Non-intrusive system for monitoring the risks of Sudden Infant Death Syndorme

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Abstract. Sudden Infant Death Syndrome (SIDS) is associated with the sudden and unexpected death of a child under the age of one who is apparently healthy. This unforeseen death, in most cases has no explanation. Although its causes are not known with certainty, we do know of the risks that can trigger them. This work presents a network of sensors to monitor the main risk factors in this pathology, such as: temperature, humidity or the level of gases in the environment. A non-invasive system is proposed since the sensors are not in direct contact with the infant, unlike most monitoring systems available today. In particular, a virtual organization of agents has been developed, it is capable of integrating different sensors on an open and low cost hardware platform.

Keywords: Sudden Infant Dead Syndrome, SIDS, WSN, e-health, pediatrics, Multi-agent system, PANGEA

1. Introduction

Sudden Infant Death Syndrome (SIDS) [1], also known as "crib death" or "white death", is defined as the death of a child who has not completed their first year of life. The death of the infant occurs abruptly, is unexpected by history and remains unexplained even after a postmortem study. This death usually occurs during sleep [2]. Apparently, a lethal episode is experienced; the infant suffers prolonged sleep apnea, with altered muscle tone and change in skin color, there is no response to small stimuli (only in the case of resuscitation maneuvers [3]).
SIDS is one of the most frequent causes of mortality in developed countries, being the third most frequent cause of death in infants in the USA (8%) and the most frequent in the post-neonatal period (40-50%), especially between the first month and the first year of life. In 90% of the cases it occurs during the first 6 months of life. Maximum incidence of SIDS occurs between the 2nd and 4th month, it is infrequent during the first month of life, sporadic after 6 months and exceptional in

children above the age of one. The incidence of SIDS has been decreasing thanks to preventive measures in most European countries, and is now between 1.5 and 2 deaths per 1000 newborns. In Spain, for example, mortality rates are 0.34 per 1000 newborns [2]. Incidence is higher in males than females and in the cold and humid months. This is due to an excess of bedding along with excessive temperature and humidity in the room. Rates increase when it comes to siblings, especially if they are twins or triplets and when the birth weight of the baby ranges between 1500 and 2500g. There is even greater risk if the weight is less than 1500g [3].

Occurrence rates of lethal episodes in the US are estimated at around 0.5-6% of newborns. Some studies suggest that 5-10% of SIDS victims had previously experienced an episode [4]. At the moment, there are no pathognomonic findings in SIDS (symptoms that would characterize or indicate this disease). It is a multifactorial process that does not follow a specific and unique cause [2]. However, the most widely accepted hypothesis is the one that relates this syndrome to a disorder in cardiorespiratory control by the brainstem, with altered arousal, blood pressure and sleep-wake cycle.

Alteration of respiratory regulation during sleep leads to a ventilation deficit. Babies at increased risk of SIDS would have a lower ventilatory response to hypercapnia or hypoxia, which would trigger progressive respiratory depression. All this, together with external factors (e.g. viral infections, exposure to tobacco smoke) can lead to death [3].

It has been shown that there is a genetic susceptibility in some infants, that, when combined with other risk factors (such as infection, anemia, cardiac abnormalities) could trigger this syndrome. In recent years, other epidemiological risk factors, related to the environment in which the child lives and the care provided, have been given increasing importance; these factors can have a positive influence on the infant and therefore decrease the frequency of SIDS, as shown in [5]. The monitoring of these factors is fundamental to try to avoid that this pathogen generates the death of the baby while it is sleeping.

This work proposes an architecture based on virtual organizations of agents that integrate different environmental sensors together with image processing techniques to monitor the main factors that can trigger SIDS. These agents will be deployed on an open and inexpensive hardware system. The PANGEA [6][7] platform has been chosen [1] for the design of the architecture, this is because it facilitates the creation of virtual organizations of agents and their integration in different light hardware devices. It integrates different virtual organizations in charge of performing tasks such as the collection of data by different sensors, real-time monitoring of collected data, management of alerts or sending information to a remote server.

The aim of this work is to obtain safer environments that reduce the risk factors involved in SIDS. This system is completely non-intrusive, since no sensor is in direct contact with the body of the baby.

This article is organized as follows: the background section contains a study of the state of the art, the Proposed System section presents the architecture developed in

the course of this work. Finally, the results and conclusions obtained are found in section 4.

2. Background

In the current literature it is possible to find some examples of MAS systems [8][9][10] focused on the remote monitoring of sensors for medical purposes [11]. Work [12], presents an architecture focused on a medical sensor system, used for monitoring the patient´s main vital signs from their own home. The proposed architecture in [4] has been taken as the starting point of the MAS architecture design described in the present work. There are also numerous examples of work that focus on monitoring systems for indoor air quality, [13][14][15][16]. In these papers the authors propose different strategies for deploying general-purpose sensors, capable of measuring air quality levels in indoor spaces.
It is less common to find works in the literature that focus on systems specifically designed for the monitoring of the newborn´s environment, with the end of preventing the risks of SIDS, one of these works is [17]. In this paper, the authors present the NanoPulse Baby SleepGuard system, a device that allows contactless monitoring of newborns, controlling their breathing and heart rate while they are asleep. The baby´s breathing is controlled using UWB radar technology that records body movements, controlling the baby´s breathing.
Another important work is [18], in this work, the authors make use of a CO_2 sensor to check the concentration levels of carbon dioxide that accumulates around the baby's crib. The authors define a threshold value, if this value is exceeded, CO_2 levels are considered too dangerous and an alert is triggered.
It has been verified that more studies are required on the topic of environmental sensors and their application in the analysis of SIDS risks. The number of works that combine monitoring using environmental sensors and other non-intrusive monitoring methods, ones that measure the pulse for example, is very low. The present work is novel in that it intends to solve current issues with respect to monitoring SIDS by combining methods and addressing more risk factors.

3. Proposed system

To have a better understanding of the proposed architecture, each of the elements that constitute the system will be explained in detail below. The diagram in Figure 1 shows the main modules that make up the proposed system, based on the PANGEA platform.

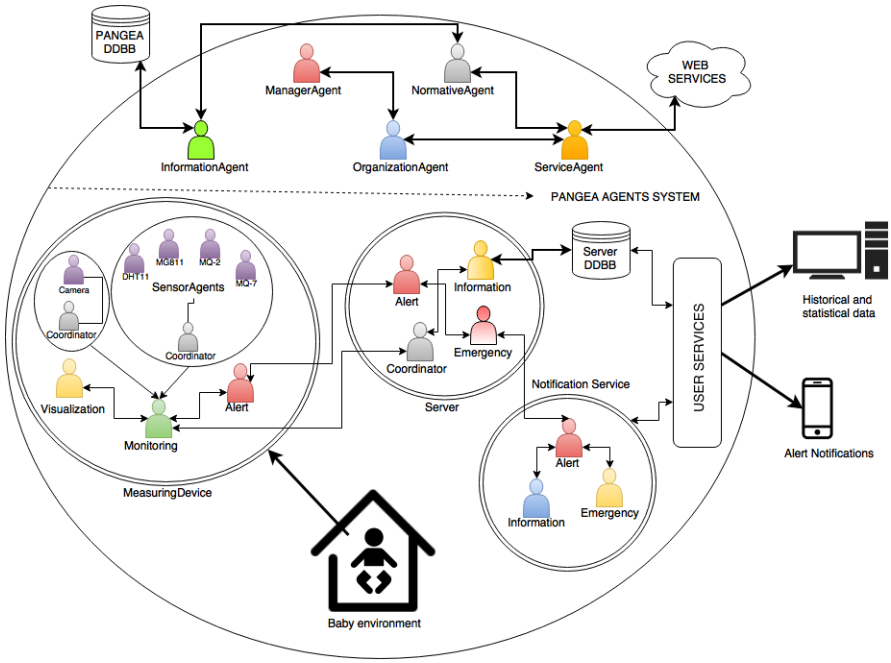

Figure 1: Proposed MAS Architecture

The first relevant element in this architecture is the organization Measuring Device. It is in charge of collecting the data from the different environmental monitoring sensors. It is also responsible for the collection and analysis of the images of the camera that will allow obtaining the heart rhythm. The roles involved in this sub-organization are as follows: Alert, monitoring, visualization, sub-organization sensors and sub-organization camera.

The agent with role monitoring will be in charge of analyzing the data obtained by the set of sensors. If values outside the normal range are detected, it interacts with the agent who is responsible for managing alerts. This agent will also provide the data to the display agent. The alert agent will be responsible for sending alerts to the server. The agent with the display role will be responsible for showing the user the data obtained in real time. The sensor sub-organization includes the coordinating agent that is responsible for collecting the data sent by each sensor and four agents (DHT11, MG811, MQ-2, MQ-7) one for each of the sensors connected to the system. The camera sub-organization will manage the collection and analysis of images captured through an IP camera. These are delicate images because they are a minor in their home, this images are analyzed locally and exclusively are sent heart rate data calculated outside the domestic network. These images after being processed are automatically deleted from the system.

The server organization has four roles: Coordinator, alert, information and emergency. The coordinating agent is in charge of managing the information coming from the sensor device. The agent whose role is information is in charge of

storing all the data, while the alert agent analyzes the different alerts that arrive from the measuring device. If these alerts require a quick intervention, the emergency agent uses a Notification Service to contact the medical center configured in the system. In this way a quick intervention is performed when the measured values indicate an emergency. For the rest of the cases in which a value is out of the range or an anomaly has been detected, the alert agent sends a notification to the mobile device of the progenitor parents.

3.1 Environmental sensing system

For the monitoring of the described factors, we will use specialized hardware that has the ability to connect different sensors. This device will act as a central monitoring node in the proposed sensor network. Currently, on the market we can find many types of devices that have this capability. Out of all of them, the Arduino platform is the most widespread, free code and at reduced cost. Therefore, it will be the device used in this work.
The description of the environmental sensors that will be part of the architecture are shown below. These sensors are compatible with the Arduino microcontroller and like this one, they have a low economic cost. The sensors included in the project are: DHT11, MG-811, MQ-2, MQ-7. The sensor network connected to the Arduino microcontroller is shown in Figure 2. This device will be responsible for collecting all environmental data in the infant's room.

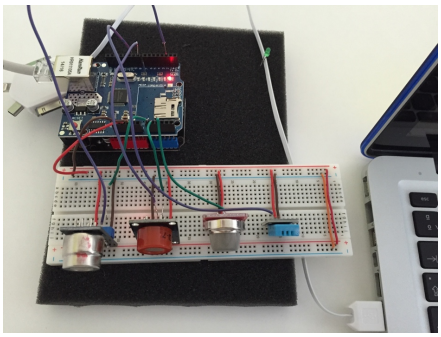

Figure 2: Prototype based on arduino board

In addition, the system will have WiFi wireless connectivity, which will enable the sending of data to the remote server. This is possible thanks to the connection of an ESP8266 module that allows to connect the Arduino microcontroller to the wireless network at home.

3.2 Calculating heart rate through OpenCV

Once the environmental factors in the infant´s bedroom are monitored, the task of obtaining the baby´s pulse through a non-invasive system is addressed. For this, photoplethysmography (Photoplethysmogram) is used. Photoplethysmography or

PPG is a non-invasive means of detecting cardiovascular pulse wave (also called, blood volume pulse) through reflected light variations. This technique provides valuable information that permits to calculate the heart rate. A small, wireless webcam is placed on the frame of the baby's crib, it will capture images needed for the treatment of data.

Firstly, a tracking and face detection system has been developed within the frames of the video in order to locate the region of interest. For this, OpenCV (Open Computer Vision) is used. The face detection algorithm is based on the work of [19] by means of a pre-trained Haardcascade capable of detecting the region of interest. Once the region of interest is located, it is separated into three RGB channels, generating a spatial average on all the pixels of the region and thus producing the three signals: Red, green and blue. The generated signals are decomposed into three other independent source signals using ICA (Independent Component Analysis). ICA is a technique for discovering signals from independent sources of a set of observations that are composed of linear mixtures of the underlying sources. This technique is used because it contains a great ability to reduce artifacts by movement in PPG signals.

The underlying signal of interest that ICA uses, is the cardiovascular pulse wave that spreads throughout the body. During a cardiac cycle (cardiovascular pulse) the facial blood vessels change volumetrically by modifying the length of the incident light path, so that these changes in the amount of reflected light indicate the time of cardiovascular events. The RGB sensors that compose a camera can collect a mixture of plethysmographic signals reflected by the light. The objective of ICA is to find a separation of the PPG signal in order to collect the independent sources contained in it.

Finally, the FFT (Fast Fourier Transform) is applied to the second resulting signal to obtain the power spectrum. The pulse frequency is designated as the frequency corresponding to the highest spectrum power within an operating frequency band, so an operating range of [0.75, 4] HZ corresponding to [45, 240] bpm, thus providing a wide range of heart rate measurements.

Figure 3 shows the system running through a wireless webcam. The software recognizes the region of interest located in the frontal region of the head (in green color) and through the analysis of the images, determines the pulse of the user.

Figure 3: Example of pulse measurement system

The alarm system is based on the detection of any anomalous values collected by any of the sensors that make up the platform. The system considers any value to be anomalous if it is outside of the normal limits which were previously defined in the system. These limits must be defined by a medical professional for each patient because the configurations can be different depending on the individual. Some of the elements that must be taken into consideration when defining these values are age, sex or weight. But these are not the only data that must be taken into account; to begin, it is essential to analyze the patient's health problems thoroughly in order to properly determine the normal range values for the data collected by each sensor.

4. Results and conclusions

The result of this work is a wireless sensor device capable of monitoring the possible risks of SIDS in an infant. A web application has been developed to control and visualize all the parameters collected by the sensor system. Figure 4 shows a capture of the developed web interface, in the very center of the image we can see the baby in real time. For security reasons this functionality is only available if the user accesses the application from the same home network in which the camera is located. At the bottom of the image, real-time values are being measured by the different sensors. To the right of the image you can see the different sensors installed in the device. Through these components it is possible to define the threshold values, on the basis of which, different warnings and alerts are triggered. It is also possible to disable or activate sensors individually or display the data history recorded by them.

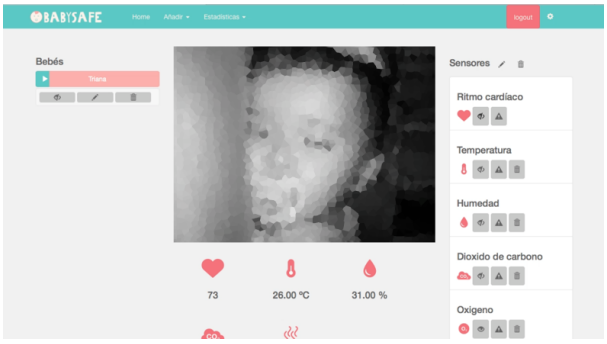

Figure 4: System web interface

In order to notify the parents and caregivers of the neonates of the incidents produced to the parents and caregivers of the infants, an application has been developed for mobile devices. This application, shown in Figure 5, consists of a simple interface through which the user can enter the access credentials to identify themselves. Once identified, the remote server will notify the user when an anomaly occurs within previously defined values in the web application. In this way, if the

anomalous values are registered in the environment in which the infant is resting, the parents or caregivers can perform a quick intervention.

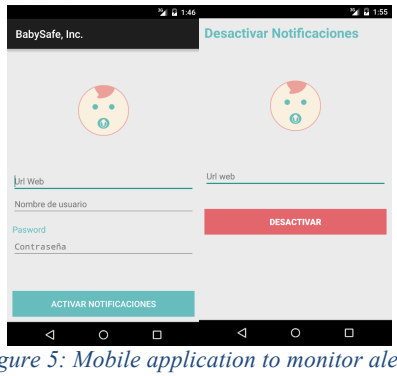

Figure 5: Mobile application to monitor alerts

In the future, we will study another of the risk factors such as the baby´s position while sleeping, this would also be done by analyzing the images obtained by the camera, as we could see if the baby drinks/sleeps in a risky position. Another possible study in the future would be the application of expert systems such as CBR (Case-based reasoning), for the automatic detection of anomalies on the basis of data recorded by the devices. By creating a system that learns over time, the system´s decision making will improve, yielding better results.
In conclusion, this work proposes a multi-agent system based on the PANGEA platform that manages a non-intrusive environmental monitoring system for the prevention of SIDS in newborns. These data are captured through a system of low cost sensors (less than 80€) in combination with an open source hardware system such as Arduino. In addition, a real-time analysis of the images captured by an IP camera located on the baby's crib. The combination of environmental data and non-intrusive system, which monitors cardiac pulse, allowing for the detection of possible anomalies in the baby´s health.

Acknowledgements. This work has been supported by project MOVIURBAN: Máquina social para la gestión sostenible de ciudades inteligentes: movilidad urbana, datos abiertos, sensores móviles. SA070U 16. Project co-financed with Junta Castilla y León funds.

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