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A Sudden Death Prevention System for Babies

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Abstract

The growth of the smartphones market share has driven the entry of a large number of new opportunities to launch new applications/mobile tools both by companies but also by individuals' entities. The prototype solution presented here fits in the increasing emerging of smartphones applications for the health sector.

This dissertation presents a solution to prevent a sudden infant death syndrome. It includes biofeedback monitoring of babies, using body sensors to collect data that will be presented in two different mobile applications: the Main Application and the Client Application. Breathing, temperature, position, and heart rate are used, and placed to the baby's body.

The Main Application will receive the data collected by the sensors via Bluetooth. This contains a monitoring tool, which parses and transforms raw data to be readable and understandable for users. This application will send the data to a Web service to be stored in a database that supports the entire created solution. The Client Application will consume the data stored in the database every previous second.

Both applications have an important functionality that allows the trigger of alert notifications when an error occurs with the data collected by the sensors and the caregiver is informed with an alert in a short time.

This document describes in detail the whole process done to deploy a prototype that demonstrates and validates the proposed solution and is ready for use.

Keywords

Sudden Infant Death Syndrome (SIDS), Infant Death Prevention, Body Sensors, Shimmer, e-Health, Healthcare Application, Biofeedback Monitoring, Android, Mobile.

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Acronyms

ADT	:	Android Developer Tools
BAN	:	Body Area Network
BCU	:	Body Central Unit
BPM	:	Beats per Minute
BS	:	Base Station
BSN	:	Body Sensor Network
BSUs	:	Body Sensor Units
CA	:	Client Application
CES	:	Consumer Electronics Show
dB	:	Decibel
ECG	:	Electrocardiography
EEG	:	Electroencephalography
EMG	:	Electromyogram
EU	:	European Union
GB	:	Gigabyte
Ghz	:	Gigahertz
GSM	:	Global System for Mobile Communications
GSR	:	Galvanic Skin Response
HR	:	Heart Rate
Hz	:	Hertz
IDE	:	Integrated Development Environment
IEEE	:	Institute of Electrical and Electronics Engineers
IT	:	Information Technology
LED	:	Light Emitting Diode

MA	:	Main Application
MAC address	:	Media Access Control Address
mAh	:	Milliampere hour
MHz	:	Megahertz
mm	:	Millimeter
NTC	:	Negative Temperature Coefficient
PHP	:	Personal Home Page
QoL	:	Quality of Life
RFID	:	Radio Frequency Identification
RMS	:	Root Mean Square
SHA1	:	Secure Hash Algorithm-1
SHIMMER	:	Sensing Health with Intelligence Modularity, Mobility and Experimental Reusability
SIDS	:	Sudden Infant Death Syndrome
SMS	:	Short Message Service
SN	:	Sensor Network
SQL	:	Structured Query Language
UML	:	Unified Modeling Language
UMTS	:	Universal Mobile Telecommunications System
V	:	Volt
WBAN	:	Wireless Body Area Network
WPAN	:	Wireless Personal Area Network
WS	:	Web Service
WSN	:	Wireless Sensor Network

1. Introduction

This chapter introduces the topic addressed in this dissertation and describes the work performed to contextualize the concepts and all the difficult processes involved on this proposal. Section 1.1 describes the focus and the main idea of this work, in Section 1.2 is presented the problem definition, while Section 1.3 clarifies the objectives of the solution presented in this document. The main contributions of this work and the corresponding articles are presented in Section 1.4.

This dissertation includes seven chapters where it can be read a brief summary of each in Section 1.5.

1.1. Focus

The sudden infant death syndrome (SIDS) is the leading cause of death of children aged one to 12 months in Western countries. According to the latest statistics, in Europe die each year about 5000 babies victims of this syndrome. The occurrence of SIDS rarely happens in the first month of life, being more frequent between the two and four months age. Between 80% and 9% of the deaths occur between the first and sixth month of life. Five percent of the deaths occur between six and twelve months. After the first year of a baby's life, sudden death can happen, but with a much smaller probability [1].

About 2300 of the babies in Europe die of SIDS every year [2]. In most countries, infant mortality is low and there is little difference in rates (Figure 1). A small group of countries, however, has infant mortality rates above five deaths per 1 000 live births. In 2010, rates ranged from a low of less than three deaths per 1 000 live births in Nordic countries (with the exception of Denmark), Portugal, Slovenia and the Czech Republic, up to a high of 9.8 and 9.4 in Romania and Bulgaria respectively, and 13.6 in Turkey. Infant mortality rates were also relatively high (more than six deaths per 1 000 live births) in Serbia and the Former Yugoslav Republic of Macedonia. The average across the 27 EU member states in 2010 was 4.2 deaths per 1 000 live births. Infant mortality rates tend to be higher than the EU average in central European countries, with the exceptions of the Czech Republic and Slovenia, both of which have had consistently lower rates [3].

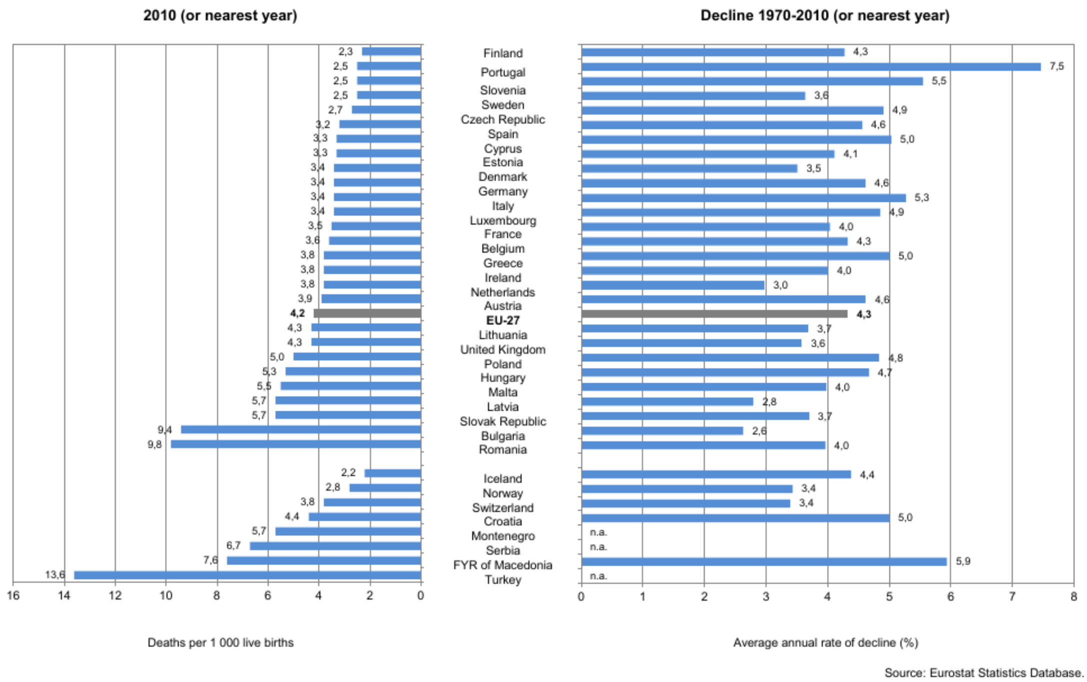


Figure 1 - Infant mortality rates, 2010 and decline 1970-2010 [3].

The phenomenon also exists in Portugal but it is unknown if it occurs. A Portuguese retrospective study showed an increase in the number of cases from 1974 to 1990, with a decrease from 1992. There was a notorious predominance of male babies, between 1 and 4 months, in the months of December to March, on weekends, at home in periods of sleep and night [4].

This emerging reality presents major challenges and opportunities for new and innovative health care services for this cause that is SIDS. The information technology (IT) has tried to create new and increasingly efficient solutions to foment the prevention and prevent this harsh reality that still haunts the lives of many families worldwide. These solutions aim to provide a better lifestyle for babies, as well as their responsible, making possible that their lives are accompanied in real time, from a distance, without disregarding the well-being, security and preventing major threats, calling the babies to their relatives without having to always be around.

Currently there are already many solutions on the market to prevent SIDS, but they are expensive and incomplete. Since detection sensors and measurement of CO_2, crying, video surveillance detection, temperature sensors, sensors for measuring heart rate and breathing. All these innovative technologies allow improvements in prevention and significant improvements in terms of quality of life (QoL), reducing the deaths and increasing monitoring of parents to their babies. These technologies also allow a better and more efficient study on this syndrome continues without concrete explanations.

They are beginning to also appear many solutions with textile sensors embedded in clothes that are more practical and comfortable for babies, but they're still expensive which makes it impossible for some families to obtain them. Last year were presented several innovative solutions at the Consumer Electronics Show (CES) in Las Vegas, where 2014 are also presented in this document in chapter II.

This type of sensors and solutions are very important, once they help the people who use them by detecting any unusual data and collecting it, and immediately send an automatic text message alert. This is the purpose of the solution: having the baby continuously monitorized, allowing the responsible to know about any suspect data.

This dissertation presents a solution created to provide health monitoring (Illustrated in Figure 2). This proposal considers two applications which together make it possible to observe the vital data of the baby remotely and allows the identification and prevention of greater threats.

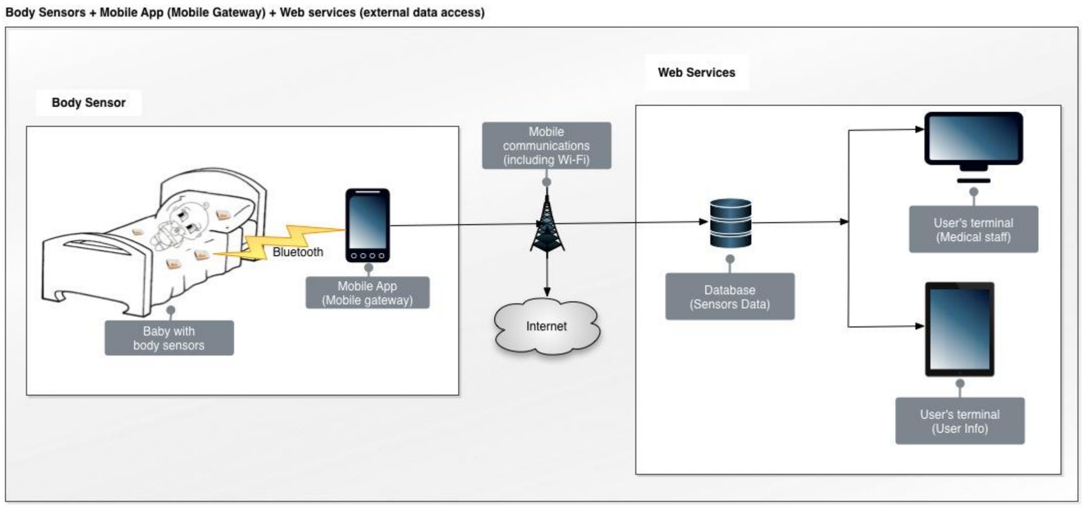


Figure 2 - Illustration of the system architecture for prevention and monitoring system with the three tiers (body sensors, storage, and Web services).

This mobile solution can reduce the time of alert and intervention in situations of risk. The relationship between mortality and time delay in treatment is a critical factor because the continuous monitoring of bio-signals promises to improve traditional health in many ways. The health data collected and stored may offer doctors a more complete understanding of health and provide a historical analysis of the parameters collected, as well as a faster response in emergency situations. This solution can be incorporated in two mobile devices such as a smartphone or a tablet, where one of them is the Main Application (MA) and in another the Client Application (CA).

The focus of this application is to make it the most complete application possible and to make it accessible to as many people as possible which makes it possible to save many babies from this unexplained phenomenon and which continues to haunt the lives of many couples throughout the world which is the SIDS.

1.2. Problem Definition

Sudden death in babies is something difficult to explain because no one knows its origin in most cases [5]. Sudden death has several causes that can be prevented, but others not, and in certain cases are fatal [6]. There are new challenges to offer a larger and better quality of life for both parents and babies.

Based on this, considering a real scenario using mobile technology, this paper proposes a system that tries to predict and detect situations that evaluate the risk of a baby and alert those are responsible by her/him or even competent authorities. The system emits an alert, in real time, so nannies can react immediately, check the baby state, and intervene if needed. The alert signs are issued through a smartphone or tablet. Body sensors, used for measuring physiological signals from a baby, are connected to the mobile device via Bluetooth and Wi-Fi.

The sensors are attached to the baby body and placed at the crib to have more accurate data for monitoring signals as heart rate, cradle temperature, baby's position and baby's breath. The mobile health tool monitors a baby and communicates through Bluetooth with a mobile device, in real time. The mobile devices display the data of each sensor and execute algorithms created to analyse the received biofeedback signals. If any issue with the baby is detected, the system notifies the person responsible by him/her immediately [7].

The document focuses on a methodology for the sudden death prevention in babies based on biofeedback and crib environment monitoring, and data processing using a combination of multiple sensors (heart rate, respiration, temperature, and position).

1.3. Objectives

The main objective of this dissertation is to build service prevention/monitoring for mobile environments, with the integration of body sensors in order to prevent the sudden infant death syndrome. The solution will be deployed on Android OS.

This product offers a consistent and robust solution for mobile health environments, using a system and simple adaptation proposal. The system will provide bio-feedback information via Internet. Also features alert notifications and messages so that the responsible for the baby can handle more quickly if something happens.

In order to achieve this main objective, the following partial objectives were proposed:

- Perform a study of the state of the art in mobile health applications, body sensors, and available approaches for interpretation of the babies data collected;

- Proposal and implementation of a mobile E-Health solution for the prevention of sudden death of babies for mobile environments;

- Creating a dataset with the data collected by the sensors, to serve as a basis of future studies;

- Demonstration, performance evaluation and validation of the proposed solution in various mobile devices.

This research hopes to produce two applications, one of them to receive, interpret and show the data collected from the sensors and another one that will serve for the baby's parents (or other that take care of babies) to follow the at distance. This query is possible because the values are being received and interpreted by the first above-mentioned application and being stored in a database which will support both applications. This database will have two objectives, both supporting both applications and making it possible to have a dataset with data collected to provide data for her studies.

1.4. Main Contributions

This section presents the scientific contribution of this dissertation for the solutions for the prevention of sudden death of babies.

This contribution includes a robust solution, adaptable in infants and of easy interactivity with the users that are responsible for the babies. This solution was thought to make it possible for parents monitoring their babies from a distance and know some of its physiological data through an Android device. It is made up of several boldly sensors of bio-feedback that collect data that will be visible both in the Android device that must be present close to the baby and also through other devices, where these are enough to have an Internet connection and the application developed.

After the data collection by the sensors, they are transferred via Bluetooth and analyzed by the mobile application, stored in the database that was developed to support the solution. This solution will allow having a continuous monitoring of the baby and its physiological data and also for future studies.

A paper with this contribution entitled “A Mobile Healthcare Solution for Ambient Assisted Living Environments”, was presented at the 16th International Conference on e-Health Networking, Applications and Services (IEEE HealthCom 2014), Natal, Brazil, October 15–18, 2014.

1.5. Dissertation Structure

This dissertation is organized in seven chapters, as follows.

This **Chapter 1** – **Introduction**: it presents the scope and motivation behind the work described in this dissertation, and the problem addressed and objectives.

Chapter 2 – **Related Work**: contains a review of the related literature addressing available solutions based on mobile sensors for health, in particular for the prevention of sudden death.

Chapter 3 – **Requirement Analysis**: is dedicated to software engineering solution developed throughout this work. It contains the analysis of requirements, use cases identifications and discussion of some possible activities to carry out in the applications developed and class diagrams. It also includes the discussion to the components diagram and for modeling and construction support base to the solution.

Chapter 4 – **Devices and Sensors Used on the Prototype**: it introduces and discusses all the devices and sensors used on the two prototypes and their relevant technologies, as well as photographs of equipment's used in the prototypes and their technical specifications.

Chapter 5 – **Mobile Solution Demonstration**: Here is made a presentation of the applications built in this dissertation, since the registration and authentication in the same, through the collection of data and your query to the visualization of text messages and notifications that are generated to alert of problems.

Chapter 6 – **System Validation and Performance Evaluation**: it This section describes the results of the solution built in this dissertation used on the tests, and focuses on the performance validation and evaluation of the solution.

Finally, **Chapter 7** – **Conclusions and Future Work**: it reviews in an argumentative way, all the work developed along this dissertation, considering the conclusions and challenges for future developments.

2. Related Work

Before performing any work, being it scientific or not, it is important to know what there is in the market in order not to develop exactly some solutions that already exist. The purpose of this type of work is to improve existing products/solutions, and can be improved the technological, scientific and others.

It is important to present some related work to subject that is being addressed and that is what is done in this chapter. An important reference to keep in mind is that there is a lot of information about some subjects, where sometimes the information becomes obsolete, as the rapid evolution of technologies. However, that's an excellent point and leads to the development of new technologies, techniques and solutions.

This chapter presents the literature related to solutions for prevention of SIDS. Starting with an introduction in section 2.1, to know the types of networks of existing sensors, already in section 2.2 are presented examples of health sensors. Finally in section 2.3 appears a little conclusion on all the technologies presented here.

2.1. Introduction

Over the years gradually we have heard a lot about sensor networks, whether they are just sensor networks (SN) or wireless sensor networks (WSN). The main characteristics of SN are the sensor, the observer and the phenomenon. The phenomenon is the subject of study which is what will be monitored by the SN, the sensor is the monitoring of the phenomenon that is being examined and passing information to the observer. But the observer is the end user that wishes to study and get answers about a given phenomenon [8].

The WSN are increasingly a topic of enormous research activity, mainly due to advances in microchip technology. Identified as one of the technologies of the 21st century [9], the WSN are emerging in different research areas such as health, environment, fire prevention, security, military areas, traffic and tourism [8, 10] and have as main characteristics: power consumption restrictions for us using batteries or raising energy, ability to deal with node failures, node mobility, communication failures, scalability for large-scale deployment, ability to resist adverse environmental conditions and ease of use [11].

The WSN are used to monitor the functioning of organs like the heart, to detect the presence of substances that indicate the cause or the emergence of biological problem, either in humans or in animals. In the environment these networks are used to monitor environmental variables such as temperature, precipitation, humidity, gas, etc., in internal places such buildings, houses, etc. , and external locations such as forests, mountains, deserts, oceans, volcanoes, among others.

WSN also are used for the detection of landslides, to detect slight ground movements and changes in various parameters that may occur before or during a slide. Through the data collected, it may be possible to meet the occurrence of landslides long before being actually happen. They are also used for monitoring the quality of water in dams, rivers, lakes and oceans, as well as in underground water reserves. In preventing fires the WSN are used for detection of smoke and fire, whether outdoors or indoors.

In the security part they are used for video surveillance, mostly parking. In the military area can detect enemy movements, the presence of dangerous materials or hidden mines. In traffic, they can be used to monitor the traffic on roads such as motorways or main avenues of major cities, so as to be able to see how the traffic by several cities of a country. In order to monitor the air pollution control the wireless sensor networks have been deployed in various cities (Stockholm, London and Brisbane) to monitor the concentration of harmful gases to the citizens.

The WSN are used in other areas of research that were not mentioned here, as for example in psychology, tourism, education, discovery of ecological disasters, among others. This type of network allows you to track, monitor, study, understand and act on a particular phenomenon or event.

Sensor networks have restrictions regarding energy and should possess mechanisms to self-configure to adapt to the environment in which they operate. With regard to traditional networks communication protocols, these must also change in order to adapt to the characteristics of WSN [12].

The sensor networks can be homogeneous or heterogeneous in relation to types, dimensions and functionality of the sensors. During the time of operation of the network, nodes may change in terms of their features, how to act or states. In this sense it is important that there is always a peer-to-peer relationship between sensor nodes [10].

Figure 3 - Example of a wireless sensor network.

This network type is suitable for situations where you can't implement a solution with wires and where they want instant access to information. Sensor nodes can move along with the observed phenomenon. As an example, we have sensors that are placed on animals to observe their behavior.

The WSN have the typical tasks to determine values of a particular parameter in a given location, detecting the occurrence of events, rate detected objects, trace a given subject, among others and is currently a major challenge and can be quite useful in obtaining information in dangerous environments or difficult to access. The characteristics that provide this type of networks like self-configuring, location, power management mechanisms among others, are also challenges and new opportunities in the area of research.

The continuous monitoring and minimally obstructive of human health through WSN is an innovative solution of great economic and social potential. It allows monitoring the life habits and early detection of abnormalities in anticipation of the emergence of diseases. According to Lymberis (LYMBERIS DITTMAR, 2007), the use of these systems allows to reduce hospital costs by reducing hospitalizations and outpatient procedures unnecessary. Also, the reduction of medical error because the interaction between the patient and the health professional will be available anytime and anywhere.

Currently, these systems are available commercially for catching some physiological information, such as, for example, the heart rate monitoring systems. The doctor accompanying the monitoring of a patient by means of a WSN can at some point, although counteract a predefined energy consumption policy, increase the level of monitoring of electrocardiogram (ECG) because it concluded that the signal captured presented some features that left doubts about the situation of the patient [13].

A body sensor network (BSN) or body area network (BAN), is a network of wireless sensors. The sensors can be connected to other devices through Wireless communication, Bluetooth or radio waves [14, 15, 16 and 17]. In particular, the network consists of several miniaturized body sensor units (BSUs) together with a single body central unit (BCU) [18, 19]. The development of WBAN technology started around 1995 around the idea of using wireless personal area network (WPAN) technologies to implement communications on, near, and around the human body. About six years later, the term came to refer BAN systems where communication is entirely within, on, and in the immediate proximity of the human body. [20, 21] The WBAN system can use WPAN technologies wireless gateways to reach longer ranges.

The rapid growth in physiological sensors, low-power integrated circuits, and wireless communication has enabled a new generation of wireless sensor networks, now used for purposes such as monitoring traffic, crops, infrastructure, and health. The body area network field is an interdisciplinary area which could allow inexpensive and continuous health monitoring with real-time updates of medical records through the Internet. A number of intelligent physiological sensors can be integrated into a wearable wireless body area network, which can be used for computer-assisted rehabilitation or early detection of medical conditions. This area relies on the feasibility of implanting very small biosensors inside the human body that are comfortable and that don't impair normal activities.

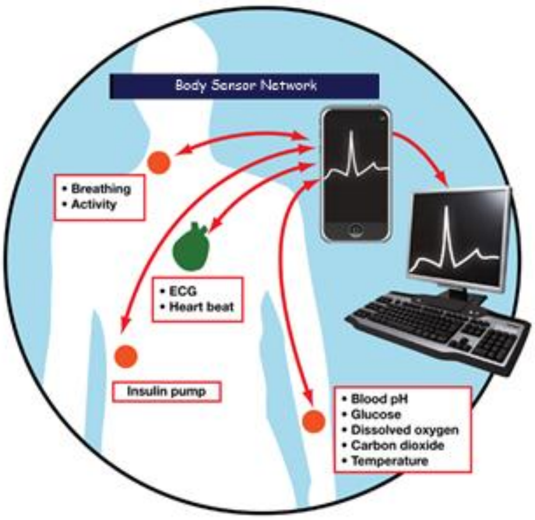


Figure 4 - Illustration of a body sensor nework.

The implanted sensors in the human body will collect various physiological changes in order to monitor the patient's health status no matter their location. The information will be transmitted wirelessly to an external processing unit. This device will instantly transmit all information in real time to the doctors throughout the world. If an emergency is detected, the physicians will immediately inform the patient through the computer system by sending appropriate messages or alarms. Currently the level of information provided and energy resources capable of powering the sensors are limiting. While the technology is still in its primitive stage it is being widely researched and once adopted, is expected to be a breakthrough invention in healthcare, leading to concepts like telemedicine and mHealth becoming real.

A typical BAN or BSN requires vital sign monitoring sensors, motion detectors (through accelerometers) to help identify the location of the monitored individual and some form of communication, to transmit vital sign and motion readings to medical practitioners or care givers. A typical body area network kit will consist of sensors, a Processor, a transceiver and a battery. Physiological sensors, such as ECG and SpO2 sensors, have been developed. Other sensors such as a blood pressure sensor, EEG sensor and a PDA for BSN interface are under development [22].

In this session are presented which kinds of sensors that there are babies in the area of health and within each type are shown some of the sensors that are already marketable or prototype. All sensors/solutions are accompanied by applications for computer, Android or iOS, where just install the application corresponding to the product, connect the sensor and view the data on the device.

2.2. Health Sensors for Babies

A BSN can be composed of sensor nodes belonging to different classes and in which each node has several types of sensors. In such scenarios it's important to choose the correct sensor type according to the observer's needs. There are numerous types of sensors that can be easily applied in people, in this case in infants, such as humidity sensors, temperature, CO2, radioactivity, sound, image, light, movement, vibration and blood pressure. It is important to note that each type of sensor displays energy consumption levels and different monitoring reaches [23].

2.2.1. Heart rate

ECG sensors are used to monitor and measure the electrical activity of the heart. There are various sensors for this purpose, as you can see below.

Electrocardiogram (ECG)

Typical electroencephalogram (EEG) and electrocardiogram (ECG) sensors require conductive gel to ensure low-impedance electrical contact between the sensor and skin, making set-up time-consuming and long-term recording problematic. We present a gel-free, non-contact EEG/ECG sensor with on-board electrode that capacity house with the skin. Active shielding of the high-impedance input significantly reduces noise pickup, and reduces variations in gain as a function of gap distance. The integrated sensor combines amplification, band pass filtering, and analog-to-digital conversion within a 1 inch diameter enclosure. The measured input-referred noise, over 1-100Hz frequency range, is 2μVrms at 0.2mm sensor distance, and 17μVrms at 3.2mm distance. Experiments coupling the sensor to human scalp through hair and to chest through clothing produce clear EEG and ECG recorded signals [24].

Figure 5 - Sensor for measuring heart rate without the need to put in suction contact with the skin.

This sensor the system consists of a set of simple capacitive electrodes manufactured on a standard printed circuit board that can operate through fabric or other insulation. Each electrode provides 46dB of gain over a .7-100Hz bandwidth with a noise level of 3.8V RMS for high quality brain and cardiac recordings. Signals are digitized directly on top of the electrode and transmitted in a digital serial daisy chain, minimizing the number of wires required on the body [25]. The system contains a suite of non-contact ECG electrodes connected along a single daisy chain that carries the analogical and digital signals. A wireless base unit transmits the physiological data to a remote device.

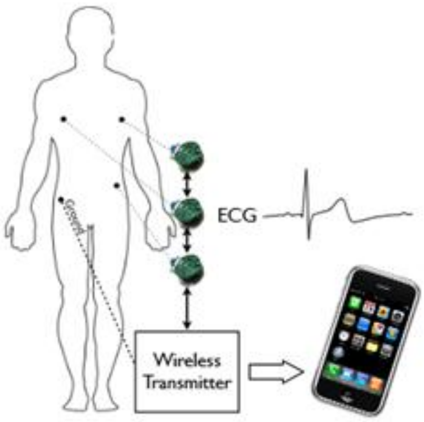


Figure 6 - Block diagram of wireless BSN.

The following is an existing solution to ECG monitoring. This solution is composed of a dress for babies, which has incorporated several electrodes in key points for the measurement of the heart rate of the baby.

The following solution shown is still a prototype and was developed in the Netherlands, Eindhoven University of Technology. The electrodes collect data that are transmitted to a sensor, where it in turn transmits the data to a smartphone or computer via Wireless [26].

Figure 7 – Photo of a smart jacket

Heart Rate Monitor with Camera

There are several applications for measuring the heart rate through cameras. For babies the cameras must be as small as possible given its members are very small and fragile. The following is a camera that can be used for these purposes and that through an application installed in a smartphone gives us the baby's heart rate.

The camera is called AiBall, measures approximately 33 mm and can be connected to the device via Wireless. The application handles the video captured by the camera and through some conversions of color models and calculations can introduce the baby's heart rate [27, 28].

Figure 8 - AiBall Camera (a) and application example with heart rate monitoring (b).

2.2.2. Temperature

There are sensors to monitor the temperature of the baby's body, but also to monitor the temperature of the room where the crib is placed.

The following shows a design of non-invasive neonatal temperature monitoring with wearable sensors. A negative temperature coefficient (NTC) resistor is applied as the temperature sensor due to its accuracy and small size. Conductive textile wires are used to make the sensor integration compatible for a wearable non-invasive monitoring platform, such as a neonatal smart jacket. Location of the sensor, materials and appearance are designed to optimize the functionality, patient comfort and the possibilities for aesthetic features. A prototype belt is built of soft bamboo fabrics with NTC sensor integrated to demonstrate the temperature monitoring [29].

Figure 9 – Photo The prototype of the proposed belt on a doll.

2.2.3. Humidity

The purpose of these sensors is detecting if there is humidity in the body of the baby or through perspiration or in diapers. The sensor below allows parents to remotely check the humidity of the baby's diaper. This solution was implemented with the Arduino and consists of a transmitter and two receivers. Have communication with the computer is done via Bluetooth and the data are presented in the application that was developed for this purpose [30].

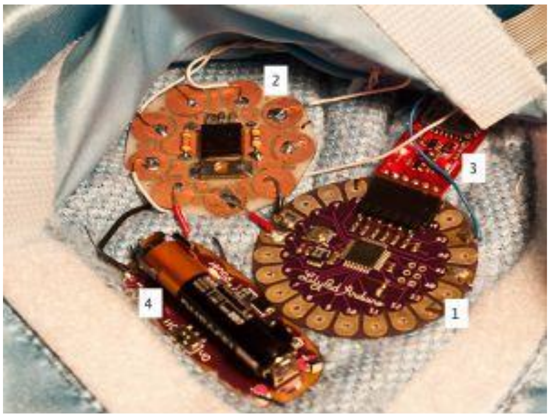


Figure 10 – Photo of a solution the humidity sensor with 1) Arduino; 2) Humidity sensor; 3) Bluetooth module; 4) Battery.

2.2.4. Breathing

Breathing sensors are used to check/monitor the breath of babies. There are many devices for this purpose, but the concept is always the same, the device detects baby's breath, sends the signal to a smartphone or computer and data are shown in the application that is installed on the device.

The Smart Baby Monitor Wristband is a baby monitoring system consists of a pear-shaped device and a bracelet. The pear-shaped device is a monitor that is placed in the baby's crib and that detects and analyzes the sounds the same. If the appliance detects cry, gives a warning to the parents' smartphone via Bluetooth. The alert bracelet will vibrate and the LED lights will light up. The color of the leds can be programmed to be a faster recognition and effective if it is an emergency or a situation within the normal [31].

Figure 11 - Smart Wristband Baby Monitor.

Another solution is the iBabyGuard, which is a baby sleep monitor, which detects baby's breath, sends the data to a smartphone that contains their application installed and are shown the data in real time about the breath [32].

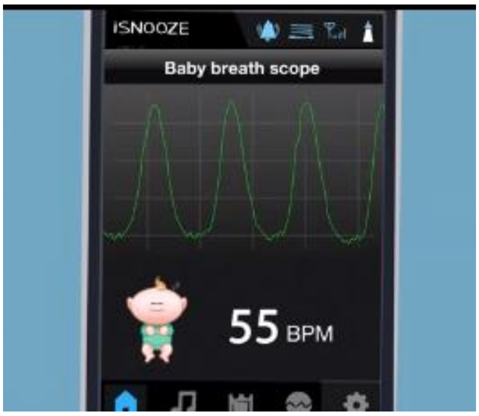


Figure 12 - iBabyGuard example of application.

There are other solutions to this effect, which are nothing less than devices that detect the baby's cry and send alerts to mobile phones of the parents of the babies, via Bluetooth or Wireless.

2.2.5. Movement

As for the motion sensors, can have multiple strands, but always with the same purpose, to detect if there are movements of the baby and be able to follow the baby in real time without the need to be around. Below are shown examples of devices with this order.

The BabyPing is a camera which is placed next to the crib and captures baby's movements in real time. The sensor is connected to the home network router via Wireless and can be accessed by all users who are connected to the same network. To do this simply install the application that comes with the device on your smartphone and accompany the baby in real time without the need to be in the same Division. The solution also lets you set a password so that only allowed the display to users containing the password [33].

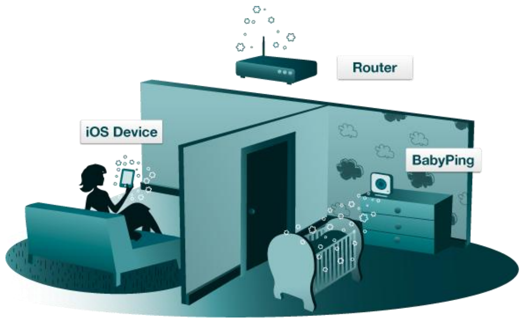


Figure 13 - Outline of operation of BabyPing [33].

The iBaby Monitor is a high resolution camera to capture every angle where the user controlling it with your smartphone and there is no need for an extra receiver [34].

Figure 14 - Solution concerning the iBaby Monitor with camera and application to your smartphone (Android or iOS).

2.2.6. CO2

The system shown below can be used for infants at home or in a hospital nursery room. The system consists of carbon dioxide (CO2) sensors and active Radio Frequency Identification (RFID) technology.

Figure 15 - Illustration of a crib with CO2 sensors deployed around the baby. The sensors are connected to a processing circuit board.

A commercial metal-oxide based CO2 sensor was chosen and characterized in sensitivity, selectivity and humidity dependence. The RFID transmission is accomplished with a wireless module at two different operating frequencies [35, 36].

2.2.7. Others

There are also solutions that consist of just a sensor that is able to measure several signals of biofeedback. An example of this is the "Mimo" Intel is a body for those who have embedded sensors that are mirrored connected to a central sensor that connects with the smartphone.

This solution (Mimo) is able to monitor the temperature, breathing, heart activity level and position [37, 38].

Figure 16 - Mimo, clothes for baby with multiple sensors.

The Baby's Fairy is an infant monitoring system that looks over the baby's vital signs. Currently an Indiegogo campaign to raise funds for the project, the Baby's Fairy consists of a wearable wristband and a parent base where a baby's heart rate and body temperature can be monitored for any changes or abnormal signs. Slated to be released in December 2013, parents can be within a range of 30 meters and monitor the baby's status when the wristband is attached to the baby's left wrist. The wristband uses an advanced heart rate sensor as well as a micro resistor to monitor body temperature.

The parent base, which is similar in size to a smartphone, displays live information, including vital sign status, connection strength and battery level, and has an in-built alert system. The Baby's Fairy doesn't require any additional installations or app downloads, and can be used straight out of the box [39].

Figure 17 - The Baby's Fairy Monitors Body Temperature and Vital Signs.

The next solution presented is a sock that is sidewalk to the baby and that has three sensors (temperature, heart rate and oxygen). These sensors are capable of measuring the temperature, oxygen levels and heart rate of the baby [40].

Figure 18 - Sock with three sensors (temperature, oxygen and heart rate).

2.3. Discussion and Open Issues

Miniaturization and tiny devices development brought designing and development industry to create such devices that smaller in size, better processing capabilities, effective memory and architecture. Sensor development put world into new domain that all technological aspect and solution are junked with sensor’s domain. Communication between these tiny devices made Wireless Sensor Network (WSN). WSN has given birth to exciting new applications of several areas of our lives at a broad class level and health caring is one of life-sustaining area.

The key role of sensors in WSNs is; to gather ,process data and make necessary computation from the environment and at last to make active many applications like as support for logistics, habitat monitoring, military operations, health care as well as emergency response. Talking to hardware availability WSN is heterogeneous or homogenous.

Furthermore, WSN classified as hierarchical or distributed roles. The study of WSN has a continuous research interest due to large potential for integrating the computing power of smart devices into everyday's life. In WSN, data is transmitted over air so many application needs employment of security measures.

Due to different demand and application, sensors designed and developed as per requirements. From last few years the sensors and tiny chips are needed too much in medical area. In medical area patient is focal entity so requirements of sensors architecture directly concern with human body. Human body have distinct characters, properties and dynamic behavior so designing, development and deployment of sensor in this prospective should need special attentions and features. Therefore, miniaturization, lightweight, cost reduction and wearable sensors require in health care system.

When these sensors deployed on patient, hospital monitoring system or in medical care units they form a Wireless Area Network (WAN) and when special on a human body attached these tiny devices then formally called Body Sensor Network (BSN). In BSN sensors used in, on, near or as required to human body in such a way that they gather data, process data, communicate with each other and process indication if integration required and communicate with Base Station (BS). Different architectural setup proposed in BSN to perform communication system however mainly it consists three parts.

Sensors on patient body performing separate network, high memory and processor units called base stations and external network that also contain medical servers. Body sensors placed on patient body just on the body stitching, wearing or hanging them or inside body through surgery or as for monitoring purpose and requirement. These sensors are design for special purpose due to the sensitivity of human body i.e. Heat, Blood Pressure, Sudden react and also side effect of artificial devices to body tissues. Body sensors communicate with BS updating their information.

Base station that is mostly high memory, processor and computational power controls all body sensors and communicate with external network. The external network constitutes medical server at which patient data store. Professionals/Physicians read their report accessing the medical server. Medical server generates reports as per required. Human body comprises of a complex inner milieu that reply to and intent on with its extraneous surroundings but is in a mode "distinguish" and "self-contained".

Human body milieu is not only on a littler scale but also need a different nature and frequency of monitoring with admiration of special and unusual challenges for BSN than those faced by generic WSN.

Below is shown a table that makes a comparison between WSN and BSN multilevel [41].

Table I - Comparison between WSN and BSN multilevel.

Challenges	WSN	BSN
Node Size	Favorable in smaller size but not limited due to wide and open environment domain.	Permeative monitoring requirement, needed miniaturization capabilities.
Dynamics	Exposed to uttermost in weather and noise.	Exposed to more predictable milieu but motional domain is a challenge.
Node Function	Constitutes many sensors and each perform specific task.	Every sensor performs multiple task due to less number of nodes and human body sensitivity.
Data Protection	Security requirement for data transfer is low and easy to implement security solution.	High security required because of information transfer is regards directly to life signs and implementation of security solution is very complex.
Power Demand	Power demand is higher but easy to supply.	Power demand is lower but difficult to supply.
Access	Replication and disposition of sensors is too much easy.	Due to implantable scenarios of sensors, replication and disposition is difficult.
Biocompatibi-lity	Do not need in many applications.	Biocompatibility must consider due to human body sensitivity.
Content Awareness	As mostly sensors are static behavior so this is not too much important.	As human body is too much sensitive for physiological changes so context awareness is very important.
Data Transfer	Ratio of loss of data is less due to well defined structure of nodes.	Additional requirements to maintain QoS and perfect data interrogation.

2.4. Conclusion

Sensor Network Solutions for babies are increasing dramatically, both to monitor signs of biofeedback, how to follow up the same, that becomes an advantage in their own security because so they are better protected in some way. About ten years ago it was rare to hear talk of wireless sensors that help in preventing sudden infant death for example, and these days, more and more companies are betting in this business, because we're walking faster to a technological world.

In this document, were presented just a few of the many sensors and existing solutions on the market, where there is a wide variety of solutions for each type of sensors, but deep down they all do the same, a few more easy, complete and convenient than the others, but it's going to be checking more and more over time.

Every day more and more solutions emerge. Prototypes ready to monitor, control or detect whatever, are environmental disasters, in the case of the environment, the presence of enemies, mines or other objects in the case of military area, in the case of tourism there are WSN to routes where the route is composed of several sensors that give information stations along the route in the case of vehicles and the traffic there are WSN to monitor traffic in avenues just as there are installed on WSN cars where the driver or other passengers in the car can interact with the same. WSN will exist in the near future in all the areas that you can imagine, because the investigation every time is more advanced and with this breakthrough technology will reach all areas and to all corners of the world. However it can be said that the BSN is a branch which emerged from the Wireless Sensor Networks.

This chapter presented a review of the literature regarding a state of the art in SIDS. These technologies, tools, techniques and solutions presented allow doctors and parents make better prevention of possible evils or a hazard to the health of babies and if necessary have a faster intervention.

So after a brief introduction, there were many existing solutions on the market to prevent SIDS.

In the following chapter will be presented all the requirement analysis that was designed to make this dissertation as possible and build the entire solution presented here.

3. Requirement Analysis

This chapter focuses on requirement analysis solution developed throughout this Master's program, mainly using the modeling language that allows presenting a system of standardized form called Unified Modeling Language (UML), which allows helping to structure the phase of development of software and describe what was done.

3.1. Introduction

Planning and modeling software is the most important phase of its life cycle, because it will be fundamental for his good functioning. It treats to identify all theirs requirement, functional and non-functional, the use cases and its main activities. The software should be developed through an object-oriented approach, which makes it possible to determine the structure of the software through classes and the relationships between them.

Beside if the software contains own database for collecting his data, it is also in this phase that it should be modeled and documented the data, for example, by using entity-relationship diagrams. The following section briefly describes the main objectives of software engineering to provide a context to the remaining part of the chapter.

3.2. Objectives

As mentioned in problem definition and objectives, the aim of this dissertation was to develop a mobile solution for Android mobile devices that allows monitoring and prevention of sudden death of babies. This solution must provide the users with the means for monitoring the health of their babies, and at the same time means to prevent sudden death and warn that events occurred.

The idea is to provide users with an easy way to follow their children from a distance, as if they were close to them. This monitoring is achieved through various monitoring sensors that will be near the baby, connected to a smartphone or Android tablet that will be around the baby. This smartphone will receive the data collected by the sensors and offers them for the user to follow the data biofeedback. The users will be able to also make this monitoring any time, anywhere via smartphone, where only need to have an internet connection, and then receive the data collected by the sensors.

The steps mentioned above should be developed, structured and well organized to be simpler to user interaction with the applications. It is important to make an effort in simplification of all the processes involved, since this effort will impact the ease of use of the application, which must be present since the planning phase and software engineering.

Given this general statement about the objectives, it is now possible to identify the general requirements of application.

3.3. Essential Modeling Requirements

The requirements' modeling provides a specification of which requirements must be implemented in the system. They are typically divided into function and non-functional requirements, depending on whether they describe the behavior that the system offers to the user or the conditions in which it must operate, respectively. Function requirements identified for the application developed under this master thesis are listed below:

- The system must only provide the data that are intended at this type of user (baby's data, data from sensors, sensor data collected in real time and historical data of the sensors);
- The application is composed of the registration page, authentication, homepage, real-time data and historical data;
- The application allows the adding new users;
- The application must to be able to encrypt the password for each user to make own registration;
- The user may access own area thought the authentication system;
- Upon successful authentication the user can see all data that are available.

This whole procedure involves a set operation that interacts with the user. It is important to distinguish the constraints for each entity involved in the system. Thus, system constraints are presented:

- Both MA and CA must need to be Wireless connection to the device, so that it is carried out communication with the web service to the database, to gain access your area and to be able to view the historical data received by sensors.

3.4. Use Cases

Use cases are an automatic activity regularly performed by an actor in the system. The process of identifying uses cases comprises one of the most fundamental tools of software engineering.

The group of uses cases identified for this solution is included in Tables II and III that summarizes the use-case diagrams more detailed in figures 19 and 20.

Figure 19 shows the use case diagram of the application that will be to receive, interpret and display sensor data to the user in real-time (MA). Some of the most important details present in the diagram are described below.

- The user to view the data collect includes that the sensors are connected. The sensors are connected through the application;
- If the data collected by the sensors are abnormal (lower or higher than normal) are sent notifications to the user to inform him of the occurrence;
- The user can only edit data regarding alert notifications to be sent, including add, edit or delete phone numbers that associate to your account.

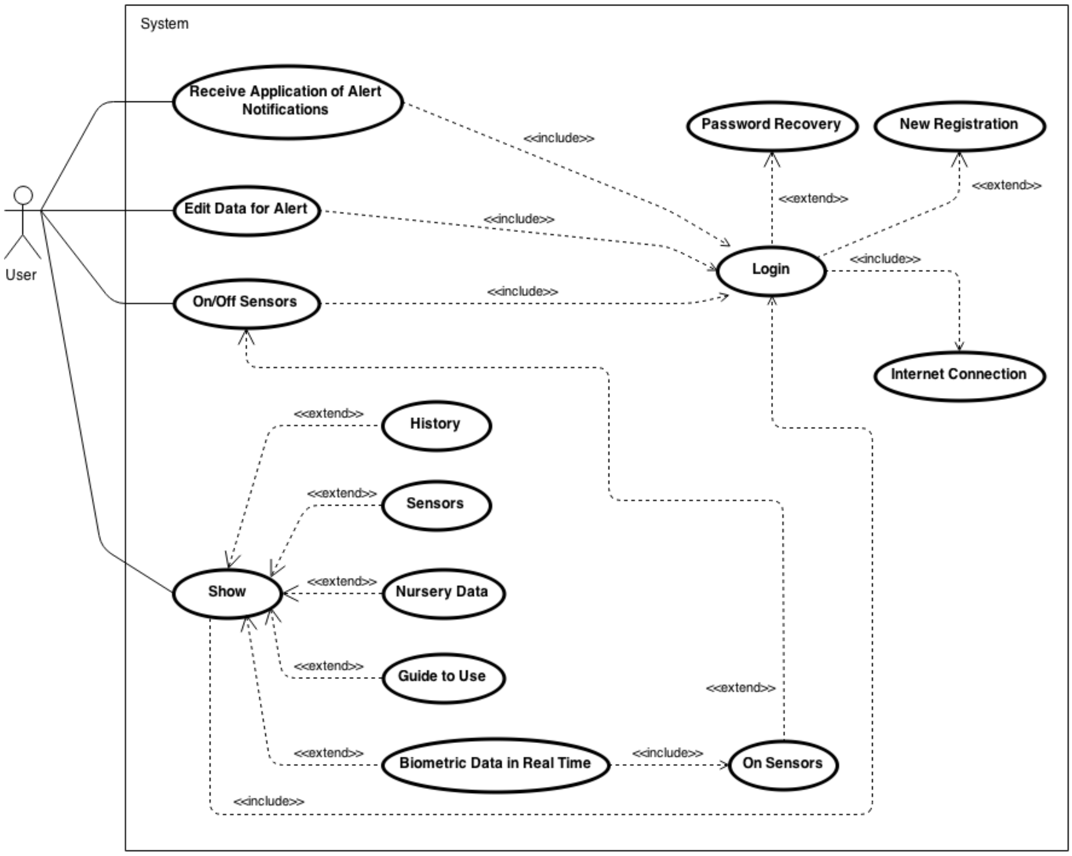


Figure 19 - General use case with the activities that can perform in the application (MA).

Table II - Use cases identified for Main Application.

Actors	Use Cases	Abstract Cases
User	Receive Application of Alert Notifications Edit Data for Alert On/Off Sensors Show Data Login in the System	Password Recovery New Registration Internet Connection Show History Show Sensors Show Nursery Data Show Guide to Use Show Biometric Data in Real Time On Sensors

Figure 20 shows the use case diagram of the application that the user can install on own smartphone to be able to monitoring baby from a distance (CA) at anytime and anywhere, provided it have internet access. Some of the most important details of this application are described below.

- The user can receive alert notifications through the application, if it have access to the internet or via SMS;
- The user will have access to the data collected by the sensors in a moment.

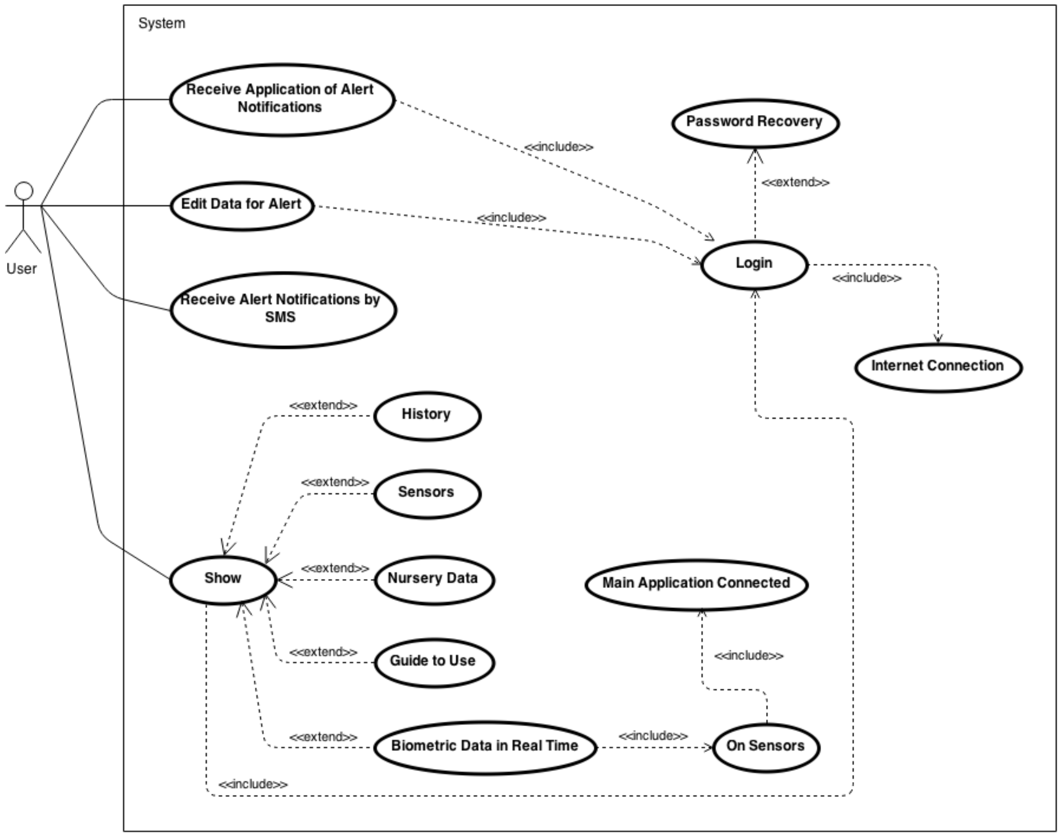


Figure 20 - General use case with the activities that can perform in the application (CA).

Table III - Use cases identified for Client Application.

Actors	Use Cases	Abstract Cases
User	Receive Application of Alert Notifications Receive Alert Notifications by SMS Edit Data for Alert Show Data Login in the System	Password Recovery Internet Connection Show History Show Sensors Show Nursery Data Show Guide to Use Show Biometric Data in Real Time On Sensors Main Application Connected

In the software engineering process, discussion of some scenarios follows to the identification of the use cases, as is also shown in this document. The scenarios are the paths that can be used to perform a particular activity or task. The following sections will be shown and described some of the most important scenarios of this solution and how they are carried out certain activities and tasks within each scenario.

3.5. Class Diagram

This section discusses the model classes conceded for the development of the proposed solution in this master's work, having the above mentioned use cases as a base. Two diagrams (Appendix B) are presented, referring to the two applications developed, as was also shown in the above use cases.

The classes present in diagrams capture the most important methods of the system in terms of attributes, operations and actions. With its analysis it can be concluded that it was given a special emphasis on the collection, processing, presentation and warning about the data collected by the sensors.

3.6. Activity Diagrams

This section includes and discusses some of activity diagrams which allow understanding the workflow of some of the most relevant characteristics of the system. They were drawn from previously identified use cases and feature process like as the registration and login of one user or the collect, processing sensor data viewing. The use cases are based on: (i) Login in the System; (ii) View Real-Time Data; (iii) View Sensor Data; (iv) View Historical Data.

The Table IV describes the interaction between the user and the system during the registration activity (MA). The activity on the user authentication system (MA and CA) is then presented on Table V. In the Table VI describes the activity of the visualization sensor data in real time (MA). In Table VII is described on the activity view of sensor data, but in this case is not in real time, where data have some delay getting application (CA), while in Table VIII is presented the process of viewing historical data (MA and CA). Finally the Table IX describes the firing activity of alert notifications when there are occurrences.

Table IV - Diagram and description for the User Registration activity in the system.

Use Case name	Login in the System (Registration)
Description	1. The user access the application. 2. Then, enter all the data that are asked in the form. 2.1. If the fields are not filled in will be shown an error message and the flow will go back to the beginning 2.2. If successful, the system sends the data to the WS to be validated 3. The data are then validated in the WS. 3.1. If they are invalid or there is any user with same email already registered, an error message is sent and the flow will go back to the beginning. 3.2. If valid data is stored in the database of system support. 4. The system displays a success message. 5. The user accesses the home page and can log in and interact with the application.
Activity Diagram	

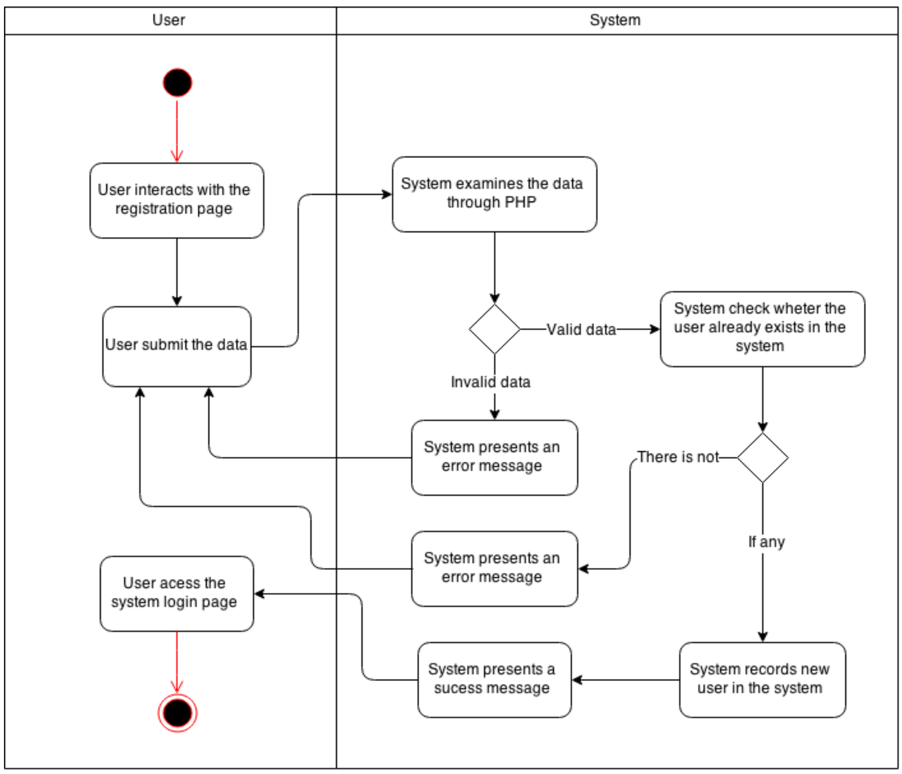


Table V - Diagram and description for the User Authentication activity in the system.

Use Case name	Login in the System (Authentication)
Description	1. The user access the application. 2. Next, enter data to login. 2.1. If the fields are empty will be shown an error message and the flow will go back to the beginning. 2.2. If success, the system sends the data to the WS to be validated. 3. The data are then validated in the WS. 3.1. If they are invalid or there is any user with same email already regisistered, an error message is sent and the flow will go back to the beginning. 3.2. If valid data is stored in the database of system support 4. The system displays a success message. 5. The user accesses the home page and can log in and interact with the application.

Activity Diagram

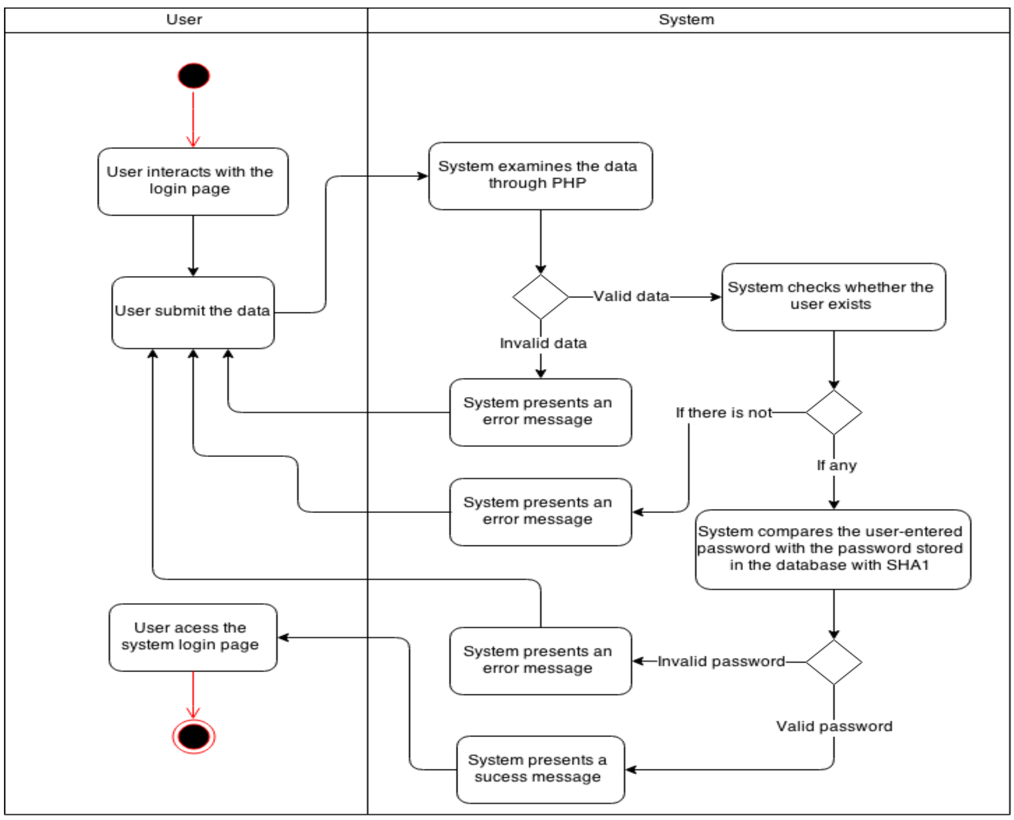


Table VI - Diagram and description for the View Data in Real-Time activity in the system.

Use Case name	View Real-Time Data
Description	1. The user accesses to the main page of the application and connect the sensors. 2. The system sends a request for communication to sensors. 2.1. If the sensors are turned off, the flow will go back to the beginning. 2.2. If the sensors are connected, data are collected. 3. The system receives every second data coming from sensors. 4. The system analyzes and treats the data coming from the sensors. 5. The data are shown to the user every second, continuously.
Activity Diagram	

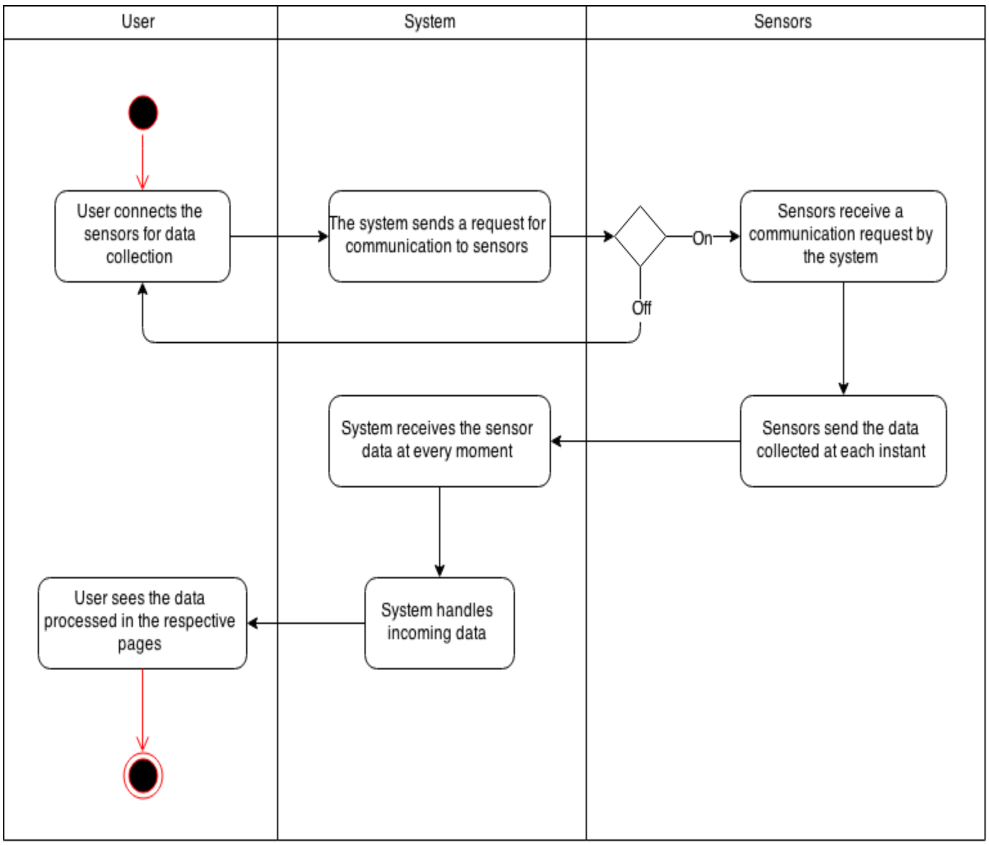


Table VII - Diagram and description for the View Sensor Data activity in the system.

Use Case name	View Sensor Data
Description	1. The user accesses the data preview page 2. The system sends a request to WS. 3. The WS collects every moment the sensor data that are being stored every second in the database and sent to the system. 4. The system shown the data to the user.
Activity Diagram	

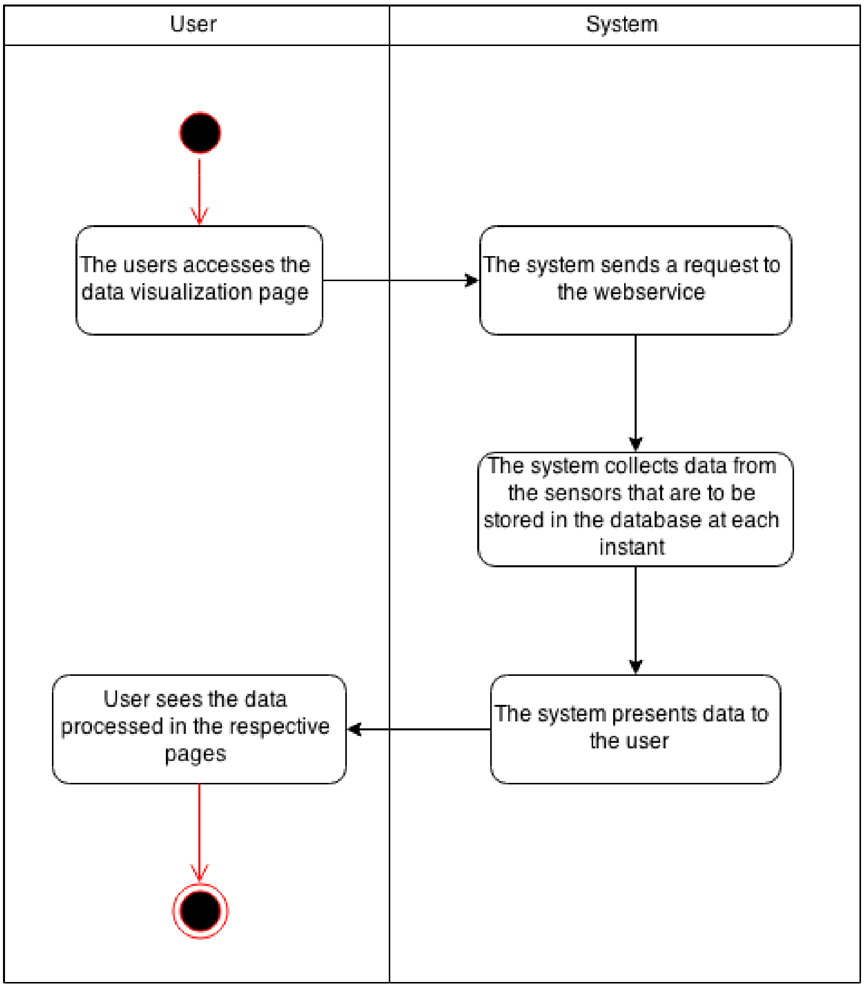


Table VIII - Diagram and description for the View Historical Data activity in the system.

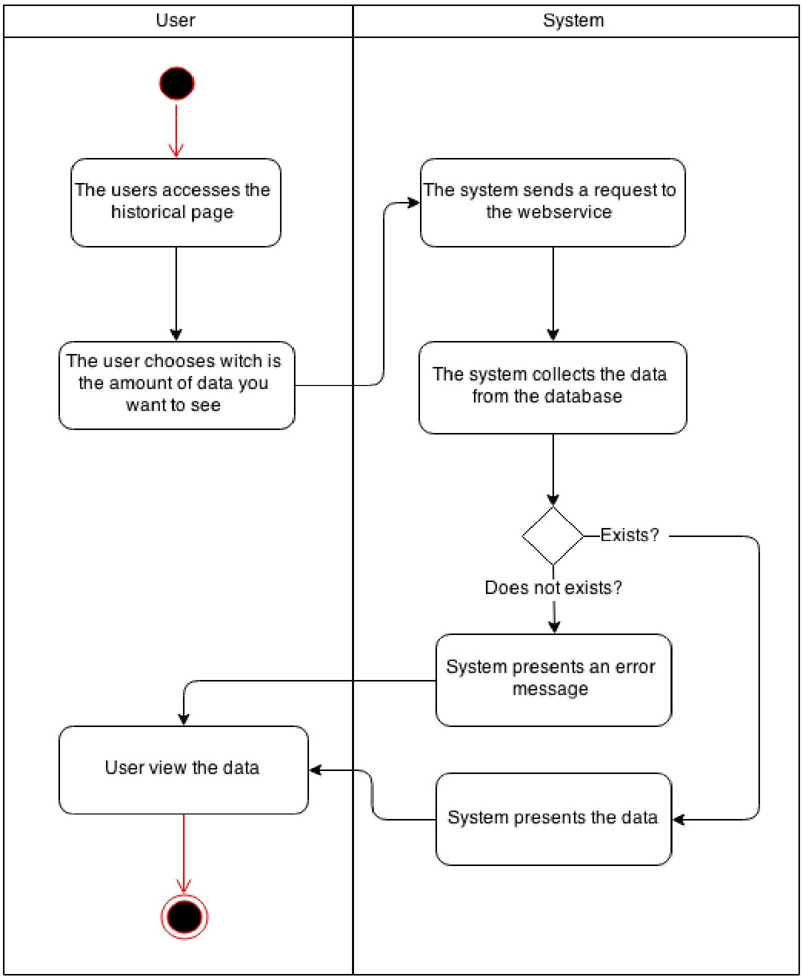
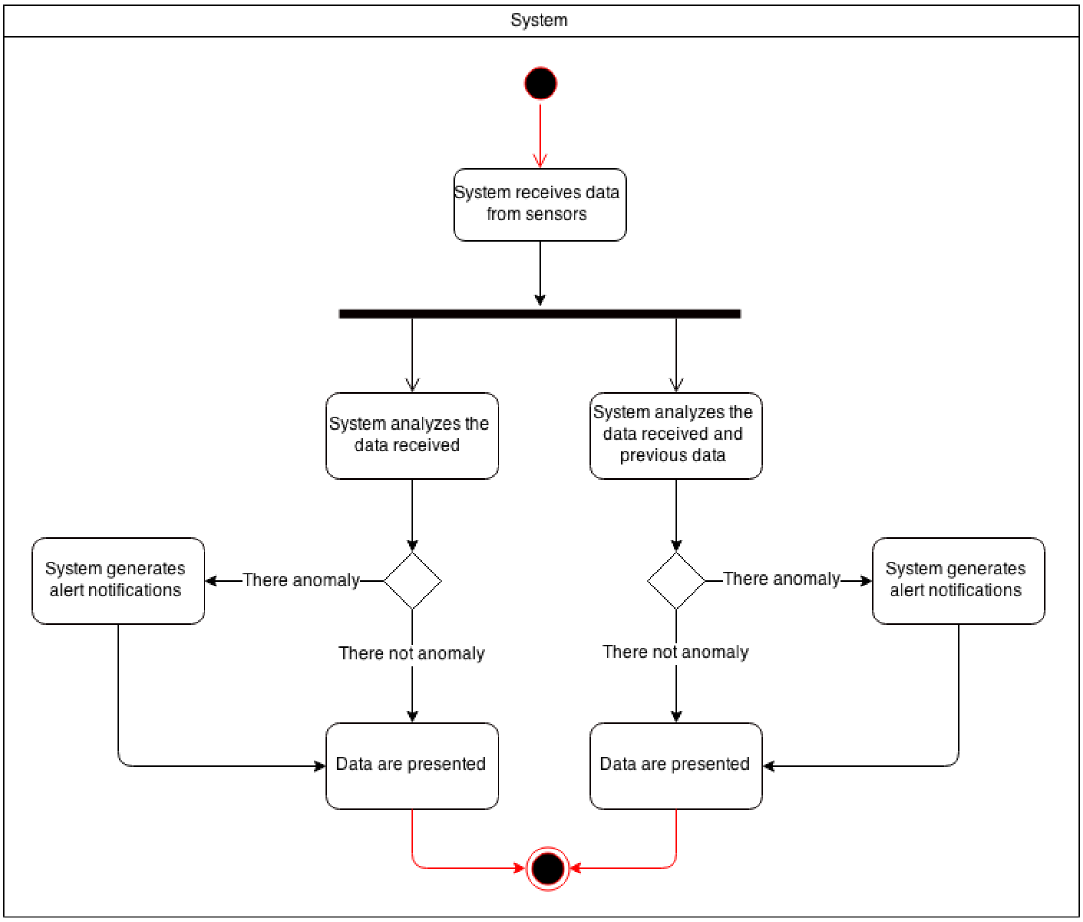
<table>
<tr><td>Use Case name</td><td>View Historical Data</td></tr>
<tr><td>Description</td><td>1. The user accesses to History page.
2. The user chooses which is amount of data that you can check.
3. Is sent a request to the WS for the provision of data for the period selected by the user.
3.1. If there are no data to show an error message is sent.
3.2. If there is data, the WS sends the data to application.
4. The data are shown in the application for the user can view.</td></tr>
<tr><td colspan="2">Activity Diagram</td></tr>
<tr><td colspan="2">
</td></tr>
</table>

Table IX - Diagram and description for the Alert Notifications activity in the system.

Use Case name	Trigger Alert Notifications
Description	1. The system receives data collected by the sensors. 2. The system analyzes the data it receives. 2.1. Is there are abnormalities, the system generates an alert notification and data are presented. 2.2. If there are no data anomalies are presented. 3. The system analyzes the data it receives and previous data. 3.1. Is there are abnormalities, the system generates an alert notification and data are presented. 3.2. If there are no data anomalies are presented.
Activity Diagram	



3.7. Diagram of Components

The component diagram for the solution developed in this master is present in Figure 21. This solution is composed of two applications that can be installed on any Android device for a WS in PHP and a SQL database. The data before being sent to the WS are validated by the application and are again validated when arriving at WS through PHP, where after follow to the SQL database. With regard to request that are made by applying for loading data from the database, these request are also loaded via the WS. Below you can see the diagram of components of the solution presented in this document.

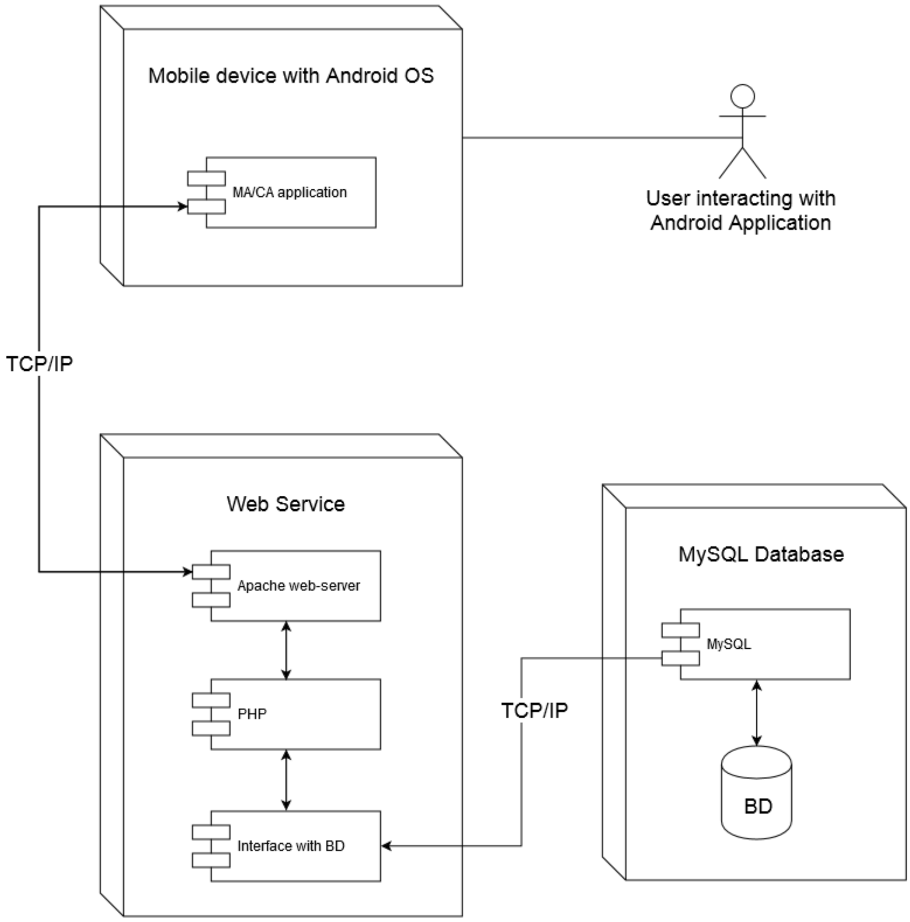


Figure 21 - The components diagram of the engineered system.

3.8. Entity-Relationship Diagram

Figure 22 shows the entity-relationship diagram that represents the database that supports the system presented in this document. Databases normally play a key role in the solutions developed nowadays, where they keep the data almost always someone or something. In this case there is no different because it will be store data of both the users and the sensors and data collected by them.

The diagram identifies the entities model the system, also showing the relationships between the entities and cardinality associated with them. The user is considered to be the main entity of database, to which most of the entities are connected.

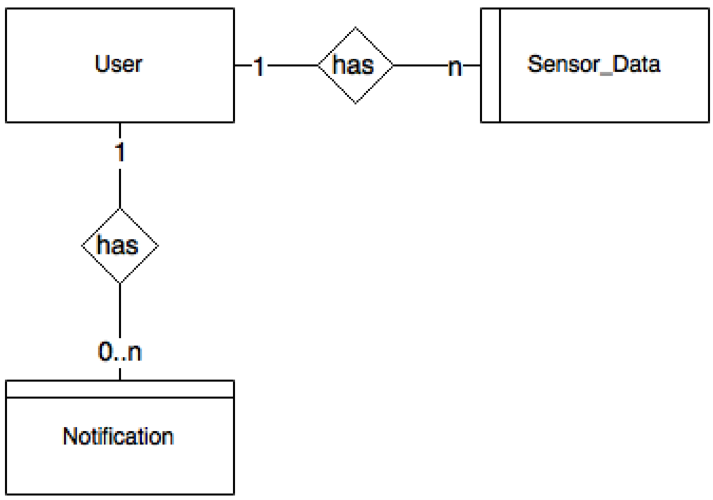


Figure 22 - Representation of the Entity-relationship Diagram of the system data base.

User (id*, name, date_of_birth, sex, email, password, salt, mobile_number, temperature_sensor, respiration_sensor, position_sensor)
Sensor_Data (idbaby*, date, temperature, position, respiration, heartbeat)
Notification (idbaby*, date, notification_type, value)

3.9. Used Technologies

The solution presented on this dissertation was developed in Java programming language. Java is an objected-oriented programming developed in the 90 in the company Sun Microsystems. Unlike conventional languages which are compiled to native code, Java language is compiled for byte code that is executed by a virtual machine.

This solution was developed for devices that have Android SO operating system and the knowledge of the Android architecture is essential in order to be possible to design and develop robust and consistent solution. Figure 25 shows the main components of the Android operating system.

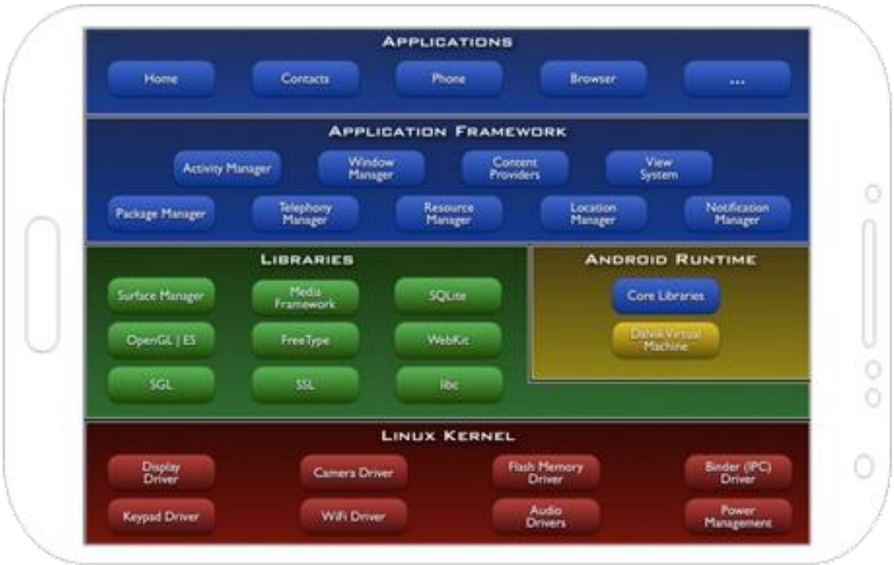


Figure 23 - Illustration of the Android OS architecture.

Already the IDE chosen for its development was the Eclipse where the plugin Android (ADT), designed to extend the capabilities of Eclipse, proving build options or event test for emulators that everyone, even those who do not have an Android device to test their applications. Normally all Android devices offer Wi-Fi and Bluetooth.

For this case is required that the device has these two types of connections to the correct functioning of the application, to receive the data that is sent from sensors via Bluetooth and the same to the database via Wi-Fi.

3.10. Conclusion

Modeling is one of the most important stages in the development of any system. It is in this phase of construction which are identified the features of software. In addition, with the modeling are identified existing streams between the entities involved in the system. By this stage it is still possible to identify possible implementation issues that may appear over the implementation of the system/solution.

This chapter was introduced all software engineering developed to implement the solution. In Section 3.2 were presented the objectives for the solution, in Section 3.3 was made the requirements analysis, showing the functional and nonfunctional requirements. Based on the requirements was developed use cases present in Section 3.4.

Already in Section 3.5 are presented the class diagrams, which by their size are present at the end of the document, in appendix. In Section 3.6 can observe the main activities diagrams of two applications and in Section 3.7 are presented the diagram of components of all solution.

In Section 3.8 is the entity-relationship diagram of the database solution support and finally in Section 3.9 are the technologies used for the development of the solution.

4. Sensors and Devices used on the Prototype

The purpose of this chapter is to show the devices and mobile health sensors that were used in the prototype that was developed within the framework of this project. The sensors are used directly only for one of the two applications (MA), which is the application that is connected to the sensors via Bluetooth to receive data that is collected by these.

4.1. Introduction

To test this solution was necessary to install the applications on mobile devices that have the Android OS. Android is the most successful platform and today is present in more than 750 million mobile devices especially smartphones becoming so pervasive and powerful.

This success is due also to the fact that these devices have Bluetooth and/or Wi-Fi to connect to other devices to support or improve applications installed in them. There are already many versions of the Android OS, but for the development, validation and testing of the solution were used versions 4.4.2 Jelly Bean on the smartphone and 4.1.1 KitKat on tablet.

In Section 4.2 are the Shimmer Kit used, in Section 4.3 the sensors that were used to make this functional prototype, where is a presentation of each of them, since the hardware component to the way the data collected. In Section 4.4 the devices that were used to install the applications, MA and CA, during development and testing. To finish this chapter, in Section 4.5 is a conclusion.

4.2. Shimmer Research Platinum

The Shimmer Research Platinum solution system, also known as Shimmer 2R Development Kit (Figure 24) offers two possibilities for communication, IEEE 802.15.4 or Bluetooth, which lets you send data to mobile devices, smartphones or tablets, without forgetting the flexibility, portability and autonomy.

Figure 24 – Photo of a Shimmer 2R Development Kit.

Each sensor has a very small size (2.0 x 4.5 cm) [42] and is equipped with an MSP430 which is a low-power microcontroller (8 MHz, 16 bit) from Texas Instruments 5, an accelerometer of 3 axes for motion-sensitive control, the main Board also includes a Micro SD slot supporting up to 2 GB of memory for data storage, enabling significant amounts of data, two modules for communications, a Bluetooth and a radio (802.15.4), a 450mAh battery rechargeable lithium, with a voltage of 3.7 Volts, along with the advantage of being rechargeable battery in a few hours and low power consumption. With this setting our system could run about two days without recharging the battery. This fact and using rechargeable batteries also are the main reasons for the choice of this platform.

It is also composed by a Groove which allows the connection to other modules of the sensors. This offers a myriad of sensors for measurement of bio-signals, such as electrocardiogram (ECG), electromyogram (EMG), the Galvanic Skin Response (GSR), Heart Rate (HR) or beats per minute (BPM), temperature, among others.

The development kit is also composed by various memory cards, charging docs and data transfer, straps to put sensors in people and also a CD which contains complete documentation on each module, the Android API and an installation program that allows you to see the whole process of initialization data, connection, purchase and viewing/processing received through sensors.

4.3. Presentation of Sensors

Position sensors, respiration and temperature (Figure 25) are accelerometer of 3 axes as was said earlier. In addition to the own theme of this dissertation is challenging, was also a challenge to transform these three accelerometers in sensors for different purposes. The decision not to use own sensors to collect the different bio signals was due to have Shimmer 2R Development Kit and enjoy the right to develop a prototype.

Figure 25 – Illustration of body sensors used on the proposed solution: a) temperature sensor; b) position sensor and c) respiration sensor.

Beneath it is made a presentation of what is most important of the sensors, its structure, what makes each of them and how is the connection to the application.

4.3.1. Shimmer Design

The SHIMMER platform comprises of a baseboard which provides the sensors computational, data storage, communications and daughterboard connection capabilities. The core functionality of SHIMMER is extended via a range of daughter boards which provide various kinematic, physiological, and ambient sensing capabilities. This range of contact and non-sensing capabilities can be reliably used both in clinical and in home-based research scenarios.

The central element of the baseplate is a Texas Instruments MSP430™ MCU, as referenced above, which has been widely used in wireless sensors [43, 44 and 45]. One of the features of this microcontroller is its low power consumption during periods of inactivity. Below in Figure 26 we can see the composition of the sensors that were used.

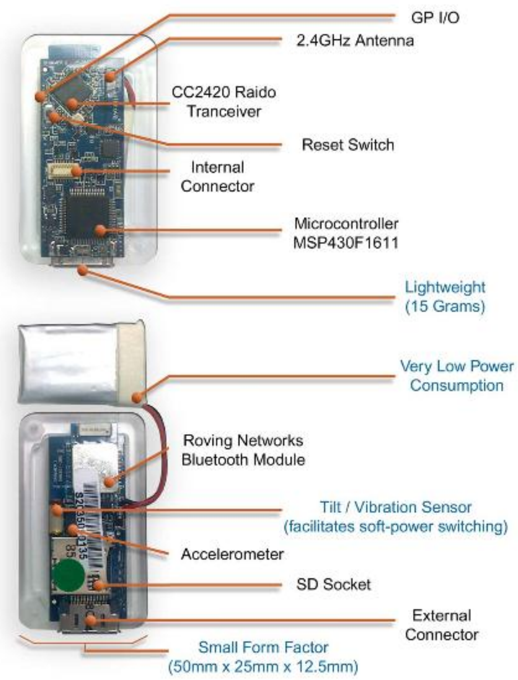


Figure 26 - Structure sensor.

The base plate SHIMMER also has two internal expansion connectors. Internal expansion allows users to connect e.g. a module of electrocardiogram (ECG), kinematics (gyroscope, magnetometer) and galvanic skin response (GSR), depending on the needs. External expansion allows the user connecting to the doc or to the charger.

4.3.2. Temperature Module

Despite the SHIMMER platform have most resources needed for this project, there is no temperature sensor. For it was used an extra module can connect to one of the accelerometers and platform that allows us to collect temperature, in this case the temperature of the baby's body. This module allows the collection of temperature between 0°C and 50°C and is almost invisible due to its small dimensions (0.762 x 9.52 mm). The module was a thermistor MA100 (Figure 27) [46], which is a NTC Type Thermistor Chip developed by Biomedical MA GE Industrial Sensing and is exclusively used for biomedical applications.

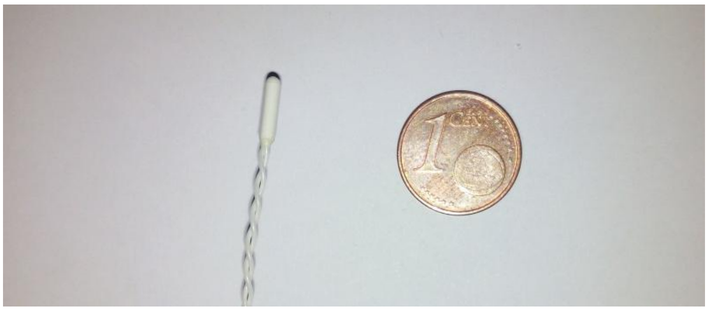


Figure 27 – Photo of the thermistor MA 100.

The temperature sensor is composed with two parts (Figure 28), a temperature sensor (MA100) and a processing unit SHIMMER platform. The temperature sensor (MA100) is the only part of the system it is necessary to put in contact with the body of the baby, because he gets to read data.

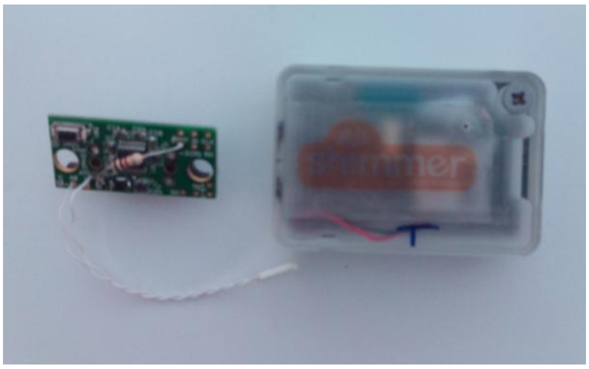


Figure 28 –Temperature sensor.

The temperature sensor measures the values and sends them to the unity of the SHIMMER. The equation (1) represents the calculation so that the values that come to SHIMMER unit are correct and transformed in to degrees °C [47].

$$T = \frac{V_{0^\circ C}[mV] - V_{cal}[mV]}{30.035\ [mV/^\circ C]} - 1.66\ [^\circ C]$$

Where:

$$V_{cal} = V_{out} \times 0.7326\ [mV]$$

$$V_{0^\circ C} = 2299.9\ [mV] \qquad (1)$$

Equation 1 - Equation to calculate the body temperature.

After the data reach the SHIMMER unit are transferred via Bluetooth to the MA and presented to the user.

4.3.3. Heart Rate Sensor

The heart rate detection with a camera is very useful for monitoring the baby in a crib. The temperature sensor is not fixed in this prototype, this is, the temperature sensor is the camera of the mobile device where is installed the MA. It is connected to the baby's arm where the skin is more sensitive and allows a better reading of the collected images that contains the color of skin pigmentation. Through the skin pigmentation it is possible to determine the heart rate in an easy and noninvasive way.

With blood pumped around the body it is possible to identify heart beating in the images collected by this camera. In a healthy person the camera captures a real-time video image of pigmentation and, when a beat is detected, it presents a more intense red color. The image pigmentation algorithm has an interval between two heart beats and it is possible to detect a different coloration of skin. The system verifies the pigmentation over an ongoing sequence of images.

The application obtains the video of the camera in real time and makes the interpretation of video frames. In the image contrast it is possible observe the difference of the color intensity between images and this phenomena allows the calculation of the heartbeat.

The application shows video captures with the exterior camera and the different colors received distinguish numbers to identify a color in a numerical scale, depending on YUV weighbridge parameters. In babies, the beats per minute diverge according to their age and these values are slightly irregular. If they have irregular heart rate parameters in a short time stamp it is considered a trouble situation.

This system does the video image recognition in the baby's skin, then, it is necessary to adjust the video capture because the baby skin is very thin. The detection of heart beats is done in a thinner area of the body such as the wrist or even in the baby hand. For the data to be the most reliable possible it is important that the camera has flash to be more visible and detectable color pigmentation of the skin of the baby.

4.4. Devices

For the development of this prototype were used two mobile devices, a smartphone and a tablet. As mentioned in the previous chapters the tablet was based on the application where was installed the MA, which is the application that receives, analyzes and treats the data that are collected by the sensors. Already the smartphone served to install the CA to test whether indeed the application receiving the data from sensors through the web service. The following are both mobile devices used in this work.

To run the MA was used a Tablet Asus Transformer Prime TF201 (Figure 29) 10 inches [48], which was an excellent choice for the development of this work, allowing good visualization of data and graphics in the application. It has a 1.3Ghz Quad-core processor, a graphics card like Bluetooth, which allows connection to the sensors used and also has a Wireless card (Wi-Fi 802.11 b/g/n) that allows the Internet connection for which the application communicates with the Web service to be able to store and query data from the database. It also has an 8 megapixel camera which in this case was the House that served as a sensor to collect heart rate data.

Figure 29 – Tablet Asus Transformer Prime TF201.

To run the CA was used a smartphone BQ 5E FHD (Figure 30) of 5 inches [49], where was also was an excellent choice, which also allows excellent visualization of data and application graphics because it contains a welcome screen dimensions and with excellent quality. Contains a MediaTek MT6592 of 2.0 GHz True8Core processor, like a Wireless card (Wi-Fi 802.11 b/g/n) that allows connection to the internet, since the CA depends on an Internet connection to function.

Figure 30 – Smartphone BQ 5E FHD.

4.5. Conclusion

In this chapter were presented the technical features and the functionality of the devices that make up the solution presented here. In Section 4.2 was presented the health sensors kit (Kit Shimmer Research Platinum). Sections 4.3 and 4.4 has been presented all the sensors and devices used in the prototype.

In the next chapter is presented the solution and described every detail to show all the work developed in this dissertation.

5. Mobile Solution Demonstration

In this chapter it will be presented the solution that has been developed in this work.

5.1. Introduction

After all the work done, since the research work to find out what was necessary to realize and know what already existed in the literature, software engineering and all development of applications. The presentation of applications will be a full tour to all the features of the same, since the registration of users to consult the data in real-time or historical.

Therefore, in Section 5.2 system architecture is presented and in Section 5.3 are presented the MA and CA to detail. In Section 5.4 are given the tools to the biofeedback monitoring, in Section 5.5 is explained as are generated when alerts are detected anomalies in data collected by the sensors. Finally and to conclude this chapter is presented a little conclusion in Section 5.6.

5.2. System Architecture

This section presents the architecture of the system proposed in this paper as well as the modules with body sensors and Web services. Figure 31 shows the architecture of SIDS detection with sensors placed on a baby body and the corresponding crib.

The baby cradle supports Shimmer sensors to collect several bio-signals parameters [50, 51]. They are connected to a smartphone or tablet through Bluetooth and Wi-Fi, sensing and allowing real-time monitoring. The baby sleep was a detectable state and this is the most danger situation for newborns because, in the early years, they spend the most time of their premature lives sleeping. Several vital functions may be measured with sensors but nothing can replace the presence of a mother (or a nanny). The mobile app is used as a gateway that provides a powerful tool to support and prevent most danger situations such as a cardiac or a respiratory arrest or prevent a baby change position.

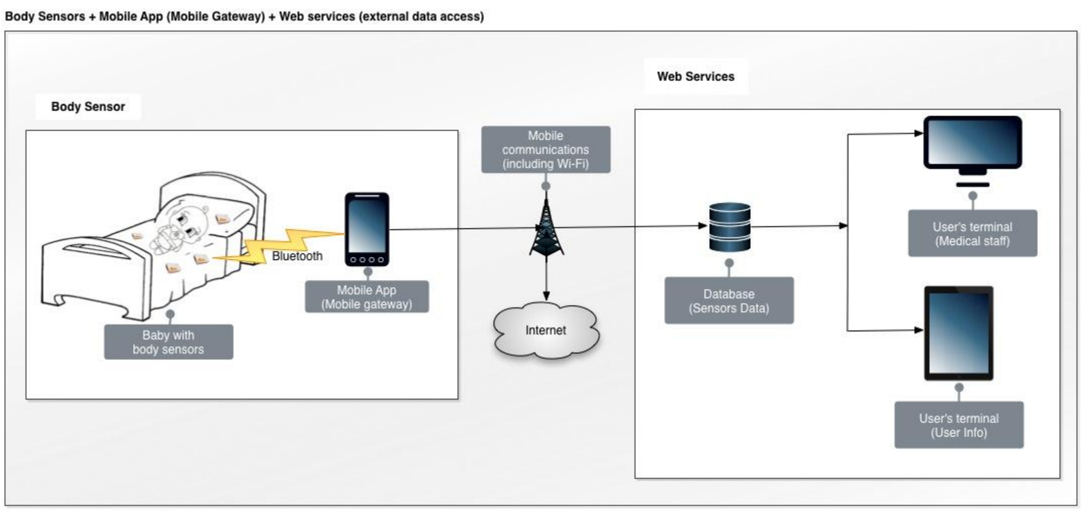


Figure 31 - Illustration of the system architecture for prevention and monitoring system with the three tiers (body sensors, storage, and Web services).

The mobile device (also gateway) can use Wi-Fi, GSM, UMTS or similar to disseminate the collected data, allowing external storage and remote access for baby monitoring at a distance.

5.3. Graphical User Interface

This section focuses on the demonstration of the solution that has been developed to be used in babies but to be used by their caregivers. Both applications are of simple interaction with the user and all features are easily visible, thus making it very simple to use. The applications are shown below where it will be reference the differences between them.

After installing the applications on mobile devices, can begin to enjoy the same. The user can choose to have only the application MA or both, because it is not possible to have only the CA. Before starting the applications is mandatory having mobile devices connected to the Internet and in the case of the device that contains the MA requires Bluetooth communication also connected. When you start the application splash screen appears. In the case of MA (Figure 32), the home screen gives you access to 3 initial options, which they login, registration and password recovery system.

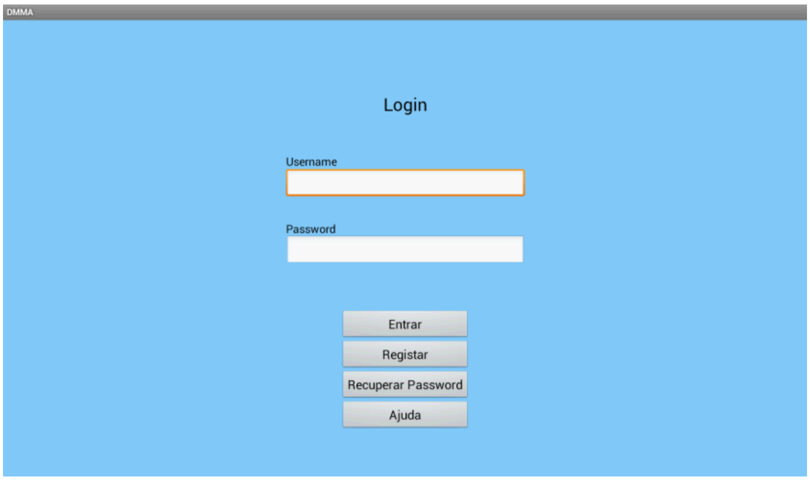


Figure 32 - Home screen (MA).

Already the initial screen of the CA allows only perform login and password recovery (Figure 33). The option of the user not being able to register through the CA was taken when the system was designed and the option was taken because if the user wishes to uses the solution will have to be complete, that is, the two applications and sensors. So to have the complete solution the user will have to register through the MA.

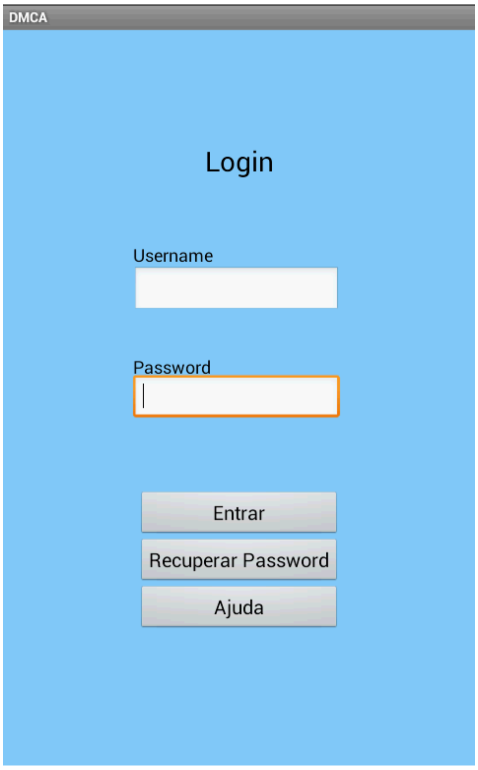


Figure 33 - Home screen (CA).

If the user forgets to enter the username or the password or the data are not the correct, an alert is displayed to inform you of the same, as shown in Figure 34.

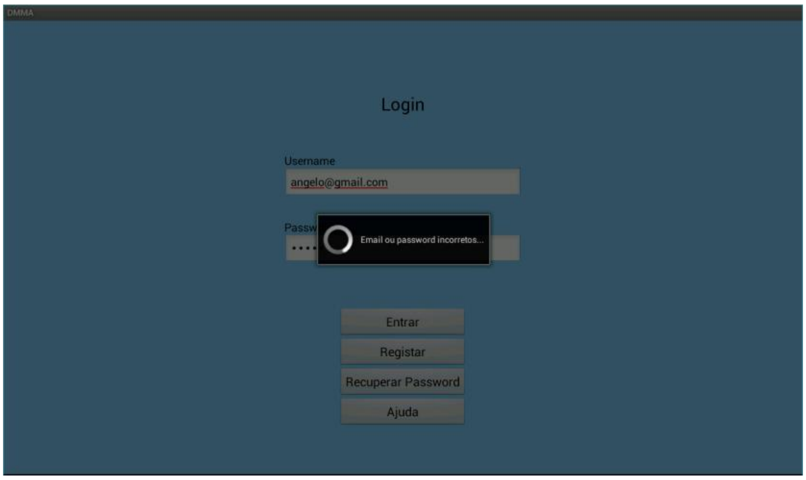


Figure 34 - Alert informing the user that the login fields are empty or incorrect.

If the user is not already registered just need to press the button "Register" in the MA and the registration screen appears (Figure 35). The user must fill in all data are requests for that registration be done successfully.

Figure 35 - Registration screen (MA).

The data that are required to register in the application are the name, date of birth and sex of the baby, as well as the email, the password and the phone number of the caregiver and the MAC address of the Shimmer sensors to be used. Some alerts may appear during the registration process (Figure 36), for example, if a field is empty or if the email you entered is already registered. Once you register you are redirected to the home screen, where you can log in below.

Figure 36 - Registration screen with alert informing the user that all fields must be filled.

Before showing the functionality of the applications, first are presented the screen that allows the recovery password if you forget it. This screen exist both in MA as in CA and allows the user to change their password, to do this simply press the button “Recover Password” that exists on the home screen and the screen will appear (Figure 37).

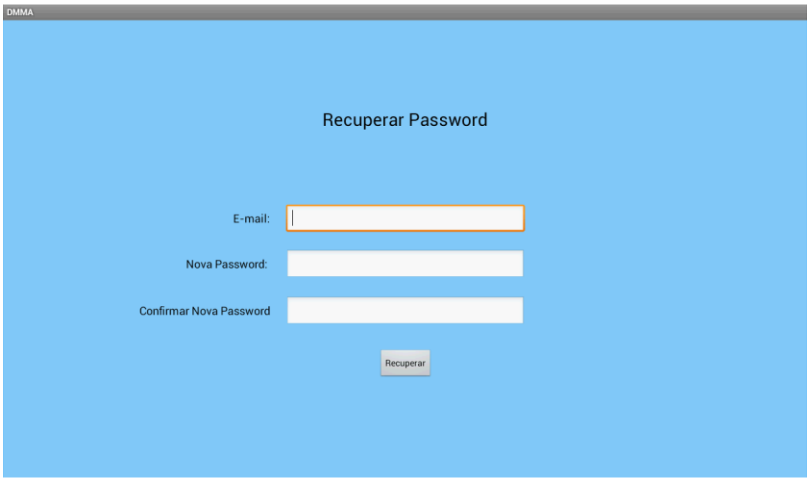


Figure 37 - Password recovery screen.

If the passwords entered do not match, the user does not fill the fields or the entered email address does not exist in the system are an alert to inform the user of the occurrence as shown in Figure 38. This is done for security, to avoid that mistake in the password that you want to insert and how to make sure that the password entered is correct. Both the registration as a password recovery is applied a cryptographic function so that the password is not stored in clear text in the database, protecting in case the database is stolen.

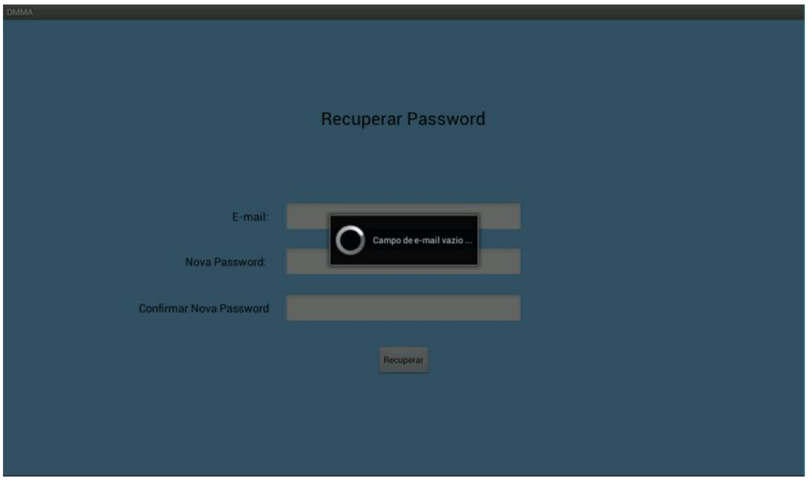


Figure 38 - Alert to inform the user that the entered e-mail address does not exist.

Is used in the dispersion function SHA1 cryptographic for the encryption of the password and for strengthening security is still used a string (salt) which is randomly generated when the user carries out the request, composed of 20 characters. The combination is used for the encryption of the password is as follows:

$$\textbf{Sha1 = salt + password + salt + salt} \qquad (2)$$

After the login, the screen that is presented to users in the MA contains the following functionality: "Connect Sensors", "Disconnect Sensors", "Real-time Data", "History" and "Usage Guide" (Figure 39).

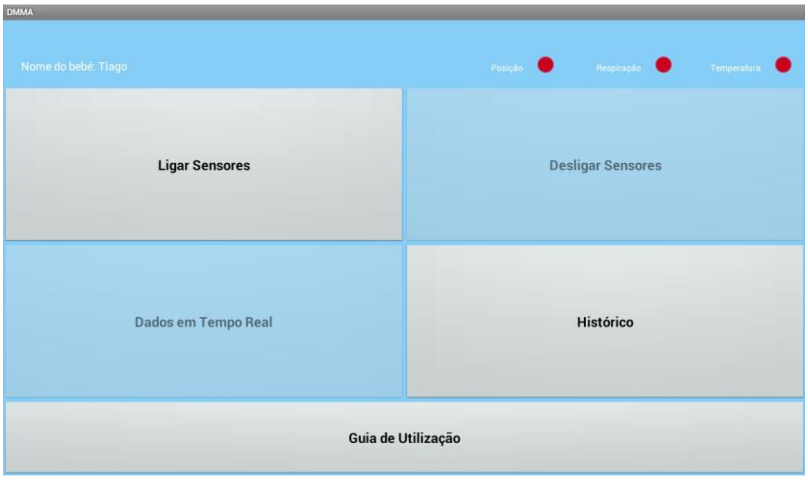


Figure 39 - Screen with existing functionality in MA application.

In CA the features shown are “Sensor Data”, “History” and “Usage Guide” as you can see Figure 40.

Figure 40 - Screen with existing functionality in CA application.

5.3.1. Connect and Disconnect Sensors

When the user clicks the button "Connect Sensors", the application makes a request to the web service that is hosted on the server. This return to the MAC address of the sensors, so as to be able to connect them. To be returned to the application request information guard several user data that will be needed for future requests to the web service. When the sensors are connected the “leds” in the upper right corner of the application change from red to green, for the user to know which sensors are connected and "Connect Sensors" deactivate Sensors. Already the buttons "Disconnect Sensors” and "Real-time Data" are assets to the user can view the data collected by the sensors or power off the sensors.

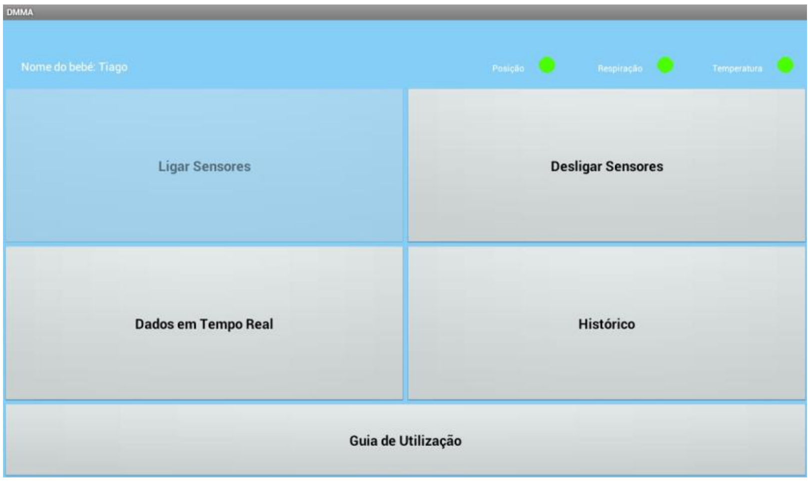


Figure 41 - Leds informing the user that the sensors are connected and ready to collect data.

The user can disconnect sensors at any time and to do this just need to click the button "Disconnect Sensors". When the sensors are switched off, the collection of data from the sensors is interrupted and the "leds" in the upper right corner of the application change from green to red. As for buttons "Disconnect Sensors" and “Real-time Data" are inactive and "Connect sensors" button is active , as shown in Figure 39 ago.

5.3.2. Real-time Data

This feature is available in the two applications but with a difference, in MA are the data that are collected by the sensors as shown in Figure 42.

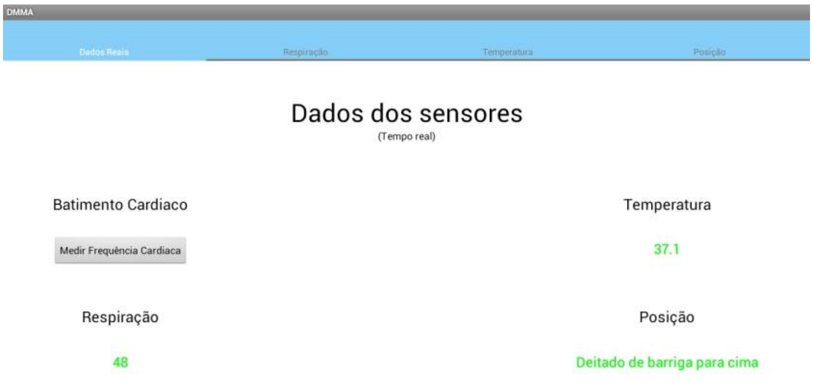


Figure 42 - Real-time Data screen (MA).

In the data available to the user are obtained from the web service, it will return every second the last values collected and stored in the database as shown in Figure 43.

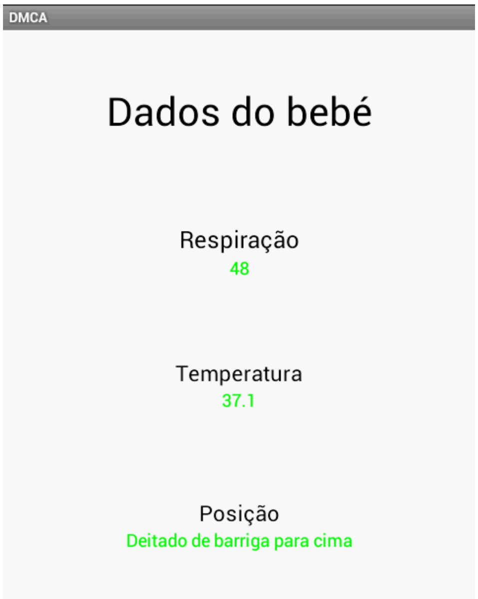


Figure 43 - Real-time Data screen (CA).

The user can view the same screen the data collected by the sensors, Temperature, Position and Respiration and he can also see in the different existing separators the graphics provided with the data collected from the sensors were connected to (case of MA).

The graphics feature the data without any transformation, that is, are presented in 3 axes, given that accelerometers are being used. These data are presented in this way to be presented a doctor or nurse to analyse and interpret the data collected.

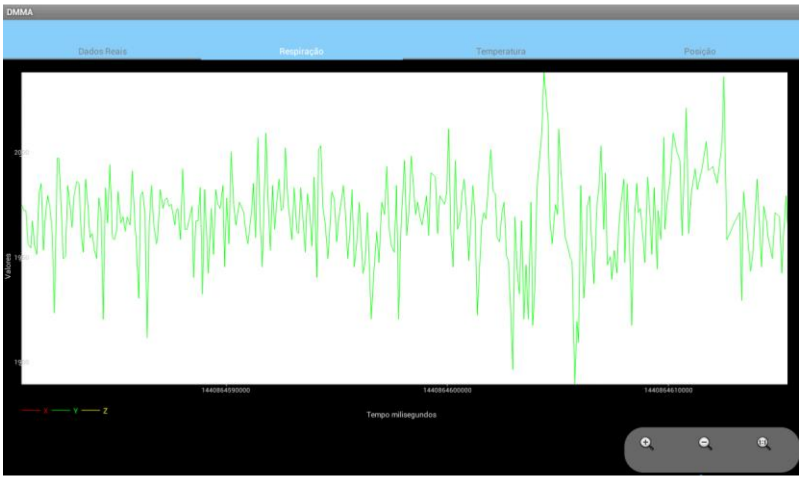


Figure 44 - Chart with data coming from the respiration sensor untreated.

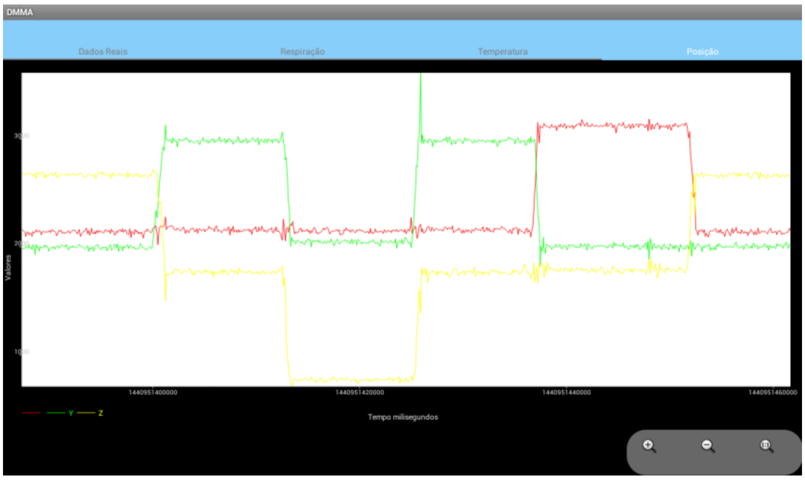


Figure 45 - Chart with data coming from the position sensor untreated.

For the Heartbeat sensor is available a button that will redirect the user to a new screen (Figure 46). To know the baby's heart rate is necessary to touch the camera of the mobile device to one of the most sensitive skin areas, such as the hand. After putting the mobile device's camera to the baby's skin, on the screen can be see the existing pigmentation in the skin of the baby and is through the pigmentation that heart rate is calculated. This process is explained further in section 5.3.

Figure 46 - Screen that allows measuring the cardiac frequency.

5.3.3. History

The Historical functionality serves to report for caregivers know if anything unusual happened in recent times with the baby. This feature allows you to view the data in charts of all existing sensors in resolving (Heartbeat, Respiration, Temperature and Position) in different dates, that is, can be found the history of the last hour, last twelve hours, last day, last week, last month and all data since the record was made.

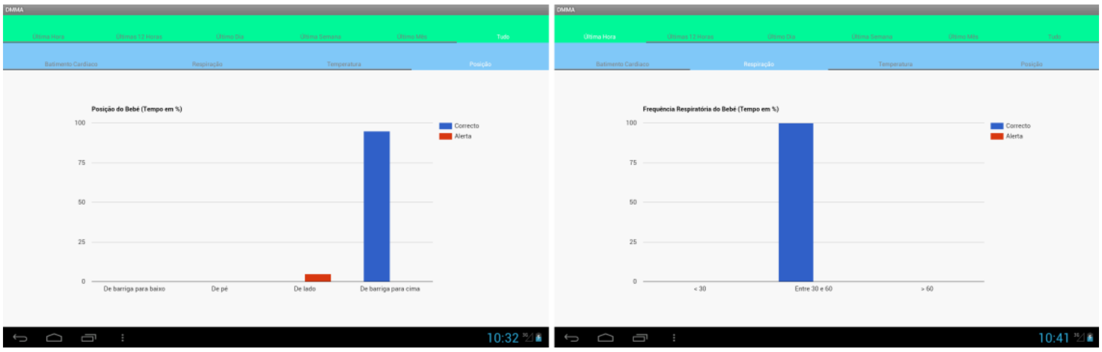


Figure 47 - History screens.

5.3.4. Usage Guide

This feature is projected to make a guided tour of the application, where the user can learn all about the same, so that eliminates any doubts as to interaction with the application.

5.4. Biofeedback Monitoring Toll

The biofeedback monitoring tool is one of the strengths of this solution, used to analyse, transform and provide the user with the data collected by the sensors. In addition still sends to the web service data to be stored in the database that supports the solution.

When the user connect the sensors is activated the tool to monitor the data collected by sensors, which will be compared with each other and with the data considered normal by reference. The data considered normal, are the values of vital signs that are considered normal in infants up to one year of life.

For the baby's position while it is sleeping, or lying in the crib is considered the baby is lying correctly as this is belly up. All other positions, lying on your stomach, lying on its side or standing, are considered riskier assets, since the baby is lying on your stomach for a few minutes can suffocate and going into cardiac arrest, or if you are standing may fall and suffer serious injuries. The baby sleeps on his side or on your stomach breathes the same air that expires, that is, the baby inhales an air rich in carbon dioxide and oxygen-poor, performing a choking, where this is no oxygen reaching the death [52].

As for the baby's body temperature, the temperature is considered normal when it is between the 36.4ºC and 37.5°C [53]. All other temperatures outside of this range are considered dangerous, more in the case of higher temperatures that are considered temperatures of fever and are very dangerous for the baby. To the respiratory rate, is considered normal for a baby with up to a year to live that has a respiratory frequency between 30 and 60 breaths per minute [54]. With regard to the normal heart rate for a baby with up to one year of life that has a frequency between 100 and 160 beats per minute [55].

These are the main vital signs of any person, be it a small and fragile baby or an adult and very healthy and that's why it was chosen as the data to be collected and work to ensure the safety of babies with this solution developed. Below is explained how were analysed and processed data that was collected by the sensors.

The data to begin collected are sent in real time to the application MA which in turn will start to be analysed by the monitoring tool. All the data are analysed every second, where are stored in variables being analysed and compared to amounts previously collected, if these already exist.

In the case of position is the frequency that is collected by the sensor is the one that is parsed and transformed, where easily can analyse what is the position in which the baby is, as shown see in Figure 48.

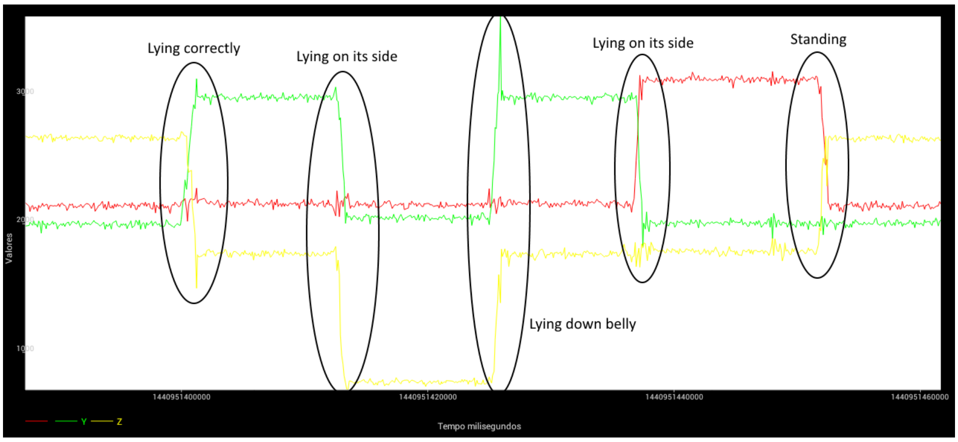


Figure 48 - Position of the baby.

For temperature data that is collected and sent every second sensor for the application already correspond to actual values in degrees Celsius (°C), because the transformation is done in the module itself that was presented in the previous chapter. The only monitoring tool presents data to the user.

The respiration sensor is used to measure the frequency of baby's breathing. The human being breathes automatically, but sometimes newborns forget breathing and die asphyxiated with lack of oxygen in the system. To prevent this situation, is used a sensor that measures the pressures performed by the baby on crib. The pressure exerted by the baby during inspiration is different from exercised at expiration. With this fact, it is possible to sense the respiratory rate. Through the mobile application, it is possible display charts.

And finally to the heart rate is calculated through analysis of the images that are collected by the camera. The latest image is analysed, where the YUV data are analysed and all the red pixels are removed. The following is applied a filter to smooth the data array that is created with the values of each pixel of the image. After applying the filter is calculated the average of the values in red pixels and is compared with the average was calculated in the previous image. The image collection is made every second. This will take between ten and thirty seconds to get an accurate heart rate.

5.5. Anomaly Detection with External Alerts

Anomaly detection system is also one of the strengths of this solution, because it allows the user to always be informed of what goes wrong with your baby's vitals, without the need to have the application open on your mobile device. The user simply has the application running on your device and the login done. From that moment all alert notifications that are triggered will be visible in the notification bar of your device.

Anomaly detection system works on the basis of data collected by the sensors after being treated by monitoring tool that was presented in the previous section. The data to be presented on the real-time data screen are being analysed every five seconds, where these will be compared with the data collected during the five seconds earlier.

In the case of heading, can be triggered an alert notification in three different situations. If the baby is lying on your stomach, lying on its side or standing for more than three seconds is triggered an alert on the two applications, if the CA is linked, to inform the caretaker of the position of the baby.

For respiration, are always analysed the five values collected every five seconds. If during this period the values are below 30 or above 60 per minute is launched a preventive alert notification to inform the caregiver. If the values are below 20 or above 70 is released a notice of danger, since the baby's respiratory frequency too low or too high.

The baby's body temperature is also reviewed every five seconds and there are two types of alerts, the alert to inform the caregiver that baby meets temperature are considered of fever and the alert to inform you that the baby is with a very low body temperature.

Below we can see a summary table (Table X) with alerts that exist in the solution to be triggered as notifications on mobile devices that have the applications installed.

Table X - Messages sent in alerts that are triggered.

Sensor	Message
Position	The baby is lying on your stomach.
	The baby is lying on its side.
	The baby's foot.
Temperature	The baby is with a body temperature of a fever.
	The baby is with a body temperature below normal.
Breathing	The baby is with a respiratory rate lower than normal.
	The baby is with a respiratory rate concern, below normal.
	The baby is with a respiratory rate above normal.
	The baby is with a respiratory rate concern, above normal.

5.6. Conclusion

In this chapter has been demonstrated all the solution developed in this thesis. In section 5.2, while architecture was presented in section 5.3 has been made a tour of both applications, to make known all the features available to users. In section 5.4 is explained the data monitoring tool of biofeedback, which is present in the feature "Real-time data", and in section 5.5 is explained how and when alerts are generated for warning of caregivers that something unusual is happening with the baby.

6. System Validation and Performance Evaluation

This chapter focuses on the system performance evaluation and validation of the proposed mobile solution for sudden infant death syndrome prevention.

6.1. Introduction

First, the requirements that are needed to run the applications correctly and efficiently in mobile devices are addressed on Section 6.2. In Section 6.3 some results achieved and collected in a real scenario are presented. Several experiments were performed to validate the system in 4 different babies, all with less than a year to live. Each test lasted an hour, a total of 4 essays were collected and stored about 44000 samples.

Section 6.4 presents the results obtained in the experiments, the alerts caused on data analysis. In some moments of the trials was forced to be originated in particular alerts of position of the baby to make sure they were triggered correctly. Finally, to conclude this chapter is made an overall assessment of the results.

6.2. Requirements for Executing the Application

Before conducting the experiments to validate the solution, applications were installed on mobile devices as if for the first time. First of all check if you have all the components that make up this solution, the two applications and sensors with battery and make sure that the server is online. Also verify that the mobile devices have Android OS versions above 3.0, Internet access and if the mobile device containing the MA has the Bluetooth connected. After checking the links, you must pair the sensors via Bluetooth and will request a code for each of the sensors. The code to be entered by the user to perform the pairing is 1234.

After you have installed the applications, is required the user to be registered in the system. For this are introduced all the data about the baby and caregiver, as well as the last 4 digits of the MAC Address of each sensor of Shimmer. Then of the registration the user may log in and enjoy all the features of the application.

6.3. Collecting Bio-signals and its Analysis

The case study it is a methodological approach to investigation especially suitable when it seeks to understand, explore or describe events and complex contexts, in which are involved simultaneously several factors [56].

Each test was conducted over the course of about an hour. The data was collected when the babies were asleep.

In each test were collected 3600 samples per each of the sensors, temperature, respiration and position and were still collected 180 samples by heart rate sensor, which gives a total of 10980 samples for each test. As has been said previously the heart rate must be measured by the caregiver of the child once it is necessary to touch the camera of the mobile device to a zone where the baby has sensitive skin, for example in the wrist or hand. All these data are stored in the database of solution support which made possible a more detailed analysis of the same.

The obtained results demonstrated a quantitative analysis of the applicability of the solution in real world scenarios. Tables XI, XII, XIII and XIV summarize the data collected in 4 trials all at different times. All the babies were apparently healthy at the time of conducting the experiment.

Table XI - First test data performed.

Sensors	Samples	Trials errors	Correct trials	Average
Heart Rate	180	22	158	88%
Respiration	3600	0	3600	100%
Temperature	3600	0	3600	100%
Position	3600	0	3600	100%

Table XII - Second test data performed.

Sensors	Samples	Trials errors	Correct trials	Average
Heart Rate	180	26	154	86%
Respiration	3600	0	3600	100%
Temperature	3600	0	3600	100%
Position	3600	13	3587	99%

Table XIII - Third test data performed.

Sensors	Samples	Trials errors	Correct trials	Average
Heart Rate	180	26	154	86%
Respiration	3600	0	3600	100%
Temperature	3600	37	3563	99%
Position	3600	37	3563	99%

Table XIV - Fourth test data performed.

Sensors	Samples	Trials errors	Correct trials	Average
Heart Rate	180	31	149	83%
Respiration	3600	0	3600	100%
Temperature	3600	63	3537	98%
Position	3600	0	3600	100%

Table XI relates to the first test carried out. As can see only obtained 22 errors in heart rate, all of which indicated the low heart beat on normal (100 beats). This error is due to the position in which the caregiver puts the baby toe in the mobile device or the time that it takes to read a certain heart rate. All other samples were collected with 100 percent effectiveness.

Table XII corresponds to the second test. It turns out those occurred 39 errors, of which 26 on heart rate and 13 in position. The cause of the occurrence of errors related to heart rate has been identified in the analysis of the first test. With respect to the errors that occurred in the position of the baby, they were forced to verify that alerts are raised when the baby is in a position of risk.

The following table (Table XIII) concerns the third test affected. They identified 72 errors, 26 in heart rate, temperature and 37 in 9 the baby's position. The relative errors were due to the temperature having reached the baby temperature above 37.5°C. The errors related to heart rate and position of the baby has been described previously.

Finally, the Table XIV relates to the last test carried out. As can be seen have been detected, although error 94, 31 related to heart rate and 63 to temperature.

The following graph shows, in percentage, the error rate obtained by each sensor in data collection in the four experiments.

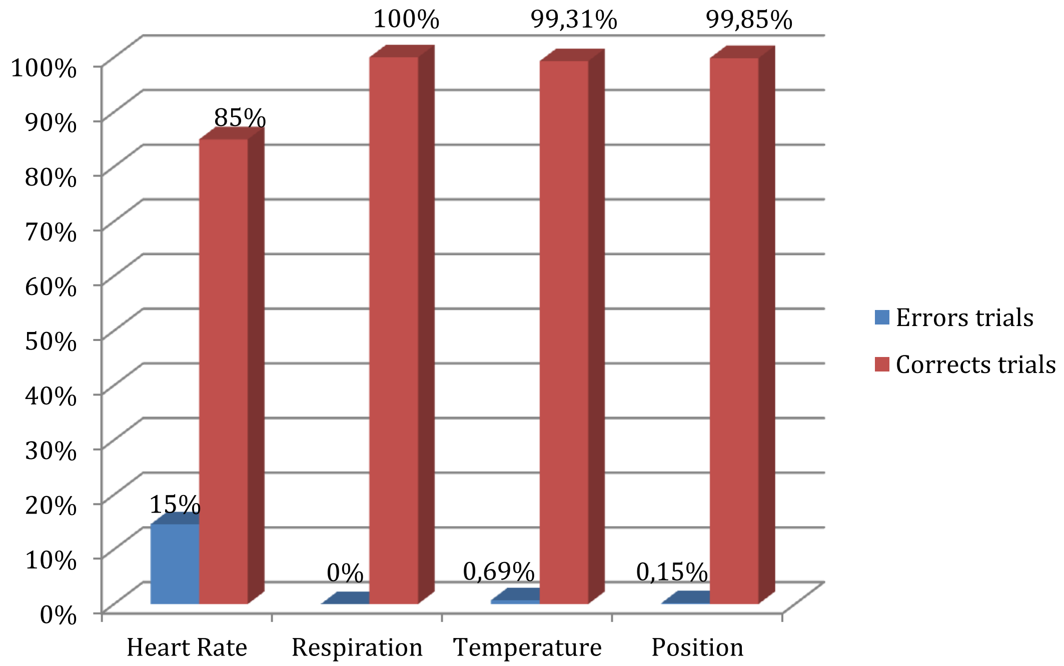


Figure 49 - Graph of percentages.

6.4. Falls Detection and its Analysis

When the values are abnormal, that is, when they are not within the ranges that were referred to in Chapter 5, are posted in alerts caregiver's mobile devices. Alerts are raised when the values read by the sensors are abnormal in a period greater than or equal to 3 seconds.

The Table XV presents the number of alerts that were released during the 4 tests.

Table XV - Number of alerts triggered during the experiments.

Sensor	Number of alerts
Respiration	0
Temperature	33
Position	7

With regard to alerts, it should be noted that there is no heart rate alerts. For respiration was not released without warning during the four tests. As for the temperature 33 alerts were launched during the 4 trials, 12 in the third test and 21 in the second. Finally for the position were launched 7 alerts, of which four in the second test and three to the third.

6.5. Conclusion

This chapter presented the requirements for the proper functioning of the solution, in Section 6.2. Section 6.3 presents the data collected during the testing director in 4 babies. Already in Section 6.4 are presented the results of the alerts that were raised.

This solution allows having a non-invasive monitoring and monitoring of vital signs (temperature, respiratory rate and heart rate) and the position where the baby is, which allows greater freedom to the caregiver that need not always be around your baby.

Besides, has the advantage that all data and alerts generated are stored in a database to support solution, to allow the caregiver or doctors have access to previous data, allowing doctors a later analysis of the data when necessary. So it is possible to recognize the situations in which the health of the baby is in danger. In this way, it is possible to identify situations of illness, through changes in body temperature; high heart rate; detect abnormal heart rhythms; situations of cardiac arrhythmias and other health situations that can be diagnosed.

7. Conclusions and Future Work

This chapter is divided into two sections. The first section presents the main conclusions of the work developed during this masters program, while in the second section are presented some of the points that can improve this work and makes it even more interesting, complete and attractive.

7.1. Main Conclusions

The main objective of this dissertation was to develop and deploy a mobile solution for prevention, supervision and monitoring of biofeedback for babies up to one year of life in order to prevent sudden death.

With the objective defined, started by doing a study of the kind of applications that exist on the market to not develop a similar application. This study is presented in Chapter 2 where you can observe many solutions/systems for the monitoring of the baby on a daily basis. Then, define the solution requirements, what are the features that would have, using sensors and all essential points to perform a requirements analysis as possible not to miss anything. This analysis is presented in Chapter 3, where are presented use case diagrams, activities, entity-relationship, classes and components, tables and descriptions.

After the analysis and definition of requirements it began implementation. Many experiments were developed to figure out how to work with the sensors, as they were collected and sent the data, and how if they could analyze the same. Completed this work, began by defining the layout for the prototype in order to be a simple layout, allowing users easy interactivity with applications. After the layout be defined was done all development necessary for the solution to be complete.

When the application was completed, it was made to be validated to ensure that all features implemented were well developed. This whole process can be seen in chapters 4 and 5.

Finally there were experiments to ensure the viability of the solution. Trials were performed in real world scenario to ensure that everything would be as it was planned earlier. All experiments go as expected and it was possible to ensure a functional and application to measure all bio-signals correctly. The experiments can be found in Chapter 6, where is presented a summary of each of the trials.

With all these points here exposed and according to the discussion contained in this section, it can be concluded that the objectives outlined for this master program have been achieved successfully.

7.2. Future Work

To complete this work, there are presented some improvements that can be made in the future to complement the work that has been described in this document:

- Firstly, improving the layout of both applications is very important to make the solution more attractive.

- Develop the solution for other mobile platforms, like Apple's iOS and Windows Phone.

- Integrate various languages in applications, making it possible its use in different countries.

- Integrate other sensors in the application such as humidity sensor and carbon dioxide, to read more data from the body of the baby, without compromising the integrity of the same.

- Make possible the integration of all sensors in clothes for babies, through textile sensors for comfort and not need the placement of sensors on the baby every day.

All these proposed improvements have focused the babies, not to mention once again the physical integrity and security.

REFERENCES

[1] Sudden Infant Death Syndrome, [Online]. Available: http://www.todopapas.com.pt/bebe/saude-do-bebe/sindrome-da-morte-subita-infantil-2640; Accessed: October, 2014.

[2] Causes of SIDS, [Online]. Available: http://o.canbler.com/artigo/sindrome-da-morte-subita-infantil; Accessed: October, 2014.

[3] Infant mortality, [Online]. Available: http://www.oecd-ilibrary.org/sites/9789264183896-en/01/08/index.html?itemId=/content/chapter/9789264183896-11-en; Accessed: October, 2014.

[4] Prevention of Sudden Death, [online]. Available: http://criancaefamilia.spp.pt/gravidez-e-primeiro-ano-de-vida/prevencao-da-morte-subita.aspx; Accessed: October, 2014.

[5] Bradley B. Randall, David S. Paterson, Elisabeth A. Haas, Kevin G. Broadbelt, Jhodie R. Duncan, Othon J. Mena, Henry F. Krous, Felicia L. Trachtenberg and Hannah C. Kinne“, Potential Asphyxia and Brainstem Abnormalities in Sudden and Unexpected Death in Infants” in Pediatrics, 11 November, 2013.

[6] "SIDS and Other Sleep-Related Infant Deaths: Expansion of Recommendations for a Safe Infant Sleeping Environment" in Pediatrics, Vol. 5, pp. 1030-1039, 1 November, 2011, DOI: 10.1542/PEDS.2011-2284.

[7] João M. P. L. Caldeira and Joel J. P. C. Rodrigues, "Body Area Networks for Healthcare", in McGraw-Hill Yearbook of Science and Technology 2014, McGraw-Hill, USA, ISBN: 978-0-07183-106-2, pp. 47-50, January 2014.

[8] "Rede de Sensores sem Fios", [Online]. Available: http://www.slideshare.net/PaulaGonalves4/redesdesensoressemfio; Accessed: October, 2014.

[9] N. Gross, "21 ideas for 21st century", Business Week, August 1999, Accessed, October 2014.

[10] "Rede de Sensores sem fios - Conhece esta tecnologia", [Online]. Available: http://pplware.sapo.pt/windows/software/redes/rede-de-sensores-sem-fios-conhece-esta-tecnologia; Accessed, October, 2014.

[11] "Wireless Sensor Networks", [Online]. Available: http://en.wikipedia.org/wiki/Wireless_sensor_network; Accessed, October, 2014.

[12] "Características das redes de sensores", [Online]. Available: http://www.gta.ufrj.br/grad/06_1/rssf/node5.html; Accessed, October 2014.

[13] “Uma arquitectura de redes de sensores do corpo humano”, [Online]. Available: http://repositorio.unb.br/bitstream/10482/1752/1/Tese_TallesMarceloGABarbosa.pdf; Accessed: October, 2014.

[14] “Developing wireless body area networks standard”, [Online]. Available: http://www.ieee802.org/15/pub/TG6.html; Accessed, October, 2014.

[15] Sana Ullah, Henry Higgins, Bart Braem, Benoit Latre, Chris Blondia, Ingrid Moerman, Shahnaz Saleem, Ziaur Rahman and Kyung Sup Kwak, “A Comprehensive Survey of Wireless Body Area Networks: On PHY, MAC, and Network Layers Solutions”, Journal of Medical Systems (Springer), 2010.

[16] Min Chen, Sergio Gonzalez, Athanasios Vasilakos, Huasong Cao, Victor C. M. Leung, "Body Area Networks: A Survey", Mobile Networks and Applications (MONET) (Springer Netherlands), vol.16, no.2, pp.171-193.

[17] Samaneh Movassaghi, Mehran Abolhasan, Justin Lipman, David Smith, Jamalipour, "Wireless Body Area Networks: A Survey", IEEE Communications Surveys and Tutorials (IEEE).

[18] R. Schmidt, T. Norgall, J. Mörsdorf, J. Bernhard, T. von der Grün, "Body Area Network BAN--a key infrastructure element for patient-centered medical applications", Biomed Tech.

[19] T. O'Donovan, J. O'Donoghue, C. Sreenan, P. O'Reilly, D. Sammon and K. O'Connor, “A Context Aware Wireless Body Area Network (BAN)”, In proceedings of the Pervasive Health Conference 2009.

[20] M. R. Yuce, "Implementation of wireless body area networks for healthcare systems", Sensors and Actuator, pp.116–129.

[21] Val Jones, Richard Bults, Dimitri Konstantas, “Body Area Networks for Healthcare”, [Online]. Available: http://doc.utwente.nl/66761/1/WG1_Val_Jones_Richard_Bults.pdf; Accessed: October, 2014.

[22] “Newsletter - Sensors for Healthcare”, [Online]. Available: http://vip.doc.ic.ac.uk/bsn/m621.html; Accessed: October, 2014.

[23] “Rede de Sensores Sem Fios, considerações sobre a sua instalação em ambiente real”, [Online]. Available: http://ubicomp.algoritmi.uminho.pt/csmu/proc/camilo-125.pdf; Accessed: October, 2014.

[24] Thomas J. Sullivan, Stephen R. Deiss, and Gert Cauwenberghs, “A Low-Noise, Non-Contact EEG/ECG Sensor”, BIOCAS 2007- Biomedical Circuits and Systems Conference (IEEE 2007), pp.154-157, November 27-30.

[25] Yu M. Chi and Gert Cauwenberghs, “Wireless Non-contact EEG/ECG Electrodes for Body Sensor Networks”, 2010 International ConferenceBody Sensor Networks (BSN)(IEEE 2010), pp.297-301, June 7-9, 2010.

[26] Wei Chen, Son Tung Nguyen, Sibrecht Bouwstra1, Roland Coops, Lindsay Brown, Sidarto Bambang Oetomo, Loe Feijs, “Design of Wireless Sensor System for Neonatal Monitorin”, 4th IFIP International Conference on New Technologies, Mobility and Security (NTMS 2011), February7-10, 2011.

[27] “Aiball”, [Online]. Available: http://www.thumbdrive.com/aiball/index.html; Accessed: October, 2014.

[28] “Cardiograph”, [Online]. Available: https://play.google.com/store/apps/details?id=com.macropinch.hydra.android&hl=pt_PT; Accessed: November, 2014.

[29] Wei Chen, Sietse Dols, Sidarto Bambang Oetomo, Loe Feijs, “Monitoring Body Temperature of Newborn Infants at Neonatal Intensive Care Units Using Wearable Sensors”, Proceedings of the Fifth International Conference on Body Area Networks (BodyNets '10), pp. 188-194.

[30] “Remote Temperature and Humidity Sensor for new parents”, [Online]. Available: http://mtifall10.wordpress.com/2010/12/11/final-project-2/; Accessed: November, 2014.

[31] “Smart Wristband Baby Monitor”, [Online]. Available: http://moms.popsugar.com/photo-gallery/33385465/Moneual-Smart-Wristband-Baby-Monitor; Accessed: November, 2014.

[32] “iBabyGuard”, [Online]. Available: http://www.ibabyguard.com/; Accessed: November, 2014.

[33] “BabyPing”, [Online]. Available: http://www.babyping.com/the-monitor; Accessed: November, 2014.

[34] “iBaby Monitor”, [Online]. Available: http://www.ibabylabs.com/store/ibaby-monitor-m3s; Accessed: November, 2014.

[35] Hung Cao, Lun-Chen Hsu, Thermpon. Ativanichayaphong, Jeongsik Sin, Harry E.Stephanou and J. C. Chiao, "An Infant Monitoring System Using CO2 Sensors", IEEE International Conference RFID 2007, pp. 134-140, March 26-28, 2007.

[36] Hung Cao, Lun-Chen Hsu, Thermpon. Ativanichayaphong, Jeongsik Sin, and J. C. Chiao, "A non-invasive and remote infant monitoring system using CO2 sensors", 2007 IEEE Sensors, pp. 989-992, October 28-31, 2010.

[37] “Mimo”, [Online]. Available: http://conectica.com.mx/2014/01/07/ces-2014-intel-le-da-un-toque-tecnologico-la-ropa-de-bebes/#!sl54f; Accessed: November, 2014.

[38] “Mimo”, [Online]. Available: http://mimobaby.com/; Accessed: November, 2014.

[39] “The baby’s Fairy Monitors Body Temperature and Vital Signs”, [Online]. Available: http://www.trendhunter.com/trends/babys-fairy; Accessed: November, 2014.

[40] Confidently See Your Baby’s Health at a Glance, [Online]. Available: http://www.owletcare.com/; Accessed: November, 2014.

[41] Zahid Mehmood, Waqas Nasar, Junaid Imtiaz, Ahsan Jamal Khan, Muhammad Ahsan Habib, “Security Requirements for Future Body Sensor Networks”.

[42] B. Kuris and T. Dishongh, "SHIMMER Hardware Guide Rev 1.3," in SHIMMER - Sensing Health with Intelligence, Modularity, Mobility, and Experimental Reusability: Intel Corporation, p. 15, 2006.

[43] B. P. L. Lo, S. Thiemjarus, R. King, and G. Z. Yang, “Body sensor network – A wireless sensor platform for pervasive healthcare monitoring,” in Proc. 3rd Int. Conf. Pervasive Computing, Munich, Germany, pp. 77–80, 2005.

[44] J. Polastre, R. Szewczyk, and D. Culler, “Telos: Enabling ultra-low power wireless research,” in Proc. 4th Int. Symp. Inf. Process. Sens. Networks, Los Angeles, CA, pp. 364–369, 2005.

[45] G. Werner-Allen, K. Lorincz, M. Ruiz, O. Marcillo, J. Johnson, J. Lees, and M. Welsh, “Deploying a wireless sensor network on an active volcano,” IEEE Internet Comput., vol. 10, pp. 18–25, 2006.

[46] “NTC Type MA100 Biomedical Chip Thermistor Datasheet”, [Online]. Available: http://www.gesensing.com/downloads/datasheets/920_321a.pdf; Accessed: May, 2015.

[47] João Manuel Leitão Pires Caldeira, “Communication Tolls with Intra-body Sensors”

[48] “Tablet Asus Transformer Prime TF201”, [Online]. Available: https://www.asus.com/Tablets/Eee_Pad_Transformer_Prime_TF201; Accessed: June, 2015.

[49] “BQ 5E FHD”, [Online]. Available: http://www.bq.com/gb/aquaris-e5; Accessed: June, 2015.

[50] Adrian Burns, Barry R. Greene, Michael J. McGrath, Terrance J. O’Shea, Benjamin Kuris, Steve0n M. Ayer, Florin Stroiescu, and Victor Cionca, "SHIMMERTM – A Wireless Sensor Platform for Noninvasive Biomedical Research", IEEE Sensor Journal, Vol. 10, no. 9, pp. 1527-1534, September 2010.

[51] “SHIMMER”, [Online]. Available: www.shimmersensing.com; Accessed: December, 2014.

[52] “Morte súbita e a posição para o bebé dormir”, [Online]. Available: http://guiadobebe.uol.com.br/morte-subita-e-a-posicao-para-o-bebe-dormir; Accessed: April, 2015.

[53] “How to take your baby's temperature”, [Online]. Available: http://www.nhs.uk/conditions/pregnancy-and-baby/Pages/how-to-take-your-babys-temperature.aspx; Accessed: April, 2015.

[54] “Pediatric Respiratory Rates”, [Online]. Available: https://www.health.ny.gov/professionals/ems/pdf/assmttools.pdf; Accessed: April, 2015.

[55] “Sinais vitais - Temperatura corporal, pulso, pressão arterial e respiração”, [Online]. Available: http://www.copacabanarunners.net/sinais-vitais.html; Accessed: April, 2015.

[56] “What is a Case Study”, [Online]. Available: http://grupo4te.com.sapo.pt/mie2.html; Accessed: August, 2015.

APPENDIX A

This appendix includes the main contribution to this dissertation. The paper is entitled “A Sudden Infant Death Prevention System for Babies” and was submitted and presented at the international conference (IEEE HEALTHCOM 2014).

A Sudden Infant Death Prevention System for Babies

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***Abstract* – The sudden infant death syndrome (SIDS) is an expert diagnosis when an apparently healthy baby dies without explanation. When physicians or coroners cannot explain the cause of death it is classified as sudden death. This paper reviews the related literature and proposes a mobile solution based on biofeedback monitoring that tries to prevent the sudden death in infants. The sudden death system uses real-time data collection from sensors to diagnose, in advance, baby health problems and prevent those are responsible for a baby. When an issue is detected by this system (i.e., the sensors send abnormal data), it sends a warning to those responsible for the baby. It allows the access to data from sensors and their analysis in real-time (such as, the baby position and the crib). Signal processing algorithms are used in real-time to prevent a sudden death. Mobile devices (such as, smartphones or tablets) are used to process the sensed data and monitoring a baby performing alerts/warnings when an abnormal situation is detected. The proposed approach is evaluated and demonstrated through a prototype.**

Keywords— Sudden infant death syndrome (SIDS); infant death prevention; Shimmer; body sensors; eHealth

I. Introduction

Sudden death is something difficult to explain in babies because no one knows its origin in most cases [1]. Sudden death has several origins that can be prevented, but others not, and in certain cases are fatal [2]. There are new challenges to offer a larger and better quality of life for both parents and babies. So parents can live more relaxed in relation to their babies and may be also more protected in some way. In a real scenario it would be possible to predict when something goes wrong with a baby in order to avoid greater evils or even death. Based on this, considering a real scenario using mobile technology, this paper proposes a system that tries to predict and detect situations that evaluate the risk of a baby and alert those are responsible by her/him or even competent authorities. The system emits an alert, in real time, so nannies can react immediately, check the baby state, and intervene if needed. The alert signs are issued through a smartphone or tablet. Body sensors, used for measuring physiological signals from a baby, are connected to the mobile device via Bluetooth and Wi-Fi. The sensors are attached at the baby body and placed at the crib to have more accurate data for monitoring signals as heart rate, cradle temperature, baby's position and baby's breath. The mobile health tool monitors a baby and communicates through Bluetooth with a mobile device, in real time. The mobile devices display the data of each sensor and execute algorithms created to analyze the received biofeedback signals. If any issue with the baby is detected, the system notifies the person responsible by him/her immediately [3]. The paper focuses on a methodology for the sudden death prevention in babies based on biofeedback and crib environment monitoring, and data processing using a combination of multiple sensors (heart rate, respiration, temperature, and position).

The rest of the paper is organized as follows. Section II elaborates on the related work about the addressed topic and Section III presents the proposed system architecture. Section IV describes the mobile application, used sensors and mobile resources while the performance evaluation, demonstration, and validation of the solution, in a real scenario, is presented in Section V. Finally, Section VI concludes the paper and pinpoint suggestions for further works.

II. Related Work

The SIDS phenomenon has been defined as a children premature death. These catastrophic events normally happen unexpectedly and without any kind of warning. Several tolls are available in the related literature or even applications to monitor and prevent the Sudden Infant Death Syndrome (SIDS).

Outdated solutions include those that react on sound meaning if the baby is alive, or display an image of sleeping baby telling if it breathes or not. These conventional baby monitor techniques can provide a false sense of security. It is extremely needful go deeper with higher precision to prevent SIDS. This is the major challenge addressed in this paper. The descriptions of the main problems in old methods are presented in order to surpass the conventional baby monitors to detect sleep apnea.

A successful case of a gadget application to Vital Signs Monitoring is presented in [4]. This system monitors the baby respiration and heart rate. It is designed for either the parental consumer or the medical monitoring assistance. Another SIDS detection system presented in [5] entitled non-invasive and remote infant monitoring system using the carbon dioxide sensors to reduce the potential risk of SIDS. This method proposes carbon dioxide sensors placed in the crib around the baby to monitor the exhaled air concentration variation.

A similar system also uses a carbon dioxide sensors and active Radio Frequency Identification (RFID) to be used on infants is presented in [6]. This method is proposed for further application in a large nursery room. This non-invasive sensors placement to offer baby comfort is the most accepted contribute through new sensors technology. The sensors placed around the baby to detect if there is anything unusual to find a correct way to prevent SIDS but it is also the most inchoate method. Usually, the best way proposed to address this issue includes wearable sensors placed carefully in specific locations.

A solution using accelerometers for the monitoring of an infant´s heart rate is presented in [7]. For SIDS detection, accelerometers are used for sensing micro-movements performed by babies.

A most complex procedure is presented in [8]. It presents a study involving five infants to assess the capability of pulse transit time and shows its potential to indicate abrupt blood pressure. It uses a standard nocturnal diagnosis of polysomnography, consisting in capturing, recording, and analyzing bio-physiological changes in a baby while sleeping. This procedure is very complex and it only is possible in an equipped lab with professional and expensive equipment.

Another solution is presented in [9]. It is based on a vest to monitor the baby's heartbeat. It includes sensors that are fully integrated into the parameterization of breathing, heart rate, temperature, and humidity, to detect excessive sweating, and continuous monitoring. It provides a mobile gateway to disseminate the collected information, allowing external storage. It offers access to user terminals as well as to monitor the baby's condition at a distance. With baby data saved in a database, later, it is possible to observe if a baby had health problems before. Thus, there has been a consistent dataset which can be used for later studies.

The proposed solution presented in this paper is designed and created to gather contributions from the related literature and distinct contributions to create an innovative approach.

I. System Architecture

This section presents the architecture of the system proposed in this paper as well as the modules with body sensors and Web services. Figure 1 shows the architecture of SIDS detection with sensors placed on a baby body and the corresponding crib.

The baby cradle supports Shimmer sensors to collect several bio-signals parameters [10, 11]. They are connected to a smartphone or tablet through Bluetooth and Wi-Fi, sensing and allows real-time monitoring. The baby sleep was a detectable state and this is the most danger situation for newborns because, in the early years, they spend the most time of their premature lives sleeping. Several vital functions may be measured with sensors but nothing can replace the presence of a mother (or a nanny). The mobile app is used as a gateway that provides a powerful tool to support and prevent most danger situations such as a cardiac or a respiratory arrest or prevent a baby change position.

The mobile device (also gateway) can use wi-fi, GSM, UMTS or similar is used to disseminate the collected information, allowing external storage and remote access for baby monitoring at a distance.

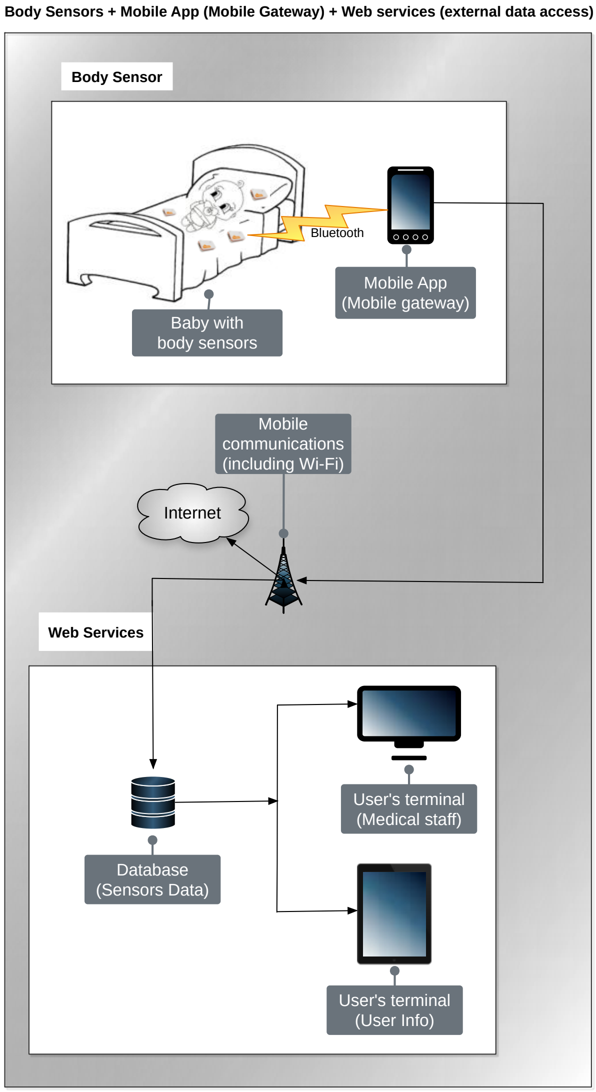

Fig. 1. Illustration of the architecture for a prevention and monitoring system with the three tiers (body sensors, storage, and Web services).

II. Mobile Application

A. *Baby SIDS monitoring toll*

Bio-physiological activity monitoring of babies body is not an easy task since their bodies are fragile and, sometimes, it is difficult to capture bio-signals due to their small size. The visual presentation of biofeedback is important for abnormal parameters detection. This biofeedback monitoring tool is designed for being deployed with available devices that can monitor the considered parameters. In this paper, the solution is demonstrated, evaluated, and validated through a prototype based on Shimmer technology and mobile devices using Android operating system.
The software is designed for working with available professional biofeedback equipment, including all the

necessary components for proper system operation. It was also used when a baby has been sleeping, but can be used in a regular daily usage with the cradle. In order to have the system working properly, the sensors should be placed in certain body areas so the data collection is performed correctly.

The sensors will be individually connected to a mobile device via Bluetooth. The mobile App presents sensors data graphically, in real-time. It also offers the possibility to see historical data of different connected sensors temporally.

A. *Detection of health problems and alerts*

The detection module of health problems collects data continuously from sensors (heart rate, cradle temperature, position, baby's breath, and a complement crying detection) and notifies users when an unexpected event occur. These warnings generated by the system are based on the pre-defined threshold values, such as minimum and maximum allowable in cases of heartbeat, body temperature, and respiration. When the collected values from the sensors surpass these threshold levels, alerts are sent to pre-defined contacts (usually, parents, nannies, and/or guardians).

B. *Sudden death prevention*

The parameters of biofeedback being collected from babies offer the opportunity to know what is happening with a baby in real time. These data allow a good way to detect possible problems related to SIDS, known as the most common cause of death in children. The data are analyzed and interpreted according to the baby's age, where the parameters by which biofeedback will vary as the baby grows. Respiratory and heart rate decreases with the growing baby. The developed algorithm is prepared for this variant of age. Figure 2 shows four sensors used to implement the proposed solution, as well as the various parameters of each may be captured. Next, each sensor will be described in detail.

Fig. 1.Sensors used to sudden infant death prevention.

1) *Heart Rate Monitor with Camera*

The heart rate detection with a camera (1) is very useful for monitoring the baby in a crib. It is connected to the baby's arm where the skin is more sensitive and allows a better reading of the collected images that contain the color of skin pigmentation. Through the skin pigmentation it is possible to determine the heart rate in an easy and noninvasive way. With blood pumped around the body it is possible to identify heart beating in the images collected by this camera. In a healthy person the camera captures a real-time video image of pigmentation and, when a beat is detected, it presents a more intense red color. The image pigmentation algorithm have an interval between two heart beats and it is possible to detect a different coloration of skin. The system verifies the pigmentation over an ongoing sequence of images.

The camera is connected to a mobile device via Wi-Fi because it would be dangerous to have wires present, which could endanger the baby while it receives data via Bluetooth from body sensors. The application obtains the video of the camera in real time and makes the interpretation of video frames. In the image contrast it is possible observe the difference of the color intensity between images and this phenomena allows the calculation of the heart beat.

The application shows video captures with the exterior camera and the different colors received distinguish numbers to identify a color in a numerical scale, depending on a YUV weighbridge parameters. In babies, the beats per minute diverge according to their age and these values are slightly irregular. If they have irregular heart rate parameters in a short time stamp it is considered a trouble situation.

This system does the video image recognition in the skin of babies, then, it is necessary adjust the video capture because the baby skin is very thin. The detection of heart beats is done in a thinner area of the body such as the wrist or even in the baby hand. The algorithm used for the recognition and interpretation of images is taken from an application developed for the Android system called Instant Heart Rate [12].

2) *Body Temperature Sensor*

The temperature sensor (2) collects the baby body temperature in real-time [13], but it is also important the surrounding environment. This sensor [14] is important if the baby is not in a warm environment. This problem is another possible cause of sudden death because babies need good thermal conditions since an extremely hot or cold environment may cause unexpected issues.

To avoid this problem, the sensor sends real-time data collected and checks whether the values are within the defined thresholds. If the values are not within the threshold levels, an alert to the nannies mobile device is delivered.

3) *Position Sensor*

This sensor is very important to avoid death, which happens very quickly in this case, death by suffocation, which is the failure of systemic oxygenation. Many parents throw their children on the left or right sides or stomach, because they have feared that when baby sleeping on their backs die from choking [15]. But no one knows the most correct baby sleep position because every position may cause problems. If baby is face down in a short time position the baby can die by suffocation and the same happens if baby sleeps on left and rights sides, because it can turn around. So to avoid this complicated issue, position sensor (3) may prevent the death by suffocation, because once the baby change position spontaneously the application automatically detect the position and sends an alert to a mobile device for control. The positioning sensor is a 3 axial accelerometer where one of the axes gives us the position of the baby (face up, face down or are lying to left or right sides). Figure 3 shows a baby lying position in a given time period. Based on the figure, the baby position is detected and illustrated.

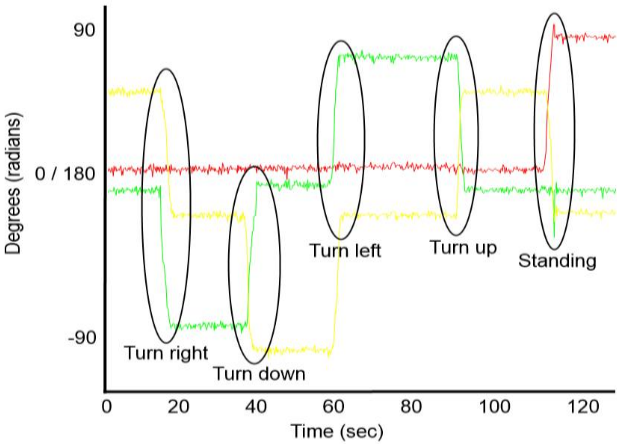

Fig. 1. Position of the baby.

1) Respiration Sensor

The respiration sensor (4) is used to measure the frequency of baby's breathing. The human being breathes automatically, with no need that anyone teach how to do it, but sometimes newborns forget breathing and die asphyxiated with lack of oxygen in the system.

To prevent this situation, a sensor that measures the pressures performed by the baby in a crib is used. The pressure exerted by the baby during inspiration is different from exercised at expiration. With this fact, it is possible to sense the respiratory rate. Through the mobile application, it is possible display charts. Figure 4 presents the frequency of the baby's breathing and if the data sent by the sensor are not within the defined threshold values (each wave length as 3 seconds), an alert to a mobile device is generated.

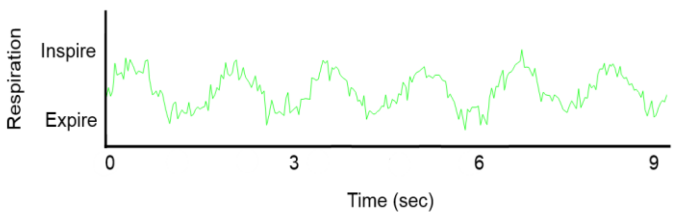

Fig. 2. Respiration signal.

B. Sudden death prevention with notifications

The mobile application collects data from the body sensors and collected bio-signals are processed by an algorithm, in real-time, to prevent sudden death. This algorithm analyzes, advise those responsible for the baby if any value of the sensors is abnormal. It also allows the combination of values among various sensors to thereby be able to make a more detailed analysis, which will allow greater control over the baby symptoms.

As above-mentioned, using data collected about heart rate, respiration, temperature, and position becomes possible to identify patterns that can expose baby to a risk [15]. Alerts are issued when something abnormal was detected taking into account the predefined threshold values.

Figure 5 presents a flowchart that summarizes the solution operation method, highlighting its main functionalities. The cycle starts when the application is installed on a mobile device and is initialized. With application running, it is easy to connect the body sensors to the device via Bluetooth. This action is performed automatically since the sensors have already been pre-registered on the mobile device. When the connection is well established with all the sensors and application starts collecting the captured data.

As may be seen in Figure 5, after connecting all the sensors with a baby, they will start collecting data from the baby's body and send data to the corresponding mobile device. The App will handle and process all the data in real-time to evaluate the reception of abnormal values. When it occurs, depending on the sensor that send the values, the mobile App generates a corresponding warning and sends it to the pre-defined users (usually, the nannies or parents). If the detected values surpass this range a worrisome data are released and then the mobile device do the corresponding alerts.

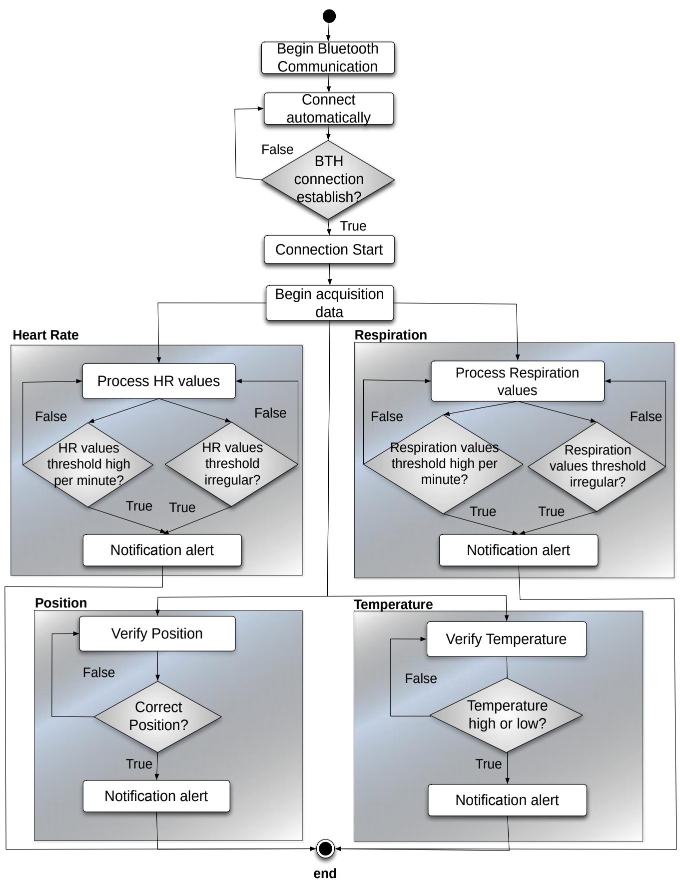

Fig. 3. Sudden infant death prevention activity diagram.

I. System Demonstration and Validation

A. Real prototype

This section presents a real testbed scenario where the solution has been experimented, demonstrated, and validated in a child (as may be seen in Figure 6). The sensors were placed in a little child to perform the experiments with the heart rate, camera, position, temperature, and respiration.

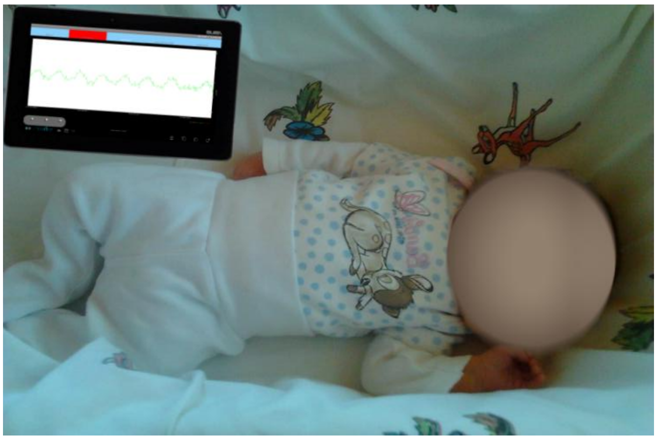

Fig. 1. Real test with the sensors placed on the baby for data collection.

The collected results can be considered normal. Nevertheless, some abnormal values have been checked but do not represent a risk for the child nor for the baby. The results are analyzed in the following section.

B. Experimental Results

Each experiment was realized along proximally one hour. The sensor data were captured when the toddler and the baby were lying in a crib.

In each trial 100 samples were collected by each sensor (heart rate, respiration, temperature, and position), which gives a total of 400 samples collected in each experiment, so to examine the captured values obtained by sensors is necessary to store an historical record.

The results have shown a quantitative analysis of the system applicability in real scenarios. Table I presents the data acquired from the child and Table II presents the data acquired from one baby, in different moments, apparently healthy to perform a system validation and indications for the prevention of sudden death were collected. A total of two main experiments were performed. Then the recorded values refer to the heart rate, respiration, temperature, and position sensors, this captured values may inform if the baby and child could die from lack of air or cardiac insufficiency just in a short period of time.

TABLE I. Experimentalresults from the First Experiments in child.

Sensors	*Samples*	*Trials errors*	*Correct trials*	*Average*
Heart Rate	100	10	90	90%
Respiration	100	12	88	88%
Temperature	100	1	99	99%
Position	100	1	99	99%

TABLE II. Experimental Results from the Second Experiments in baby.

Sensors	*Samples*	*Trials errors*	*Correct trials*	*Average*
Heart Rate	100	15	85	85%
Respiration	100	17	83	83%
Temperature	100	3	97	97%
Position	100	0	100	100%

Taking into account the data collected, the warnings observed significant values presented in Tables I and II. The system establishes breathing rate and heart of the child and the baby. These parameters are not always constant because it can vary depending on the condition of both, have fever or crying heart will pump faster. Depending on the condition of each was possible to estimate a value close to the heartbeat and this value differ with age, and a younger baby has a faster heartbeat accelerate. As we can see in the tables, there is a higher rate of error in the data collected in the baby because your body is more unstable. However, the final average are always close to 92%, which is a great brand and demonstrates this approach is a viable alternative both useful and protection for babies and children, but this solution was created especially for babies.

C. Results analysis

Figure 7 shows the results of the performed experiments of trials and error rates obtained in the two essays together. The results presented correspond to the averages of the sum of the values presented in the tables for each sensor.

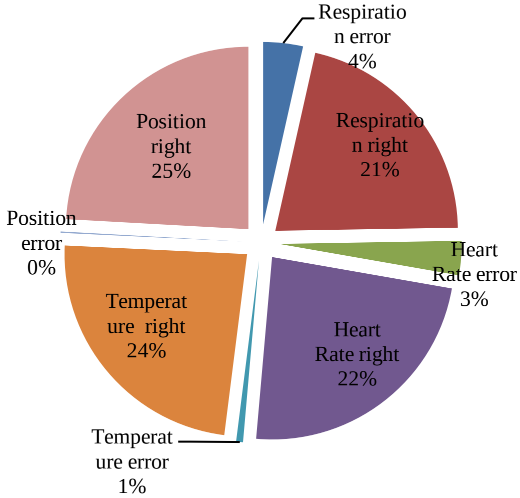

Fig. 2. Statistical result of the performed experiments.

The statistical error rates are very low, which is expected but it is justified by the controlled environment and also because the babies are healthy (to the best of authors knowledge). Furthermore, if the error rates are high something should be wrong with the baby's health. The obtained results in the essays are within the expected results, which represent hit rates of all the sensors stand around 90%, which means that babies also present a healthy state.

The temperature sensors and position error rates are almost zero because the baby's body temperature is stable in the most cases. It also occurs with the position sensor where the infant is lying.

I. CONCLUSION AND FUTURE WORK

The system proposed in this paper tries to offer a reliable solution for SIDS prevention. It was designed to bring comfort and a better living for parents, nannies, and babies. So parents are more rested because this system protects the baby. The solution is based on wireless sensor networks connected to a mobile device through Bluetooth that act as a sync. With the proper readings, sensor data processing through a mobile device, in real time, it becomes possible the creation of a warning system based on notifications for SIDS prevention. It is assumed that not all deaths are preventable, but many can be avoided with this system.

For future work the integration of more sensors and resources to turn the system more complete. One of the features will integrate a camera so that you can see the baby without us being close in the mobile device screen. Another feature to be implemented will be to detect the baby's crying by tapping the microphone of the mobile device. This smartphone or tablets have the application installed and stay close to the crib. The purpose of this feature is to alert parents when the baby is crying.

Finally a humidity sensor will be implemented to detect the moisture from the diaper.

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REFERENCES

[1] Bradley B. Randall, David S. Paterson, Elisabeth A. Haas, Kevin G. Broadbelt, Jhodie R. Duncan, Othon J. Mena, Henry F. Krous, Felicia L. Trachtenberg and Hannah C. Kinne", **Potential Asphyxia and Brainstem Abnormalities in Sudden and Unexpected Death in Infants**" in *Pediatrics*, 11 November, 2013.

[2] "SIDS and Other Sleep-Related Infant Deaths: Expansion of Recommendations for a Safe Infant Sleepeing Environment" in *Pediatrics,* Vol. 5, pp. 1030-1039, 1 November, 2011, DOI: 10.1542/PEDS.2011-2284.

[3] João M. P. L. Caldeira and Joel J. P. C. Rodrigues, "Body Area Networks for Healthcare", in *McGraw-Hill Yearbook of Science and Technology 2014*, McGraw-Hill, USA, ISBN: 978-0-07183-106-2, January 2014, pp. 47-50.

[4] Ziganshin E.G., Numerov M. A., Vigolov S. A., "UWB Baby Monitor", *5th International Conference Ultrawideband and Ultrashort Impulse signals* (UWBUSIS 2010), September 6-10, 2010, pp. 159-161, DOI: 10.1109/UWBUSIS.2010.

[5] Hung Cao, Lun-Chen Hsu, Thermpon. Ativanichayaphong, Jeongsik Sin, and J. C. Chiao, "A non-invasive and remote infant monitoring system using CO2 sensors", *2007 IEEE Sensors*, October 28-31, 2010, pp. 989-992, DOI: 10.1109/ICSENS.2007.4388570.

[6] Hung Cao, Lun-Chen Hsu, Thermpon. Ativanichayaphong, Jeongsik Sin, Harry E.Stephanou and J. C. Chiao, "An Infant Monitoring System Using CO2 Sensors", *IEEE International Conference RFID 2007*, March 26-28, 2007, pp. 134-140, DOI: 10.1109/RFID.2007.346161.

[7] M. Trifunovic, Vadiraj A. M., Van W. D. van Driel, "MEMS Accelerometers and their Bio-Applications", *13th International Conference Thermal, Mechanical and Multi-physics Simulation and Experiments in Microelectronics and Microsystems* (EuroSimE 2012), April 16-18, 2012, pp. 1/7-7/7, DOI: 10.1109/ESimE.2012.6191749.

[8] J. Y. A. Foo., C. L. Parsley, S. J. Wilson, G. R. Williams, M. Harris, D. M. Cooper, "Detection of Central Respiratory Events Using Pulse Transit Time in Infants", *27th Annual International Conference Engineering in Medicine and Biology* (IEEE-EMBS 2005), *January 17-18*, 2006, pp. 2579-2582, DOI: 10.1109/IEMBS.2005.

[9] Carsten Linti, Hansjürgen Horter, Peter Österreicher, Heinrich Planck, "Sensory baby vest for the monitoring of infants", *International Workshop Wearable and Implantable Body Sensor Networks* (BSN 2006), April 3-5, 2006, pp.3 pp.137, DOI: 10.1109/BSN.2006.49.

[10] Adrian Burns, Barry R. Greene, Michael J. McGrath, Terrance J. O'Shea, Benjamin Kuris, Steve0n M. Ayer, Florin Stroiescu, and Victor Cionca, "SHIMMER™ – A Wireless Sensor Platform for Noninvasive Biomedical Research", *IEEE Sensor Journal*, Vol. 10, no. 9, September 2010, pp. 1527-1534, DOI: 10.1109/JSEN.2010.

[11] Shimmer, www.shimmersensing.com, February 2014 (accessed May 2014).

[12] Instant Heart Rate, https://play.google.com/store/apps/details?id=si.modula.android.instantheartrate, February 2014 (accessed May 2014).

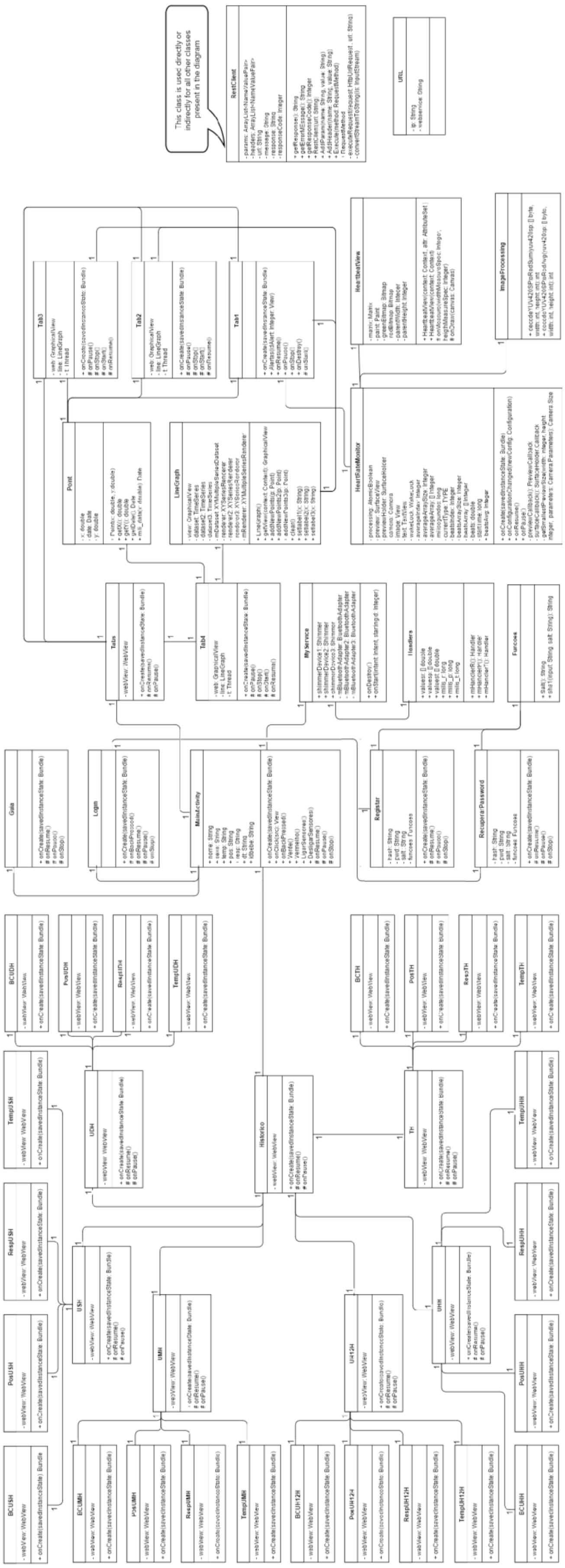
[13] João M. L. P. Caldeira, José A. F. Moutinho, Binod Vaidya, Pascal Lorenz, and Joel J. P. C. Rodrigues, "Intra-Body Temperature Monitoring using a Biofeedback Solution", *The Second International Conference on eHealth, Telemedicine, and Social Medicine* (eTELEMED 2010), St. Maarten, Netherlands Antilles, February 10-16, 2010, pp. 119-124, DOI: 10.1109/eTELEMED.2010.23.

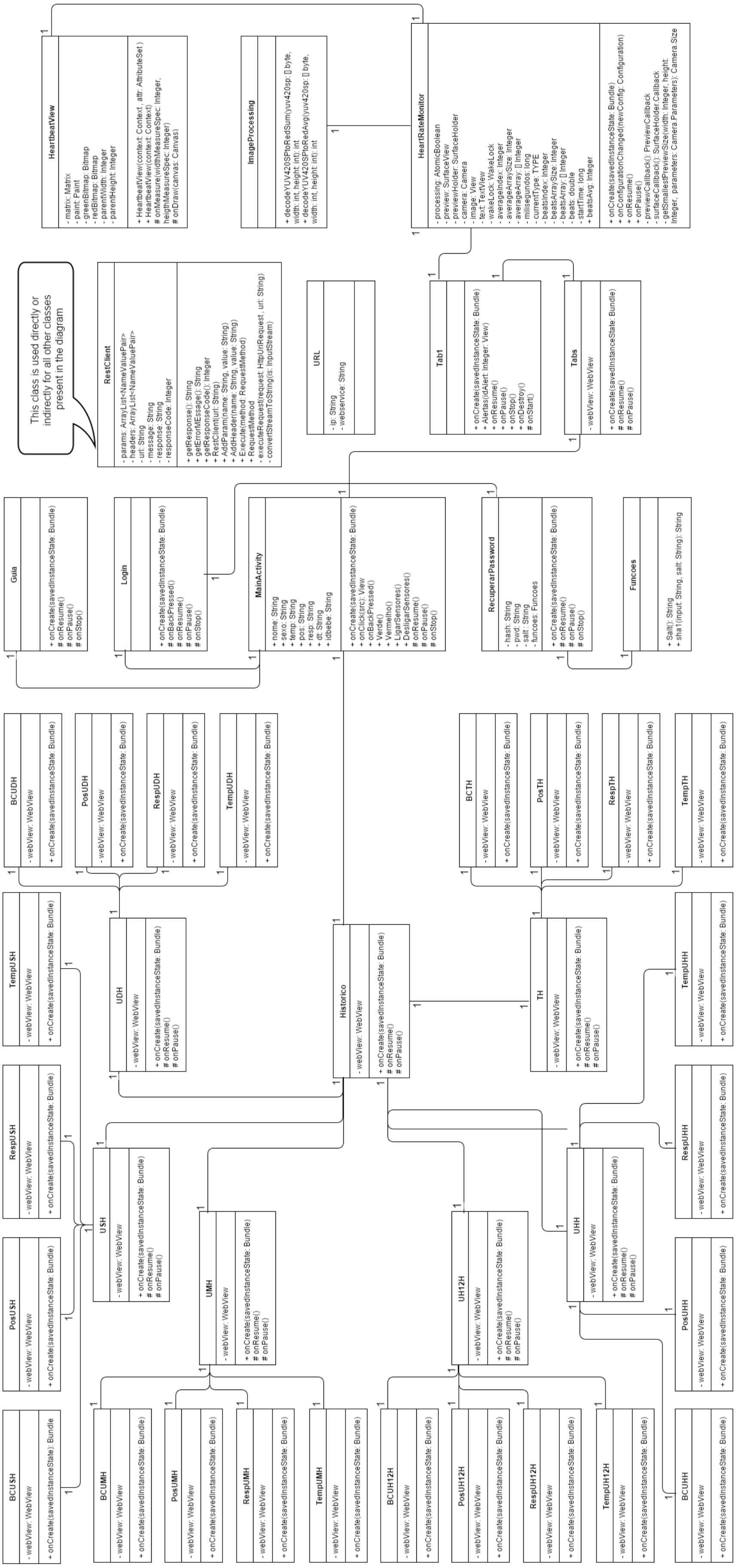
[14] Orlando R. E. Pereira, João M. L. P. Caldeira, Joel J. P. C. Rodrigues, "A Symbian-based mobile solution for intra-body temperature monitoring", *12th International Conference on E-Health Networking, Applications & Services* (IEEE Healthcom 2010), Lyon, France, July 1-3 2010, pp. 316-321, DOI: 10.1109/HEALTH.2010.5556548.

[15] Edgar. T. Horta, Ivo. C. Lopes, Joel J. P. C. Rodrigues, Sudip Misra, "Real time falls prevention and detection with biofeedback monitoring solution for mobile environments", *15th International Conference on E-Health Networking, Applications & Services* (IEEE Healthcom 2013), Lisbon, Portugal, October 9-12, 2013, pp. 594-600, DOI: 10.1109/HealthCom.2013.6720746.

APPENDIX B

This appendix includes the class diagrams related to both developed applications. The first diagram is related to the class diagram of the main application, while the second refers to the Client Application.




This class is used directly or indirectly for all other classes present in the diagram
HeartbeatView
ImageProcessing
HeartRateMonitor
RestClient
URL
Tab1
Tabs
Guia
Login
MainActivity
RecuperarPassword
Funcoes
BCUDH
PosUDH
RespUDH
TempUDH
BCTH
PosTH
RespTH
TempTH
TempUSH
UDH
Historico
TH
TempUHH
RespUSH
RespUHH
USH
UHH
PosUSH
UMH
UH12H
PosUHH
BCUSH
BCUMH
PosUMH
RespUMH
TempUMH
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