Open System for Monitoring Vital Signs of Babies to Help in the prevention and Diagnosis of Sudden Death

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Abstract—This paper presents deals with the design and implementation of a system to monitor the vital signs of a baby, to support the diagnosis and pediatric care. The text presents an approach on monitoring signals, normality standards, and measurement devices. It also represents how tools used to implement the project, and how they are associated. The concept of a wearable computer is used, where computers are becoming accessories in which we wear and use on a daily basis. The system consists of a temperature sensor, a motion sensor and a heart rate sensor connected to the micro controller that sends this data over the Wi-Fi network, to a server. The data is served by an application, developed for Android devices, which performs the interface between the user and the system. At the end of the development, it was verified that the proposed objectives were achieved, the transmission of the data read in the sensors achieved the expectations.

Keywords—Wearable Computer, Android, Open Hardware/Software, Monitoring Remote, IoT

I. INTRODUCTION

The evolution of computing, in particular, electronic devices is increasingly fast. They became small, cheap and with more resources, it is possible to design solutions involving hardware and software to automate many tasks of everyday life.

This advancement includes mobile communication techniques, embedded computing, and miniaturization of electronic devices and sensors, which are generated for the development of applications in the medical field, allowing an optimization of the of the services provided by health professionals.

Wireless communication improvements have expanded the possibilities of monitoring and control in electro-medical devices remotely, increase the locomotion by the health professionals. The miniaturization of mobile electronic devices increased battery efficiency, and reduced semiconductor power consumption enhance the development of countless innovative solutions through ubiquitous computing[1].

Ubiquitous computing is the idea that computing moves out of workstations and the personal computers and becomes pervasive in people’s daily lives, wherever we are. It is a trend that has been growing exponentially in recent years [2].

As the portability and functionality of electronic equipment are increasingly improved, "wearable" devices are revolutionizing the marketplace as a new way of taking care of health. These devices are called wearable computer [3].

The term wearable computer is defined as a wearable, portable computer that supports the human being in day to day tasks, or allows the monitoring of parameters, making this data available to the person later.

Wearable computer can be classified as a computer that is always connected and always accessible [4], and can be dressed by newborn to the elderly, having functionalities such as monitoring body temperature, blood pressure, heart rate, among others.

This paper present deals with the use of a wearable computer in newborn children continuous monitoring, principally during sleep. It can help parents, especially those with little experience, to deal with routine situations, such as Monitoring of fevers, movement in the cradle of newborn babies, as any anomaly detected, combined with a rapid action, may contribute to decreasing the risk of sudden death.

Sudden death is still not accurately explained by science, and remains one of the leading causes of infant mortality. Sudden Infant Death Syndrome (SIDS) is defined as the sudden death of a baby less than 1 year of age, usually associated with sleep. One of the possible ways to discover the cause of sudden death is to monitor vital signs, where by crossing the data and analyzing them later, the physician can produce a more accurate and more reliable report [5].

Besides, monitoring can generate statistics that when analyzed could detect some types of anomalies, such as congenital heart diseases. Once monitored it is possible achieve more efficient diagnoses, improving the cure or treatment.

To perform remote monitoring, concepts about Internet of Things, known by the acronym IoT, were used to design the proposed system. This is the term used to classify common day-to-day devices that have access to the Internet. These devices are capable of measuring data, controlling systems and even serving in-house tasks. Via sensors or wearable devices, you can intermittently or continuously monitor and record relevant data on a server on the Internet, offering an important
solution although the limits imposed by the traditional monitoring of these signals, allowing even triggering notifications that can help prevent a worsening of that user of the system.

The use of IoT concepts, together with low-cost electronic components with open standards, known as free hardware, allows a flexible development, with openness to include new features such as sensors or actuators, leaving the architecture in which are inserted open for future customizations or optimizations. Another feature of these elements is low cost, as well as easy integration with other systems, such as database servers in the cloud.

This work presents a prototype of one wearable computer based on free hardware applying the principles of IoT, which allows to remotely monitor, using an Android device, the vital signs of a newborn, being that this data is stored remotely in a server in the cloud. This data can be accessed by Android Device, which also has the function of personalizing alert parameters, such as being informed when any of the vital signs are outside a previously registered range, thus considering an abnormal reading. The history of all readings performed by Wearable Computer is also available in graphics on the Android device.

II. RESEARCH PROBLEM

According to the World Health Organization, in 2015, 6.5 million children died before reaching the age of five. Many countries still have a high infant mortality rate, particularly those in the African Region with about 81 infant deaths under five for every 1,000 live births. Inequalities in infant mortality among high and low-income countries remain large. In 2015, the under-five mortality rate in low-income countries was 76 deaths per 1,000 live births, about 11 times the average rate in high-income countries (7 deaths per 1,000 live births) [6].

In addition to social inequality, several factors contribute to the composition of these numbers, among them diarrhea, pneumonia, HIV, among other diseases. Sudden infant death syndrome is classified in the other group, which is characterized by deaths during sleep or by unknown causes.

As reported by the Centers for Disease Control and Prevention [7], about 3,500 babies under one year of age die every year from unknown causes in the United States. From this number 44% of the cases were classified as sudden infant death syndrome. Another major risk for newborns is accidental asphyxia during sleep or strangulation in bed.

In the United States, these numbers declined considerably following the campaigns of the American Academy of Pediatrics knowing by Safe Sleep in 1992, Back to Sleep in 1994, and the Sudden Unexplained Infant Death Investigation Reporting Form in 1996, which encourage safe sleep, counseling Parents about the best ways to put their babies to sleep [7].

In Brazil, this index is calculated by the (SUS) Sistema Unico de Saude (Unified Health System) and is included in the list of avoidable causes of death that can be reduced by adequate health promotion actions combined to health care actions. The World Health Organization classifies Sudden Infant Death Syndrome in a group called: Symptoms, signs and abnormal findings of clinical and laboratory exams, and SUS follows this classification hierarchically [8].

In the year 2015, 31,441 deaths of children under 4 years of age were recorded in Brazil according to the Child and Fetal Monitoring Panel. Of these deaths, 953 (2%) were classified as sudden death, represented by Chapter XVIII in the International Classification of Diseases. These cases are divided into 3 groups: Early Neonatal (full first week of life) 167 in 2015, Late Neonatal (three weeks following) 66 in 2015 and post neonatal and following 720 in 2015. The numbers total a total of 953 deaths By 2015, and are declining due to government campaigns for follow-up and counseling to prevent Sudden Infant Death Syndrome [9].

Several epidemiological studies carried out since the 1960s show some factors that contribute to an infant’s risk profile. Among them: young mother, multiparous, short interval between pregnancies, absence of prenatal care, prematurity, low birth weight, brother who died of SIDS, low socioeconomic level, and a predominance of males, ethnicities and geographic regions. Strong evidence suggests that there is a risk up to 14% higher when infants sleep in the chest position down. From these indications, the campaign "Reduce the risk of SIDS" was initiated in Brazil in the 1990s, and a reduction in postnatal mortality was observed up to 50%, depending on the region of the country. A study carried out in Rio Grande do Sul, in the cities of Pelotas and Porto Alegre, showed that cases of SIDS are underdiagnosed and are not included in official statistics. This same study attributes an index of 4% for the Pelotas region as a consequence of SIDS, and an index of 0.08% in the region of Porto Alegre. Comparing with the numbers in this study, an estimate of approximately 6,120 cases per year can be attributed in Brazil [10].

III. MATERIALS AND METHODS

With the intention of trying to identify the cause of sudden death, as well as allowing countries to predict risks associated with newborn sleep, such as turning face down and being asphyxiated, this project aims at a flexible and low-cost solution to monitor Physiological data during sleep.

For the development of the proposed system, several questions were studied, such as the correct functioning of the sensors, as well as the identification of the best place to wear a Wearable Computer in a baby, in order to obtain a more accurate measurement of the data. Another concern was the integration model of the intelligent abdominal belt with the servers, as well as its integration with the user’s Android Device.

The Figure 1 presents the general scope of the system, focusing on the integration model.

In the figure it is possible to observe that the abdominal belt is dressed in the baby, and has a mechanism of wireless communication to send the data read in its sensors to a remote server.

The integration of this data with the Internet happens through the Wi-Fi communication (802.11), which sends the data to an Ubiods server, which stores this data. Wearable Computer communication designed with the Internet happens through a traditional Wi-Fi router, identical to what is found in most homes with Internet access.
The data stored on this server can be accessed on demand by an application developed for the Android platform, which can be run on smartphones and tablets. The Android has become the most used operating system worldwide, according to the website Static Counter [11], corresponding to 37.93% of all devices running any operating system. The Android platform was chosen for its success, which corresponds to 81.7% of smartphones and 66.2% of tablets worldwide, according to the website Statista [12].

This data can also be accessed by a Java notification service Firebase, maintained by Google, which has the function of sending messages to Android devices registered on the platform. These messages are asynchronous and do not require the user to be running the app to receive such information.

For a better operation of the platform, the user can register using the Android device a Range than would be the normal data for reading the sensors, any data considered abnormal is notified to the Android device by the Firebase Notification server, as being a risk situation. An example of a parameter is the body temperature being greater than 37.5 degrees (fever) or a heart beat less than 50 (cardiac arrest).

The following are detailed about the components that are part of the system overview.

- **Wearable Computer:** A solution found to capture the data by sensors was the development of an abdominal belt. This range contains the temperature, beats and position sensors (accelerometer) which are coupled in strategic places to better measure such data. Also found is a micro-controller that connects Wearable Computer to the Internet via a WI-FI router. This micro-controller is powered by a battery. In the sequence more details of this belt will be presented.

- **Wi-Fi Router:** A Wi-Fi router allows a connection to the wireless Internet. This type of connection is present in a large number of homes around the world. This device allows the micro-controller, like other home appliances, to connect to the Internet and transfer data in virtually real time.

- **Ubidots Server:** For the exchange of information between the microcontroller and a remote monitoring device, such as a Smartphone or Tablet, a database service was chosen in the cloud for IoT called Ubidots. In its free version, it is used in the project, it is possible to use up to 20 devices, reading and recording. It is also possible to record the data up to 60 times per minute. There is a limitation of 500 thousand recordings, valid for 3 months, after this period this counter is reset. In Ubidots, each client has a passkey, sharing in the environment variables fed with the data read from the sensors. Communication is done through the HTTP protocol, in which the message with the information is transferred or retrieved from the server.

- **Device Android:** The Android platform provides free application development tools for smartphones and tablets, and these are the focus of this work. Android is maintained by Google, and allows the application to easily integrate with native device features. The platform is developed based on the Linux operating system and is composed of a set of tools that act in all phases of the project development [13]. This platform was chosen for the facilities in programming, it contains several libraries and programmers willing to assist in problem solving. Also by the range of users, which represent a market with greater scope in all the world-wide territory.

- **Firebase:** This tool provided by Google makes it possible to use the integrated notification system on the Android platform. Using the Firebase Cloud Messaging service, or FCM, it is possible to notify an application on the client device with information read from a database. Such notifications can be received by the client device from anywhere, provided that the client is connected to the Internet.

Once the overall scope of the system was defined, the next step was to design the abdominal belt. Among the challenges is the choice of lightweight, comfortable, low-cost and low battery consumption materials.

The Figure 2 show the elements of hardware present in the abdominal band.

![Image of the abdominal belt components](image-url)
The temperature sensor is on the side of the chest, below the armpit.

The following is a quick explanation of each component that makes up the range as well as the reason for his choice:

- **Abdominal belt**: The abdominal band was developed using Neoprene material, which is a high quality, comfortable and flexible synthetic rubber. It is a highly resistant material and has great malleability. In addition, it offers elasticity in all directions and provides a perfect modeling to the body, besides not absorbing water. Slots in the material were created to improve the breathing of the baby’s skin.

- **Temperature Sensor**: As a temperature sensor, the DS18B20 sensor is used, which can measure temperatures in the range of -55°C to + 125°C. This sensor is very precise and has characteristics such as low cost and small size, which for the purpose of the project justifies its use.

- **Photoplethysmograph Sensor**: This sensor is responsible for measuring heart rate. The sensor used is the pulse sensor which, when it detects a pulse in the heart, it is able to reproduce it in wave form, sending it as electrical signal signal to the microcontroller.

- **MPU 6050**: The integrated module contains an accelerometer, a gyroscope and a temperature sensor. The accelerometer is used to identify when a movement occurs, and its principle of operation is based on measuring the acceleration of the object itself, through internal calculations. It also makes it possible to identify the positioning of the sensor in relation to a preset reference. The module also provides a temperature signal which is used to measure the ambient temperature, and a gyroscope signal.

- **Battery**: For prototype, a rechargeable lithium ion battery was used, which is not expensive. Called Power Bank from Sony company, with power capacity is approximately 3000mAh. This battery has a larger size than those found in the market, but for prototyping purposes responds well to the desired.

- **Microcontroller and Communication Module**: The company Particle IO has a tool named Spark core, whose usefulness is the prototyping in the Internet of Things area. This kit consists of an ARM Cortex M3 microcontroller and a SimpleLinkTM CC3000 Wi-Fi module that enable data acquisition and transmission over the Internet through the Wi-Fi 802.11 b/g protocol.

IV. RESULTS

As a result of this work, we have a prototype Wearable Computer containing temperature, position, and heartbeat sensors, all integrated inside a Neoprene belt with is fits to improve a baby’s thermal sensation. These connected with a micro-controller access the Internet through Wi-Fi, powered by a battery, and are sent to an Internet server.

The belt weighs approximately 200 grams, the microcontroller itself, being coupled to the Wi-Fi card, measures around 3 centimeters, which together with the sensors contained in the range provide a good size for the application. The belt is made of a comfortable material, which makes its prolonged use possible.

One of the critical points of the Designed Wearable Computer is the battery, since lighter batteries usually have a very limited range, and larger batteries are large and uncomfortable to be worn by a baby.

In order for the user to have access to the developed Wearable Computer data, an application in the Android Platform was design, in order to read the current data accurate by the sensors, these are present in the Ubidots server, as well as verify a history of reading this data, these are displayed in a graphic.

The figure 3 displays the application’s home screen, which contains all the important information to avoid browsing between screens. The instantaneous values of the internal temperature, which represents the temperature of the baby, the external temperature representing the temperature of the environment, the amount of heart rate per minute and the position of the baby are displayed on the screen. Also in graph form the reading history is displayed. This graph is dynamic and interactive, and the user can click and drag to see older values.

A verification of errors in the system can be implemented, this verification makes it possible to determine if the readings should occur, they occurred. It is very useful because often the system performs incorrect readings, and the parameters passed to the application appear to be correct, however there may be an inconsistency in this data, generating a false interpretation by the user.

Also a parameter screen has been developed, it can be accessed by the user through a menu. In this screen, you can register critical parameters, such as in which situations the user would like to receive notification. As an example, we can cite body temperature above or below a range considered as normal temperature, the same for heart rate. The user can also be informed if the baby moves in the crib (preventing a newborn from falling over, for example), or information such as room temperature too high or too low, or Wearable Computer Critical / Wearable battery Computer without sending information to the server in a longer time than the registered, so the user knows that the connection as Wearable Computer has been lost.

The figure 4 displays an incoming notification. This message identifies the sender with the name of the application as well as the text of the problem (in the example, Non-standard heartbeats).

By clicking on the message, the user is directed to the main screen of the application. Upon receiving the notification, in addition to the sound effect, a vibration effect of the device is also performed.

The tests were carried out in a controlled environment, in an adult human being, and in a baby. They demonstrated the operation of the device and provided an analysis of what should be improved or improved for greater usability. The battery has a system life of approximately 20 hours, and its...
battery life is approximately 4 to 5 hours. It was noticed the need to be implemented a system to check the charge of this battery, warnings of the state of this charge and the needed to recharge it.

The purpose of the work was to develop a wearable computer in which a baby’s vital signs were conditioned and transmitted to an android device. Everything was made using low-cost hardware as well as free software. Larger, more accurate tests will be performed in the future, since the first part of the experiments, part of this more technical, operated as expected.

The system was designed to be as dynamic as possible, and the architecture was validated proving that it is possible to develop it, as well as adding more sensors to it. More sensors would enable a check of extra vital signs, or even sounds and an abnormality check.

V. CONCLUSION

Smart sock 2 [14] is the name of a device found on the market with similar functions. It is a sock capable of measuring the heart rate, blood oxygenation rate, and transmitting this data to a cellular application. However its price is around 299 dollars.

This system, made with free hardware / software has a cost of approximately 40 dollars, and adds more vital signs in the measurement.

This work has integrated free/open-source hardware and software to help prevent a problem that affects thousands of children every year: sudden death, as well as helping parents monitoring vital newborn data, and also inform the user about the environment where the baby is and about the operation of Wearable Computer itself.

The results of this study could be used by parents who
are concerned about the health status of their children, health professionals who wish to keep a register of physiological parameters about their patients in order to study and decides what is best.

The project was developed in order to facilitate the integration of new hardware resources such as sensors, facilitating their presentation and monitoring by the application.

In addition to submitting the data sent by Wearable Computer, there is the possibility of notification, if any data is not in the normality standards registered by the user.

During development, some limitations have been encountered and can be circumvented in future releases, as the limitations of the free version of Ubidots server (in the free version the number of users and sensors is limited). For a commercial version, one should use the paid version of Ubidots. Another limitation is the size of the battery used, for a commercial version, one should study the possibility of a smaller battery, even at a higher cost, for better comfort of the baby.

Another improvement that must be deployed on the platform concerns security and fault tolerance mechanisms, preventing Wearable Computer from stopping sending data to the server and sending this data in encrypted form.

However, these limitations did not impede the testing and validation of the architecture. The acquisition of data using the sensors was implemented through a micro-controller, which in turn allowed the transmission of data to the server. The development of the application took into account factors such as usability, dynamic enabled the visualization of the vital signs to read in the sensors. Also for the development of the abdominal belt were used light and small, that low energy consumption designed to IoT.

As a increase of the project, it is desired to add more sensors, such as blood pressure and oxygenation rate of the blood, increasing the usability of the device and opening a wider range in the monitoring of vital signs based on normality standards. Also find a solution for the authentication of users, allowing greater privacy in the data recorded on the server and also a provision of this data on different platforms, such as an Internet site for example, so that the data can also be monitored by a health professional.

The innovation proposed in this work may help the field of monitoring of vital signs in newborns, it is a cheap solution that can be used by parents and health professionals/universities to increase the amount of information for the study of sudden death.

REFERENCES