A Sudden Infant Death Prevention System for Babies

Ângelo M. Fonseca[1], Edgar T. Horta[1], Sandra Sendra[1,2], Joel J. P. C. Rodrigues[1,3], J. A. F. Moutinho[4]
[1] Instituto de Telecomunicações, University of Beira Interior, Portugal
[2] Universidad Politécnica de Valencia, Spain
[3] University ITMO, Saint-Petersburg, Russia
[4] Health Sciences Faculty, University of Beira Interior, Portugal

angelofonseca300@gmail.com; edgar.horta@it.ubi.pt; sansenco@posgrado.upv.es; joeljr@ieee.org; jafmoutinho@fcsaude.ubi.pt

***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 take care 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; body sensors; eHealth

I. Introduction

Sudden death is a phenomenon 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 they 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.

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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.

III. 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 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.

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.

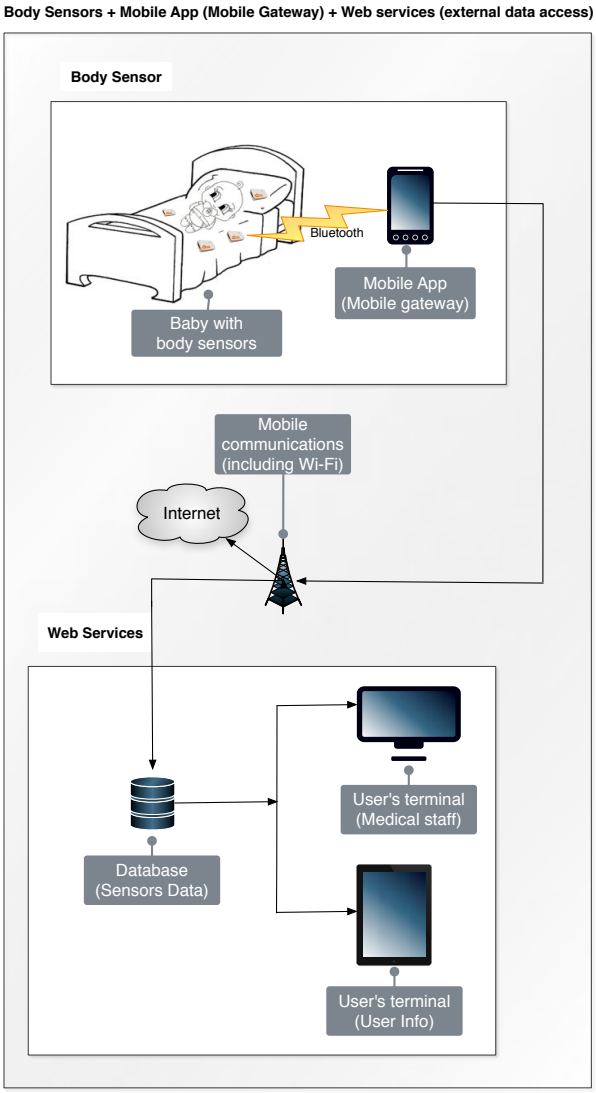

Fig. 1. Illustration of the system architecture for a prevention and monitoring system with the three tiers (body sensors, storage, and Web services).

IV. 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.

B. 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).

C. 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 change when 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 deploy the proposed solution, as well as the various parameters of each one may be captured. Next, each sensor will be described in detail.

Fig. 2. 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 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 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 babies 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. 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 three-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.

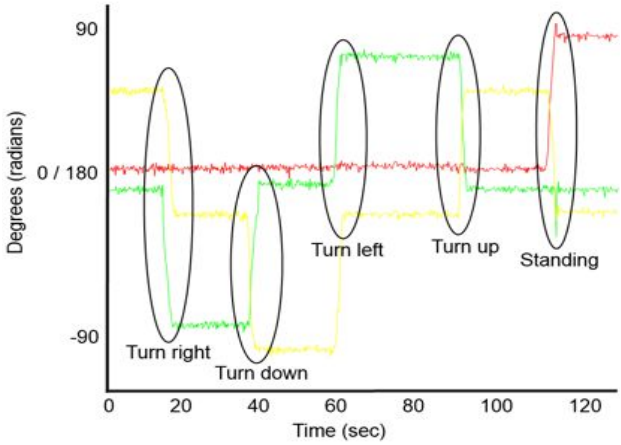

Fig. 3. Position of the baby based on date collection from a three-axial accelerometer.

4) 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.

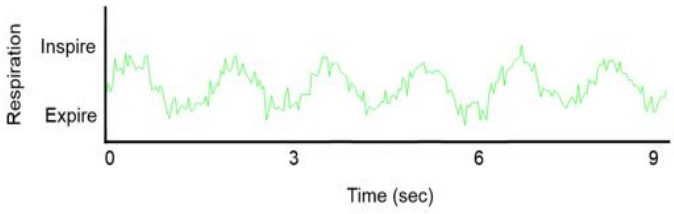

Fig. 4. Respiration signal.

D. 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.

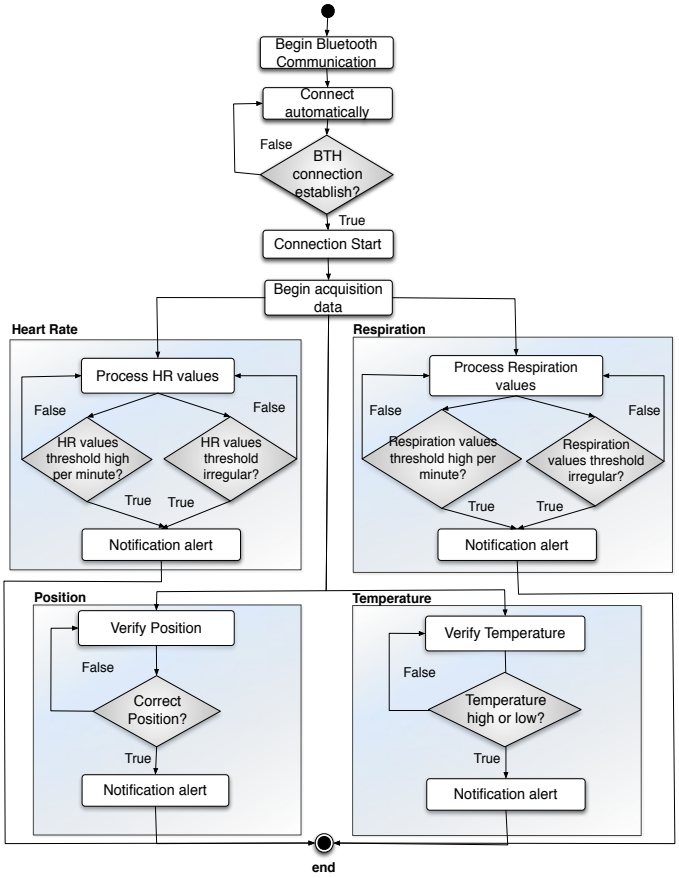

Fig. 5. Sudden infant death prevention activity diagram.

V. 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. 6. Real experiment 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 neither 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. These captured values may inform whether the baby and child could die from lack of air or cardiac insufficiency just in a short period of time.

TABLE I. Experimental Results from the First Experiments in a 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 a 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 one it 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 may be seen in the tables, there is a higher error rate in the data collected in the baby because his/her 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 presented results correspond to the averages of the sum of the values presented in the tables for each sensor.

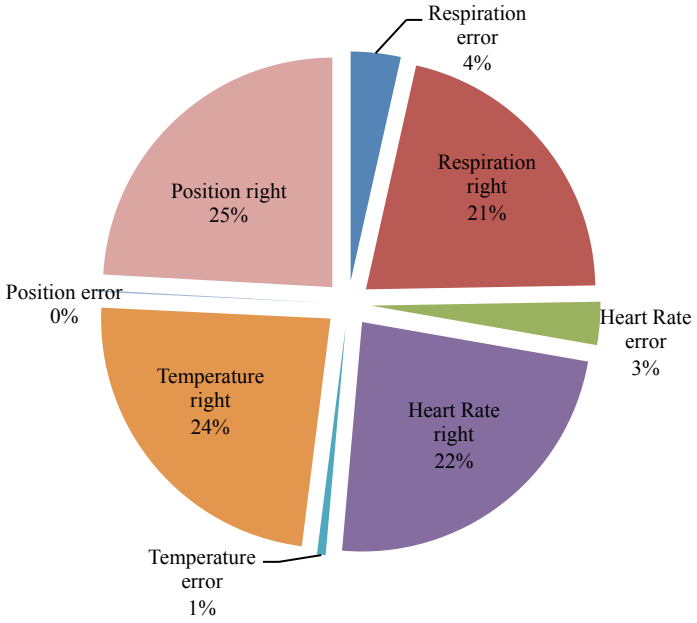

Fig. 7. Statistical result of the performed experiments for the four sensors.

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.

VI. 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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