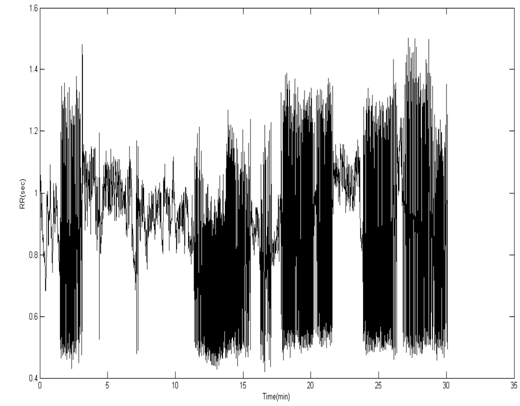
The following tests were performed (Table 4.1) only to validate the implementation, since the method has already been studied [67] [68]. These tests were performed considering the removal of certain samples of the original signal (RR intervals by MIT-BIH arrhythmia DataBase) when a beat is not detected, or falsely detected from our implementation, with the purpose of synchronizing the two signals, for correlation calculation.

Beat classification

As demonstrated in [38] no tests were performed, considering beat classifications using as input the RR intervals from MIT-BIH arrhythmia database. With the purpose of

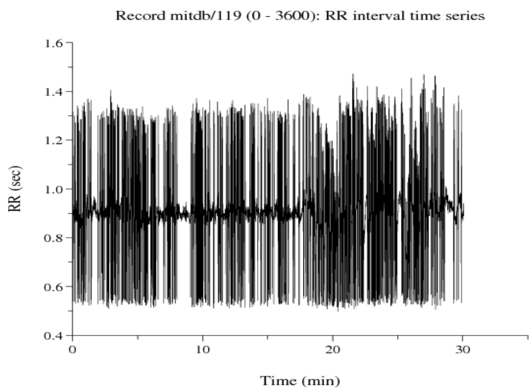


(a) RR Intervals acquired from MIT-BIH arrhythmia database (dataset 106).

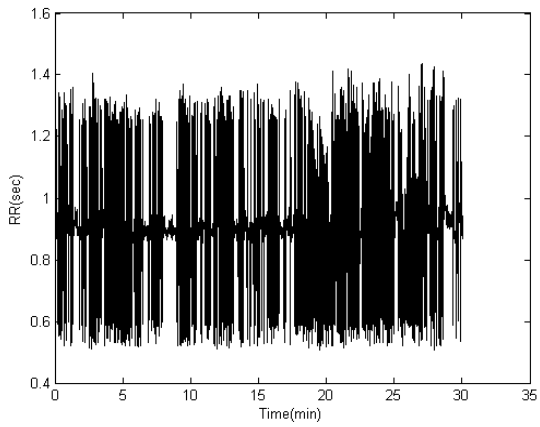


(b) Our QRS detector output (dataset 106).

Figure 4.13: Comparison between RR Intervals acquired from MIT-BIH arrhythmia database and our QRS detector output (dataset 106).

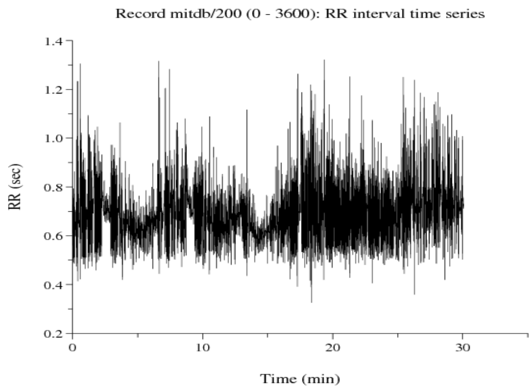


(a) RR Intervals acquired from MIT-BIH arrhythmia database (dataset 119).

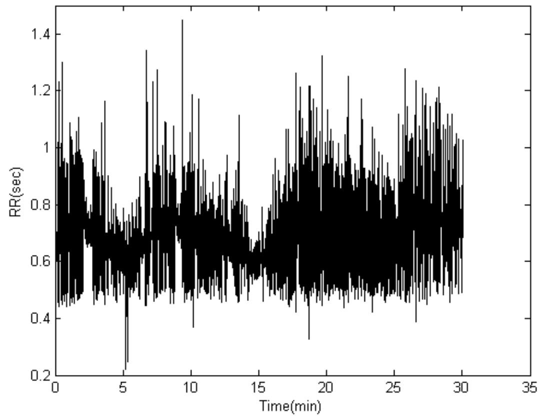


(b) Our QRS detector output (dataset 119).

Figure 4.14: Comparison between RR Intervals acquired from MIT-BIH arrhythmia database and our QRS detector output (dataset 119).

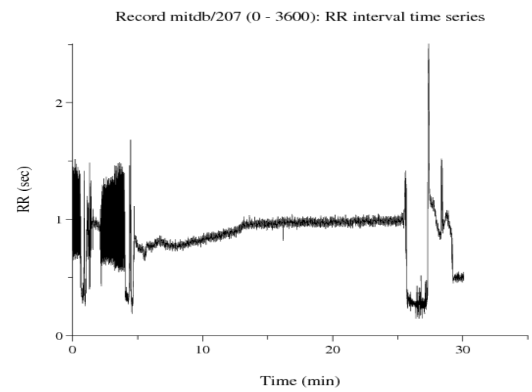


(a) RR Intervals acquired from MIT-BIH arrhythmia database (dataset 200).

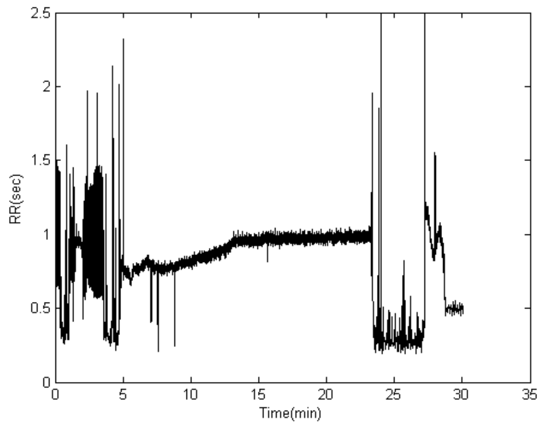


(b) Our QRS detector output (dataset 200).

Figure 4.15: Comparison between RR Intervals acquired from MIT-BIH arrhythmia database and our QRS detector output (dataset 119).



(a) RR Intervals acquired from MIT-BIH arrhythmia database (dataset 207).



(b) Our QRS detector output (dataset 207).

Figure 4.16: Comparison between RR Intervals acquired from MIT-BIH arrhythmia database and our QRS detector output (dataset 207).

Dataset	Number of beats	True negatives considered	False positives considered	Correlation
106	2027	4	0	99.62%
119	1987	0	0	99.75%
200	2601	4	4	98.61%
207	2251	60	30	92.35%

Table 4.1: Correlation analysis between RR Intervals aquired from MIT-BIH arrhythmia database and our QRS detector output.

Dataset	N		PVC		VF	
	Sensivity (%)	Specificty (%)	Sensivity (%)	Specificty (%)	Sensivity (%)	Specificty (%)
106	98.64	99.81	99.81	99.84		
119	98.90	100	100	98.90		
200	93.91	95.49	94.79	93.97		
207	100	100	95.24	95.81	42.9	100
Total	97.86	84.53	97.41	96.71	42.8	99.92

Table 4.2: The beat classification performance.

evaluating that, tests were done, considering the sensitivity and specificity of arrhythmic beats detection algorithm (Table 4.2).

4.4 Application tests and results

In the Droid Jacket application tests, we considered following some scenarios. We used Droid Jacket as a Server (connected to VJ Server) used to understand the scalability of the Droid Jacket as a gateway module and monitoring unit.

Droid Jacket as server and monitoring scalability

All tests were performed using real time data streaming originating from a file.

- Test 1: ten simultaneous external connections requesting ECG signal and Droid Jacket working in the server mode.
- Test 2: ten simultaneous external connections requesting ECG signal and the Droid Jacket monitoring four simulated units at the same time.

- Test 3: ten simultaneous external connections requesting ECG signal, the Droid Jacket working in the server mode and Droid Jacket monitoring ten simulated units at the same time.

  The tests were successful, proving that this system is scalabe, since a mobile device can work as a node of a network and monitor signals at the same time.

4.5 Final considerations

In order to make a final balance/assessment of all work's scenario, a SWOT (Strengths, Weakness, Opportunities and Threats) analysis was done (Figure 4.17).

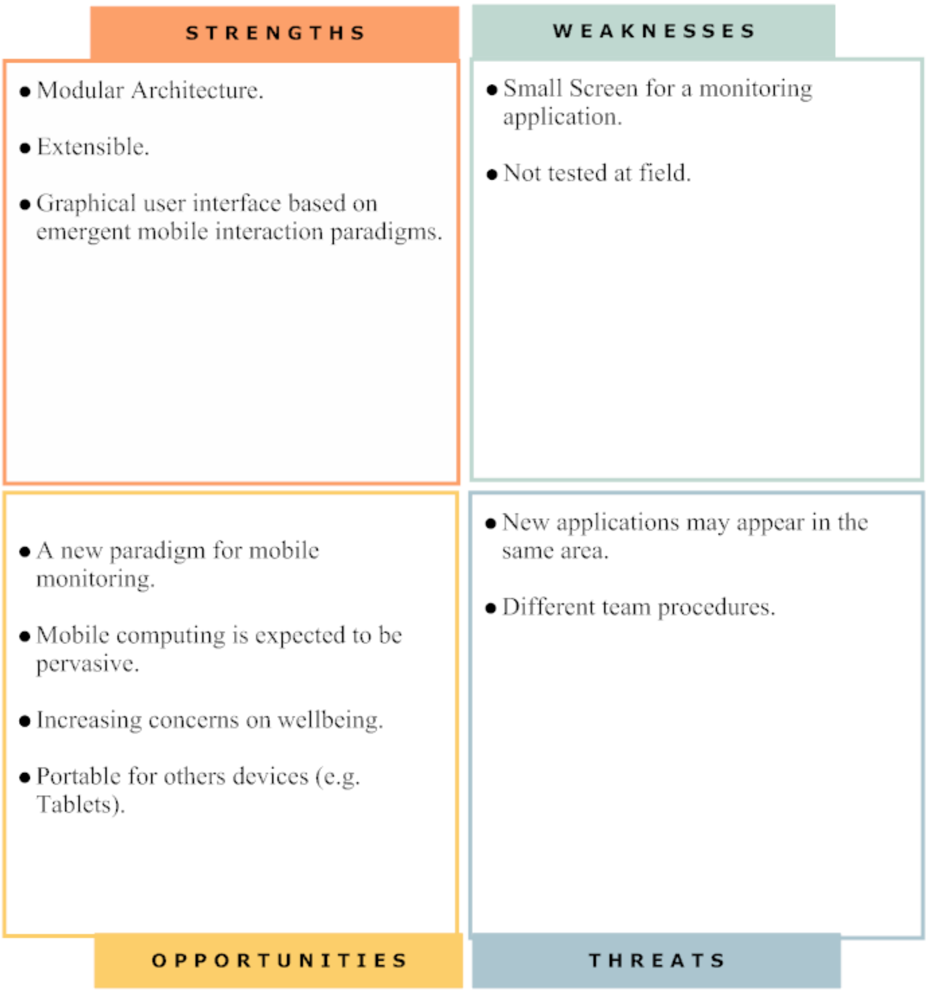


Figure 4.17: SWOT analysis.

From the SWOT analysis we can have an overview of the potentiality of a system like this. Although the main focus of this dissertation was to define an architecture supported by a modular framework for signal acquisition, session management, integration of processing and alarms, that is promissing for installation in several environments in different platforms (running Java based applications), since desktop to mobile systems. The application turns out appellative, despite having the screen size limitation for the signal monitoring and the implementation of small processing modules. Other types of tablet devices might be a threat to this. The application still requires exhaustive testing, especially on the field.

Chapter 5

Conclusions and Future Work

We designed a conceptual architecture called TeamMonitor to support scenarios where monitoring multiple individuals is needed. As proof of concept we described the Droid Jacket, an Android application that follows the TeamMonitor design. Choosing Android allowed us to implement modules in Java that could be reused in any Java environment. The concept of implementing deploying modules from a standard workstation to the Android mobile device was a reality (e.g. BIOSal). A modular architecture was developed, thinking about future developments, including an oriented high-level programming approach. By defining concepts such as bridges, drivers, detectors and data stream providers that were directly mapped into Java interfaces and/or reference implementations without platform specific concerns allowed our solution to be extensible. However, the setup still lacks specialization to be applied in operational environments but already demonstrates the basic concept: acquiring a team status in a distributed environment and being able to monitor and determine relevant conditions in real time either visually or automatically - in our case using beat classification and arrhythmic episode detection [38]. To our knowledge, there are many mobile monitoring applications, including solutions that use the latest smartphones [63] [69] that monitor vital parameters of an individual. However there are very few [18] that make use of smartphones to monitor multiple individuals, taking advantage of the fact that mobile operating systems support multi-threading. As future work we are already addressing open issues identified in Droid Jacket: managing storage, namely keeping an historical record of data and events more efficiently; providing a general data format, where a good review of most common signal data formats can be found at [70]; propagating urgent information; and support for offline analysis of the ECG to support more thorough analysis (e.g. more complex algorithms, use other computational resources). Considering ongoing evolutions of the Vital Jacket®, it is our goal to integrate other physiological measures in the system alarms and processing. Examples are oxygen saturation by pulse oximetry (SPO2), respiration, temperature, movement, posture, galvanic skin response (GSR) and blood pressure, which are already being integrated in the new wearable prototype. With these improvements we plan to extend the Droid Jacket from the status of proof of concept to an operational solution, namely by extending the simple cardiac abnormalities detector to more specific and high level services that allow detecting more complex mental and physical status that can be used as indicators of stress.

Appendix A

The Light Java Plugin Framework

In this appendix will be introduced more implementation details of a modular framework for dynamic loading of new plugins. For a better understanding at how this loading is done, it is necessary to present the main entities that manage this:

Plugin Controller: the principal entity of this framework, responsible for external access to the API, loading and making available plugins, only needing an uniform resource indentifier (URI) to be accessed. After that it will select the respective Gatherer, Class-Gatherer in the case of classPath URI, File Gatherer for directories, jar and .class files, and finally HTTP for remote files. Each entity will load classes and their dependencies, using the Java Reflection API [71]. Java Reflection is an API that allows Java to expose all class information during runtime, from field to methods. Afterwards each class and its features are associated with a plugin that is registered at the Plugin Register.

Plugin Register: is responsible for plugins mapping, so users through Plugin Controller may obtain new instances of a particular plugin interface. An advantage is that we can plant new plugins at external locations, loaded at runtime in our application. The Plugin Register also has a caching mechanism, to avoid loading plugins several times during application's execution. After all plugins were loaded, Plugin Controller through Plugin Register provides access to instances of loaded plugins, specifying only the interface.

A.1 How to use the Light Plugin Framework

The pseudo-code shows how to load plugins from different modes respectively such as a class file, a folder containing class files, directly a JAR file, remote file, or .class files from Classpath (Figure A.2).

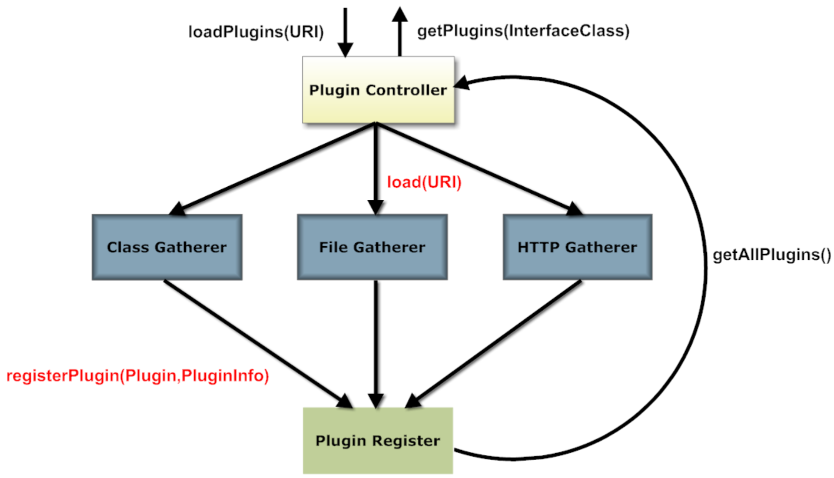


Figure A.1: Light Plugin Framework dynamics

$pc \leftarrow PluginControllerFactory.createPluginController()$
$pc.loadPlugins(URIClass.toURI(ImplementationClass))$
$pc.loadPlugins(newFile(\text{"}testplugins/\text{"}).toURI())$
$pc.loadPlugins(newFile(\text{"}testplugins/plugin.jar\text{"}).toURI())$
$pc.loadPlugins(URIClass.toURI(\text{"}https://spideroak.com/storage/plugin.jar\text{"}))$
$pc.loadPlugins(URIClass.toURI(\text{"}classpath://*\text{"}))$

Figure A.2: Pseudo - code explaining different ways for loading plugins

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To access the loaded plugins, it is only required to get an instance of PluginController call one of its services, getPlugins(): always returns the same instance, opposed to getNewInstancesPlugin(), which always returns a new instance (Figure A.3)

$pc \leftarrow PluginControllerFactory.createPluginController()$
$PluginsList \leftarrow pc.getPlugins(InterfaceClass))$
$PluginsList \leftarrow pc.getNewInstacesPlugin(InterfaceClass))$

Figure A.3: Example of how to get a Plugin

Appendix B

VJ Server services and events

Commands	Command Replies
getDevicesList()	Lists all the devices connected to the VJ Server (up to 4 at same time)
Start(Device, ECG, Events)	Starts to send the ECG data and/or Events related to the selected device.
Stop(Device, ECG, Events)	Stops to send ECG data and/or Events related to the selected device.
getBattery(Device)	Reads the battery level from specific device.

Table B.1: High level VJ Server avaliable commands.

Events	Observations
LowBattery (Assynchronous event)	When the battery level is low the VJ Server returns a message.
LeadDisconnected	When the a lead connected to VJ box is disconnected the VJ Server returns a message.
VJBoxDisconnected	When the VJ box is disconnected, the VJ Server returns a message.
VJBoxReconnected	When the VJ box is reconnected, the VJ Server returns a message.

Table B.2: High level VJ Server available events.

[1]

[1] ECG Data is sent in block (number of samples equals to sample rate (200 Hz in our case)

Appendix C

Droid Jacket

In this appendix will be explained with more details the Droid Jacket application packages.

Maps Package

The Maps package is responsible for all operations that deals with location services and providing all necessary support for units location and visualization. This package has the entities to create map views, from icons to balloons. In this case, the GPS coordinates from units are simulated, where notifications are activated by the Maps Activity, however when we use real GPS coordinates, monitoring and alarms notifications will be triggered by SignalsService (Figure C.1) like ECG from VitalJacket®, integrated with BIOSAL. Signals Services will receive positions through BIOSAL, and a out of perimeter notification may arise, by distance calculation amid the mobile device and a firefighter, where it must be under a defined perimeter. Notifications will be generated by the Notification Manager. Meanwhile maps will receive all GPS positions (Figure C.1), to exhibit them on a map.

Open GL Package

The Open GL package is responsible for the entities that control the graphical processing with the purpose of drawing vital signs as ECG. In order to perform this task, we used the Open GL ES 1.1 [61] [60], a low level API to create graphics, a subset of the Desktop version, widely used in mobile operating systems. A dedicated ECG renderer was implemented in order to accomplish the real time ECG display. At Droid Jacket, a monitoring activity creates an ECG renderer, that extends a generic Renderer. When it is

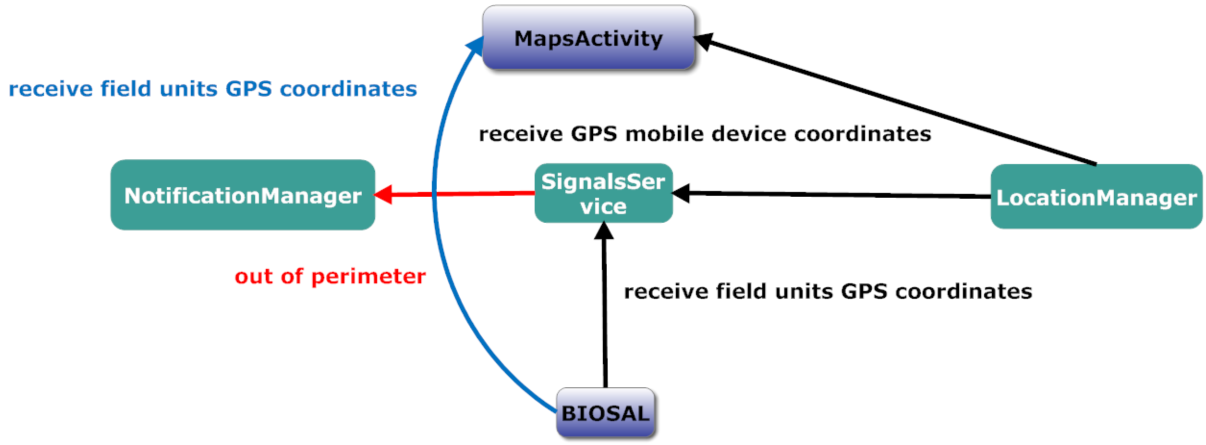

Figure C.1: Interaction between BIOSal and Maps Activity.

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created it is passed to Gl Surface View, a view responsible to access Open GL ES services and display graphics at the mobile device screen (Figure C.2).

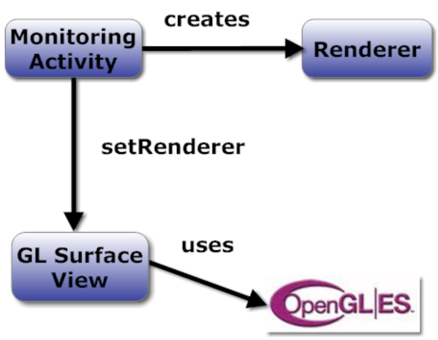

Figure C.2: Interaction between Monitoring Activity and Open GL ES.

Charts Package

The package is responsible for the charts, we used a previously developed API charts for the Android platform [72].

Units Package

The Units package is responsible for dealing with personal information about each team unit, and to create an adapter model between the database and the object entities.

Server Package

The Server package was created to provide the Server mode feature and socket connection with a DataSource. This feature appeared with the need of a possible client that has connectivity to a mobile device, to access it. To achieve this, a mechanism was created, a local ServerSocketHandler that receives requests from clients to provide data. When a request is received, it creates a Socket Wrapper (a thread entity) in order to handle the connection between the DataSource and a client, working as a data relay (Figure C.3). A simple connection with a DataSource is done by ConnectionSocket, an unit that hides all details of the server connection, since we only know the IP address and port.

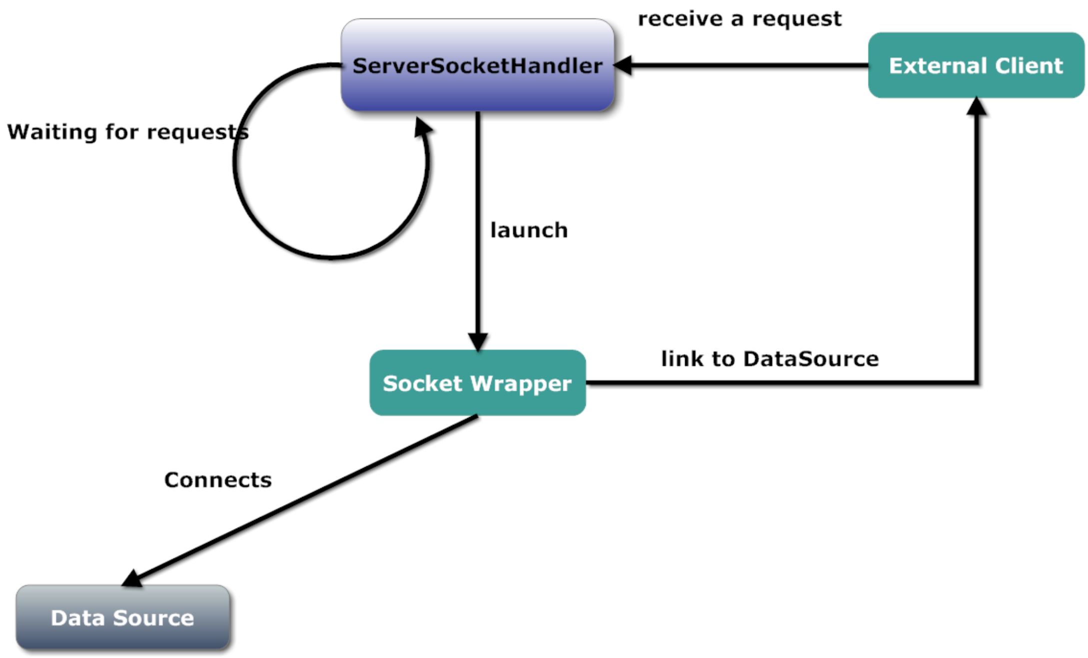

Figure C.3: Mechanisms behind Droid Jacket Server Mode.

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