International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 19 (2018) pp. 14177-14187

Non-Invasive Model for Detection of Extrinsic Risk Factor of Sudden Infant Death Syndrome

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Abstract

The Sudden Infant Death Syndrome (SIDS) is defined as one disease of the general group of sudden and unexpected infant deaths (SIMI). SIDS is defined as the death cycle of a child under one year, thereafter the complete necropsy analysis, there is no cause to justify his death, although the premise that suggests that the death of the baby is an event that occurs by drowning or accidental suffocation has arisen. Thermal imaging is a non-invasive technique used in the medical environment to monitor the position, temperature, and breathing of patients. This work presents a non-invasive model using thermal images to determine the position in which the infant is sleeping, through the computing of child's temperature and the respiration used as input in the diffuse controller. The results showed changes in the temperature of the minor, related to the temperature of the skin and breathing, the study was carried out with a database of 7,189 images in 6 children under 1 year of age. The proposed method presented a high performance to detect the infant's position with a Kappa coefficient of 0.812.

Keywords: SIDS, thernal imaging, non-invasive methods, fuzzy logic.

INTRODUCTION

The Sudden Infant Death Syndrome (SIDS), is used when a sleeping infant, who has apparently been quite well, is found unexpectedly dead. Pathological evaluation, including ancillary testing, is unable to discern a cause of death [1]–[4] . The SIDS is the leading cause of death in Western countries in children between one and twelve months. It has become a nightmare that torments many parents. According to the statistics for 2011, 5,000 infants die every year in Europe, victims of sudden death syndrome. In Spain, around 100 babies die every year, which means that the syndrome affects one in every thousand babies [2].

In spite of the campaigns carried out for the prevention of SIDS, in the United States "Back to Sleep" and in Colombia "Safe Sleep", the death rates caused by Sudden Infant Death Syndrome continue to be constant. In the United States each year about 3,500 children die due to Sudden and Unexpected Deaths [4]–[9].

The cause of SIDS is still unknown. However, some challenges to the thermoregulatory capacity of babies or thermal stress have been implicated in many of the known risk factors, such as sleeping position, suffocation and elevated temperature [9]. The most studied factors that statistically present an increase in the risk of deaths from SIDS are classified as extrinsic (environmental factors) and intrinsic (factors associated with the baby) [10].

The temperature of the skin is the most important parameter to trigger changes in behavior. However, in terms of impact on the thermoregulatory autonomic response, the thermal contribution of the skin contributes only about 20%. The temperature of the human body is a complex phenomenon [11]. Therefore, in this research, digital thermography was used as a non-invasive technique.

Thermography is a technique based on the detection of the temperature of bodies that is applied to a multitude of areas such as industry, construction or medicine [12]. Thermography is a method of diagnostic imaging that consists of capturing the infrared radiation emitted by living beings, therefore, it is considered a non-invasive medical diagnostic method, which provides information on physiological processes by examining the distributions of skin temperature that comes from physical processes and may be related to blood perfusion. It is complementary to anatomical investigations and often reveals problems when the anatomy is normal [13].

The continuous monitoring of breathing is important to determine the sleep status of a person under study. Within the methods found, plethysmography is used, which is used to measure changes in volume of different parts of the body such as lungs and multi-normal algorithms of data representation using the method of moments and then calculating the measure of divergence [14][15]–[18]. Canlin Li and Lihua Bi presented the real-time monitoring of the position of the baby, added to the definition of alarms and possible risks that were taken into account for the design of the model, obtaining results in relation to the detection of the position of the child while he slept, in this study the captured images were used to a minor [19]. On the other hand, Meng - Chien Yu et al, analyzed to the fact that sleep is essential for the mental and physical health of a person, so an analysis technique was implemented of images with a depth camera to monitor the person's breathing rate, the position to sleep and the movement of the body during sleep without any physical contact [20].

The main focus of this work is to be able to apply thermal image processing techniques within the medical and biological area, to a public health problem with reference to the Sudden Infant Death Syndrome (SIDS) [21]. In this way, the objective is to develop a non-invasive model for the detection of extrinsic risk factors for SIDS. For the measurement of the temperature ranges, thermography was used, which is an integral part of the development of this research, which led to the construction of a database of thermal images of 6 children under one year of age. 7,189 images, under the informed consent of the parents, acquired with the IR OPTRIS PI-450 thermal camera, with thermal sensitivity (NETD) of 40 mK, an FPA-type, non-refrigerated detector (25 x 25 μm), an optical resolution of 382 x 288 pixels, a spectral range of 7.5 - 13μm, a temperature range of -20ºC to 900ºC, the frequency of the image of 80 Hz / sg and characterized by a lens at 1000mm [22].

Some authors mention as an important pattern of temperature measurement to the cutaneous electrode, however, it is considered that infrared thermography (IRT) is a reliable tool to measure and map the temperature distribution of human skin and help to evaluate thermoregulatory reflexes, within these investigations, temperature sensors and image processing methods were used [15], [16], [23]–[26].

The document is organized as follows: Section 2 shows the experimental setup as the description and extraction of the characteristics of the images. Section 3 illustrates the proposed methods of processing, architecture and methodology, on the determination of the position from the measurement of temperature and respiration, based on thermal images. Section 4 provides the experimental results and finally, the document concludes in section 5 and shows the future works in section 6.

EXPERIMENTAL SETUP

The human beings by nature is homoeothermic, it maintains its constant temperature and emits heat to the surrounding environment. The only interface between that heat production and the environment is the organ of the skin. This dynamic organ is constantly adjusted to balance internal and external conditions, while satisfying the physiological demands of the organism [12], so it is essential to know and configure the emissivity value of human skin. The study was done following all the ethical requirements for non-invasive studies with minors, and with each of the informed consent of the parents. The capture of the images was made based on the visualization and analysis of the measurement environment where the child was sleeping, the location of the thermal camera and the configuration of the camera with an emissivity parameter of 0.98.

The image acquisition was done by using of the OPTRIS IR PI-450 thermal camera. The capture of the images from 6 children with a range of ages between one month and 12 months of age was performed following medical requirements. A database of 7,189 captured images with the IRON color map, provided by the PI-Connect as presented in table 1. The measurements were made under different environments and different focal distances, without affecting the position and without imposing conditions on the child's position, in order to have the best approximation to the real environment.

The acquired images are a 3-dimensional matrix of *288x382x3* with TIFF format (Tag Image File Format), which were processed using the MATLAB software. The images were treated as a matrix whose indexes of rows and columns identify a specific point of the image, each of these points have a value within a range of [0,255] interpreted as discrete data, which give value to each of them. The channels of the photo (RGB). The thermal images were converted to gray scale to perform the processing in real time, since the amount of information per image is reduced to a single channel and, therefore, the number of operations is reduced, and the time of execution of the algorithm.

The characterization of the thermal images was developed through the relationship curve, between the equivalence in the pixel range of the captured image and the equivalent temperature value. The generated curve of the pixel-temperature equivalence, is the one obtained from the characteristic equation of polynomial type, obtained in the previous works [27]. Thus, the image was binarized and divided into 4 parts as follows: head, forehead, eyes-nose-mouth and the neck. We selected the forehead and eyes-nose-mouth Region of Interest (RoI) to determine the temperature and respiration. Once the characteristics of the images were extracted, with respect to the child's temperature and respiration values, in order to find a relationship between the temperature, breathing and position, in the child while asleep.

Table 1. Number of images obtained with Iron, Rainbow and other color maps with the total recording time.

SAMPLE	**AGE**	**IRON CMAP**	**TIME (s)**
SUBJECT A	6 MONTHS	505	505 s
SUBJECT B	9 MONTHS	651	651 s
SUBJECT C	5 MONTHS	87	3600 s
SUBJECT D	1 MONTH	1.670	1.670
SUBJECT E	4 MONTHS	1.542	1.542 s
SUBJECT F	12 MONTHS	2.734	2.734 s
TOTAL		7.189	10.702 s

METHODS

The pipeline that described the proposed model is presented in Figure 1. It describes the procedure followed for the development of the research, in addition to explaining the methodology that was applied, which was constructed to provide a frame of reference, structured and defined, in order to relate the data obtained within a context of reproducibility.

Proposed Model of the non-invasive detection

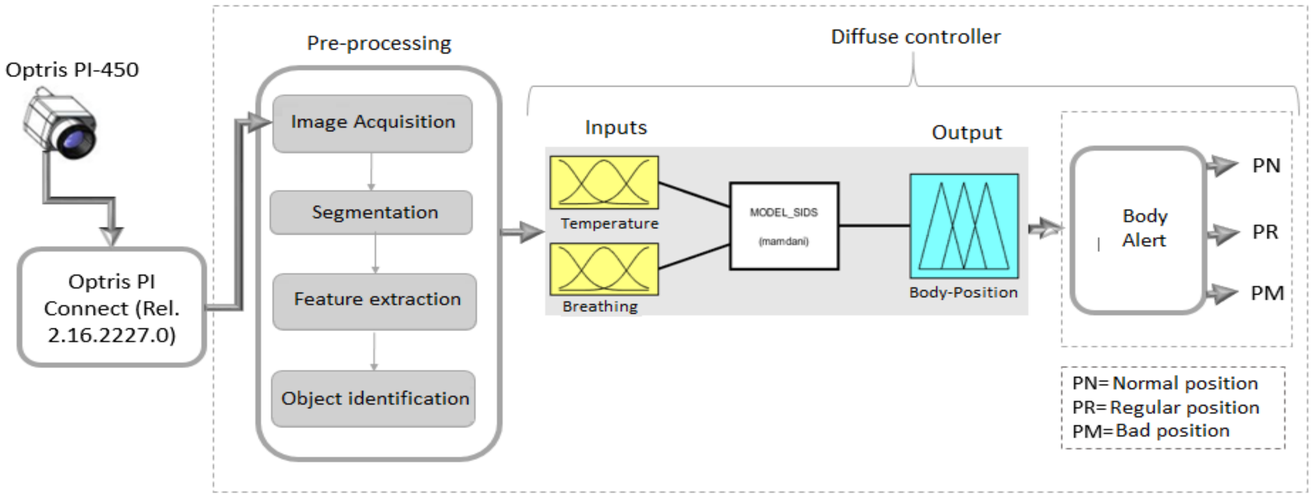

Figure 1. Block diagram of the non-invasive detection model of the minor's body position.

The histogram and its corresponding equalization was computing to obtain the number of pixels in each intensity level was obtained [28], thus it was possible to apply thresholding and binarization techniques for the extraction of the characteristics of 4 RoI in the image. The values corresponding to the RoI 2 and 3 corresponding to temperature and respiration respectively, are calculated by means of equations 1 and 2:

The temperature defined as the mean or expectation of a discrete random variable, where x_i represents all possible values of the variable and, $p(x_i)$ the probabilities of each of these values as shown in Equation (1) [28].

$$\mu = \sum_{i-1}^{n} x_i \, p(x_i) \qquad (1)$$

The breathing is defined as the median of a grouped data set. Where: x_i is the lower limit of the median class; $N_{M/2}$ is the position of the median; N_{i-1} is the cumulative frequency of the pre-median class; f_i is the absolute frequency of the class of the median and (x_{i2}-x_{i1}) is the amplitude of the interval of the class of the median as presented in Equation (2).

$$Mdn = x_{i1} + \left(\frac{N_M/_2 - N_{i-1}}{f_i}\right)(x_{i2} - x_{i1}) \qquad (2)$$

The block diagram with the algorithms required for the pre-processing of the thermal images acquired in this research is depicted in Figure 2.

Pre-Processing

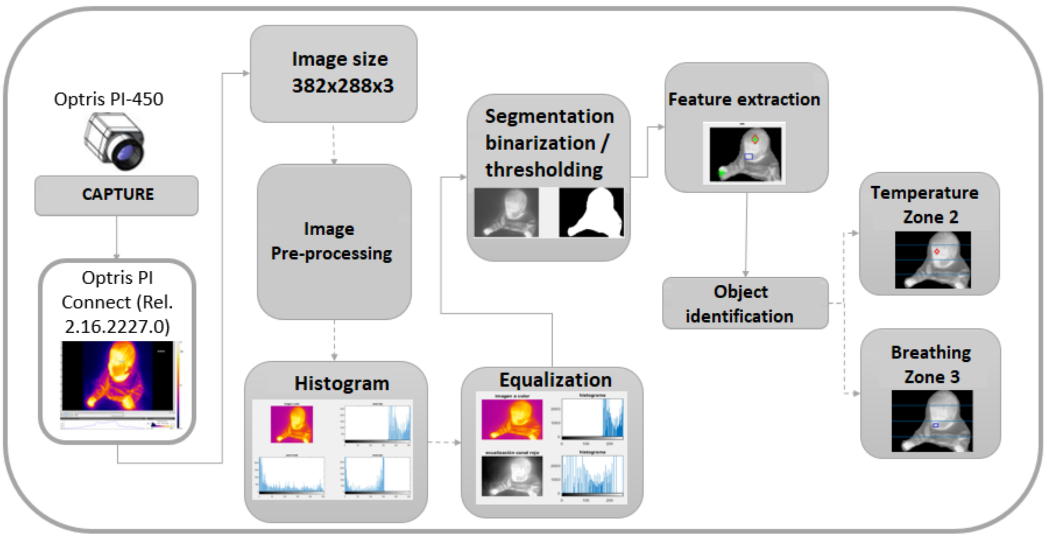

Figure 2. Algorithms used in the non-invasive model for position detection.

The temperature and breathing are variables that present a certain degree of uncertainty. The behavior of temperature in the skin is related to non-linear dynamics, for this reason it was decided to make use of fuzzy logic controller. According to the studies reported, and a public health expert, the normal and abnormal ranges of temperature and respiration were defined in children under one year of age while they sleep. These ranges were defined by means of fuzzy sets, for the inputs to the fuzzy controller.

The position of the children while asleep is one of the most studied factors in the SIDS. In this research, it was selected as the output parameter of the fuzzy controller, therefore it was designed with a set of rules so that from breathing and temperature infer the different scenarios of the controller.

The structure of the controller contains four fundamental blocks (rule base, fuzification block, inference block and defusing block). For the design of the controller, the definition of the rules, which were made based on the literature and with the help of a health expert as reported in table 2. The description of the selection parameters of each of the input and output variables, with their respective membership function according to the designated parameters, is summarized in the following table:

Table 2. Membership functions and general parameters table.

Variable	Inputs / Output	Range	Labels	Value	Membership function	Parameters
Input variable 2	Temperature	[30-39]	Hyperthermia	HIPER	Trapezoid	>36.4
			Normal	NORMAL	Triangular	[36.0 36.25 36.5]
			Hypothermia mild	HIPO-LEVE	Triangular	[35.5 35.7 36.1]
			Hypothermia moderate	HIPO-MOD	Triangular	[31.5 33.45 35.4]
			Hypothermia serious	HIPO-GR	Trapezoid	< 31.5
Input variable 1	Breathing	[30-39]	Normal	RESP-NOR	Triangular	[36.35 36.5 36.65]
			Excess CO2	EXC-CO2	Trapezoid	>36.55
			Excess O	EXC-O	Trapezoid	<36.45
Output variable	Position body	[0-100]	Normal position	POS-NOR	Triangular	[62.5 100 137.5]
			Regular position	POS-REG	Triangular	[25 50 75]
			Bad position	POS-MAL	Triangular	[37 5.0 37.5]

RESULTS

In this section, the performance of the proposed model is analyzed, based on the diffuse Mamdani type controller. The controller was applied to a sample of 6 children, who aged between one month and 12 months old. The control block has real-time monitoring of the 3 variables and visual alarms of the state of the position, designed in MATLAB's SIMULINK.

From the variables and temperature ranges assigned in table 2, the following rules were defined:

Figure 3 shows the simulation that results from entering a temperature and breathing input in normal ranges with values of 34.5ºC, which infers a normal alert-position output according to the previously defined fuzzy rules.

Table 3. Definition of Inference Rules for the fuzzy controller for the detection of SIDS.

		Breathing		
		RES-NOR	EXC-CO2	EXC-O
Temperature	HYPER	POS-MAL	POS-MAL	POS-MAL
	NORMAL	POS-NOR	POS-REG	POS-REG
	HIPO-LEVE	POS-REG	POS-REG	POS-REG
	HIPO-MOD	POS-REG	POS-MAL	POS-MAL
	HIPO-GR	POS-MAL	POS-MAL	POS-MAL

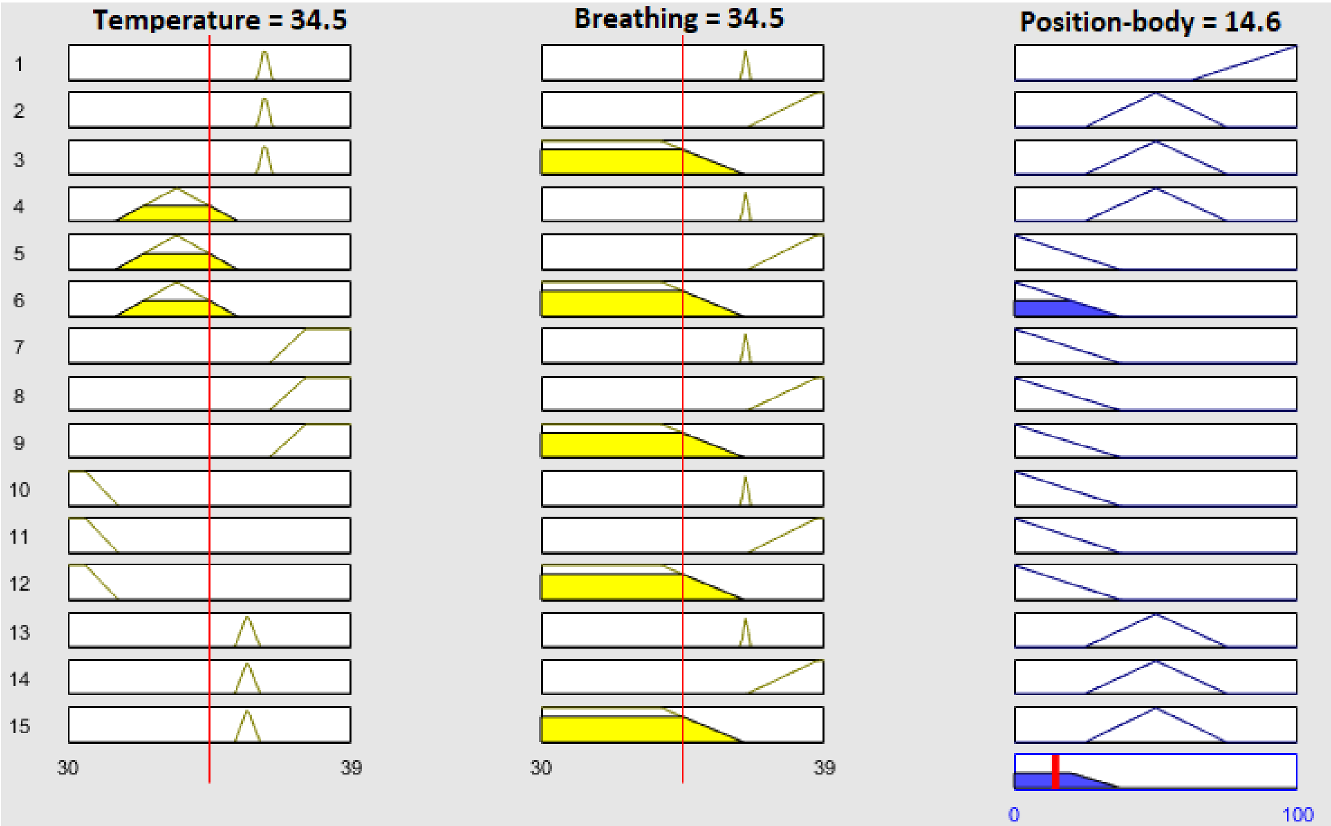

Figure 3. Value of Normal position using temperature and breathing inputs in the fuzzy controller.

A set of tests were conducted in order to validate the behavior of the model in a real environment, additionally with this model slight and severe temperature changes are observed in the specific ranges of skin temperature. Three different transition points were defined, between the related membership functions of the variables of temperature and respiration inputs. The results shown in this investigation indicate that the measurements of the variables obtained from the established temperature ranges can determine possible warning signs, in order to prevent or even register sudden infant deaths.

A systematic grid was performed, for the relationship of the values of each of the points of intersection of the input variable I (temperature), combined with the values of the input variable II (breathing), obtaining an output behavior for each one of the points raised in relation to (T, R, P). The figure 4 shows the surface with all the possible values that can be obtained in the input and the values that can be obtained in the output. Additionally, we observe the behavior of twelve (12) different transition zones called P1-P12, where each zone was formed by a set of six points.

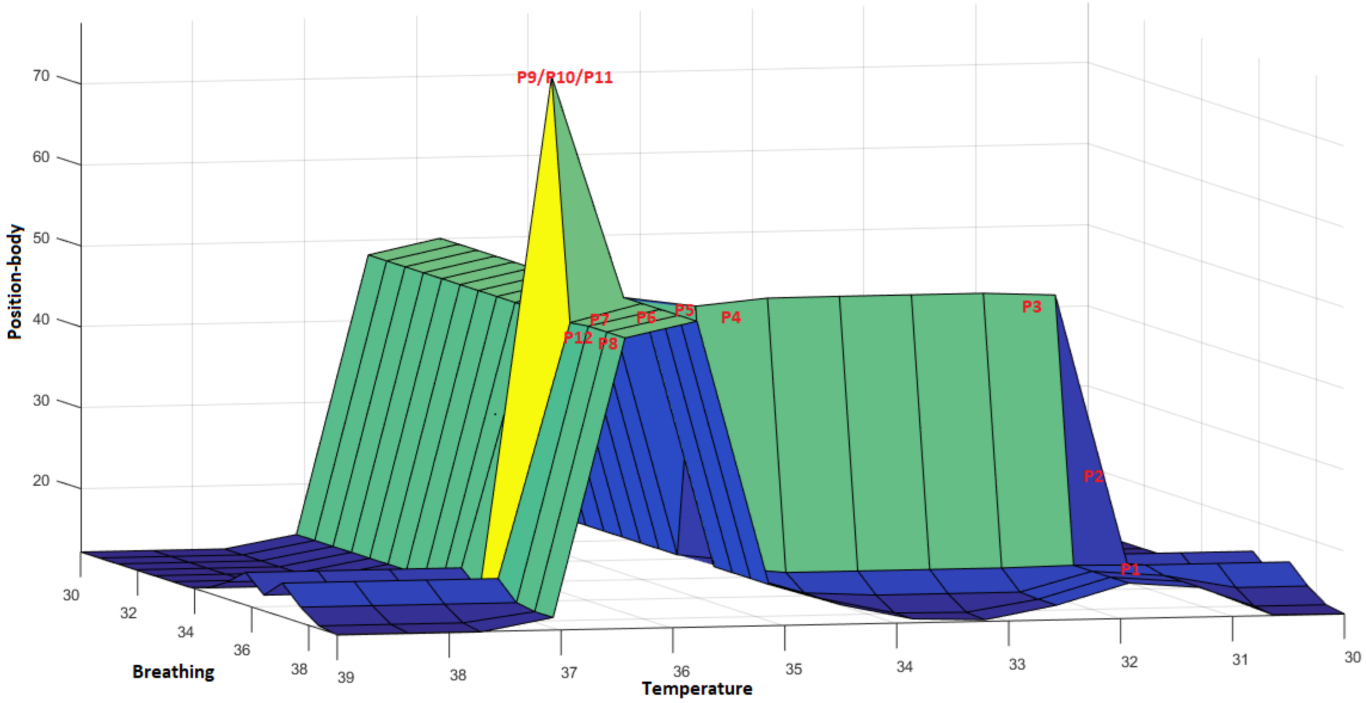

Figure 4. Surface of all the possible input and output values at the critical points of the model.

Moreover, figure 5 shows the characterization of the temperature ranges established for the controller inputs: plotting the normal position (yellow color), regular (green color) and bad (blue color). Here the position transitions and the values are displayed where two membership functions can be activated, which can be seen from the change of the output.

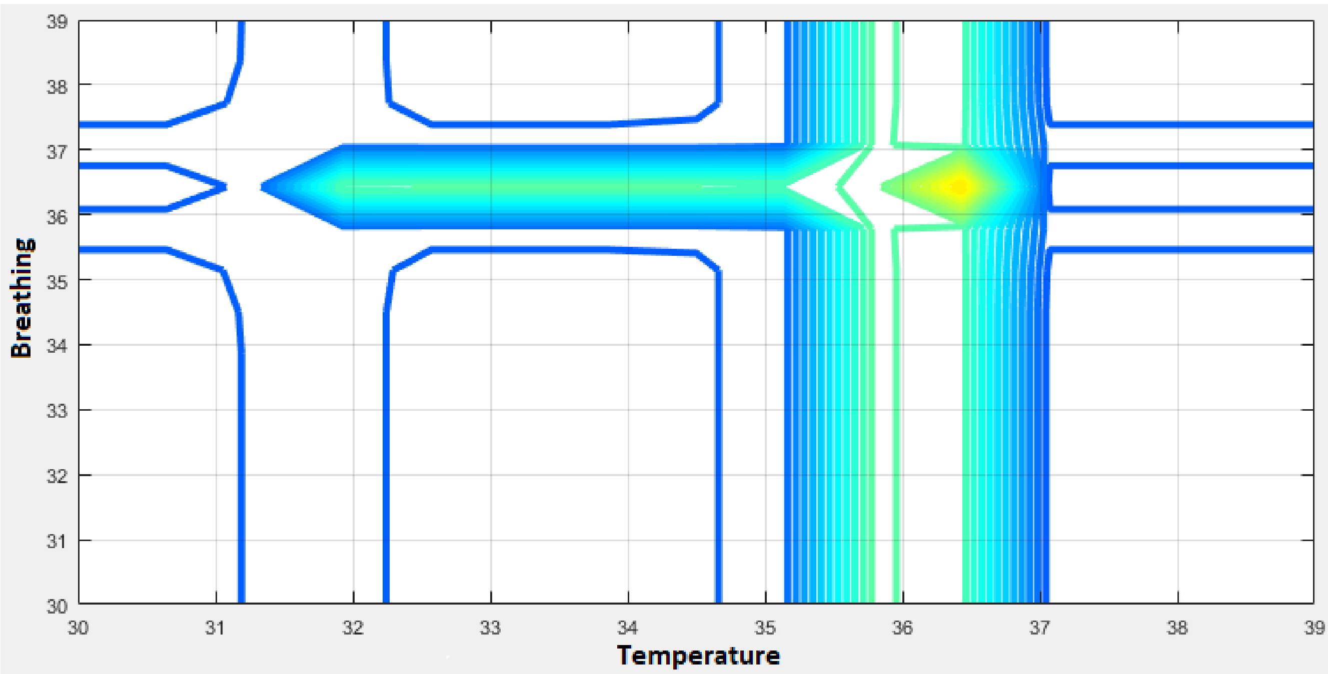

Figure 5. Top view of the surface of all the critical points in the model.

Within the results of this investigation, a specific case was observed in subject B (Table 1), which was recorded during 651 s, generating a snapshot every 1 s for a total of 651 images, with the standard color palette of type Iron. During this time, the minor presented significant changes from the start of the capture until the minor woke up from the dream in which he was. In figure 6 shows the behavior that occurs in the output of the controller, during the captures that were made in Minor B, assuming each snapshot in real time, processed second by second. In this case, variations of the signal with respect to the position are presented, according to the temperature ranges in the regions of interest chosen, described in section 2.

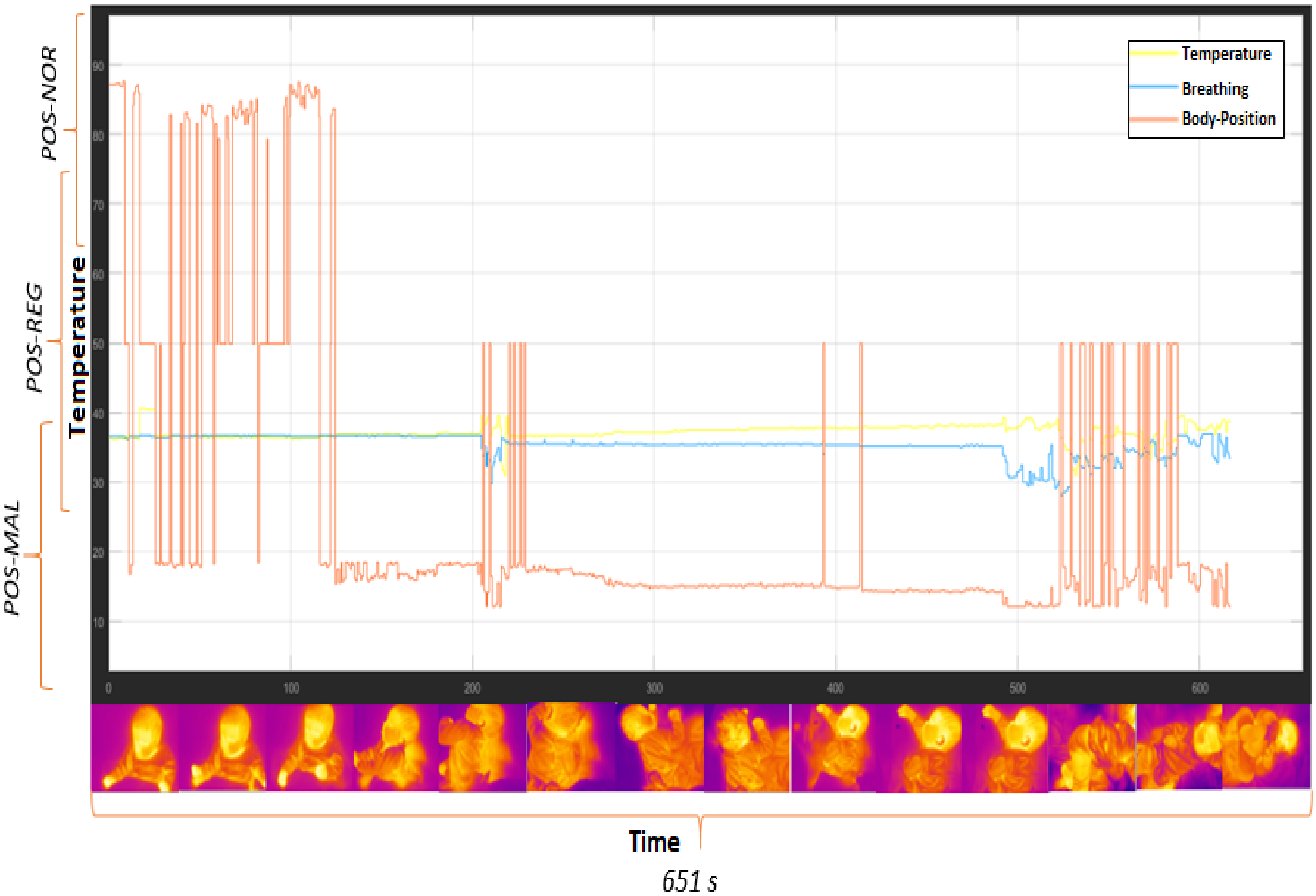

Figure 6. Position, breathing and temperature behaviors of Subject B.

Due to the behavior of thermoregulation presented by infants, we can explain the variations that occur at the beginning of the recordings, the results show that the temperature of minors is regulated as they fall asleep. On the other hand, it can be shown that in capture number 120 or equivalent to the 120 seconds elapsed, the child began to show warning signs, alterations were observed in the signals when the child began to change the position of the dream and in the points critics where the child was totally upside down, significant changes were shown when the child was crying and the output shown by the driver was a regular and bad signal, causing an alteration in the temperature and breathing measures, related to the changes presents a minor when there is stress or hyperventilation.

On the other hand, in figure 7 shows the validation of the model for the data obtained from Minor C, being a case where the child was recorded for 1 hour, during which the child did not present any alarm regarding the position. After an hour of recording with captures every 41 seconds, 87 snapshots were generated, until the minor woke up. The model was validated with the catch of Subject C, to verify the constant change in the signals obtained. The validations of the remaining 4 subjects were not reported, as they did not show significant changes, and during the recording time there were no alarm signals, as for the position in which they initially fell asleep.

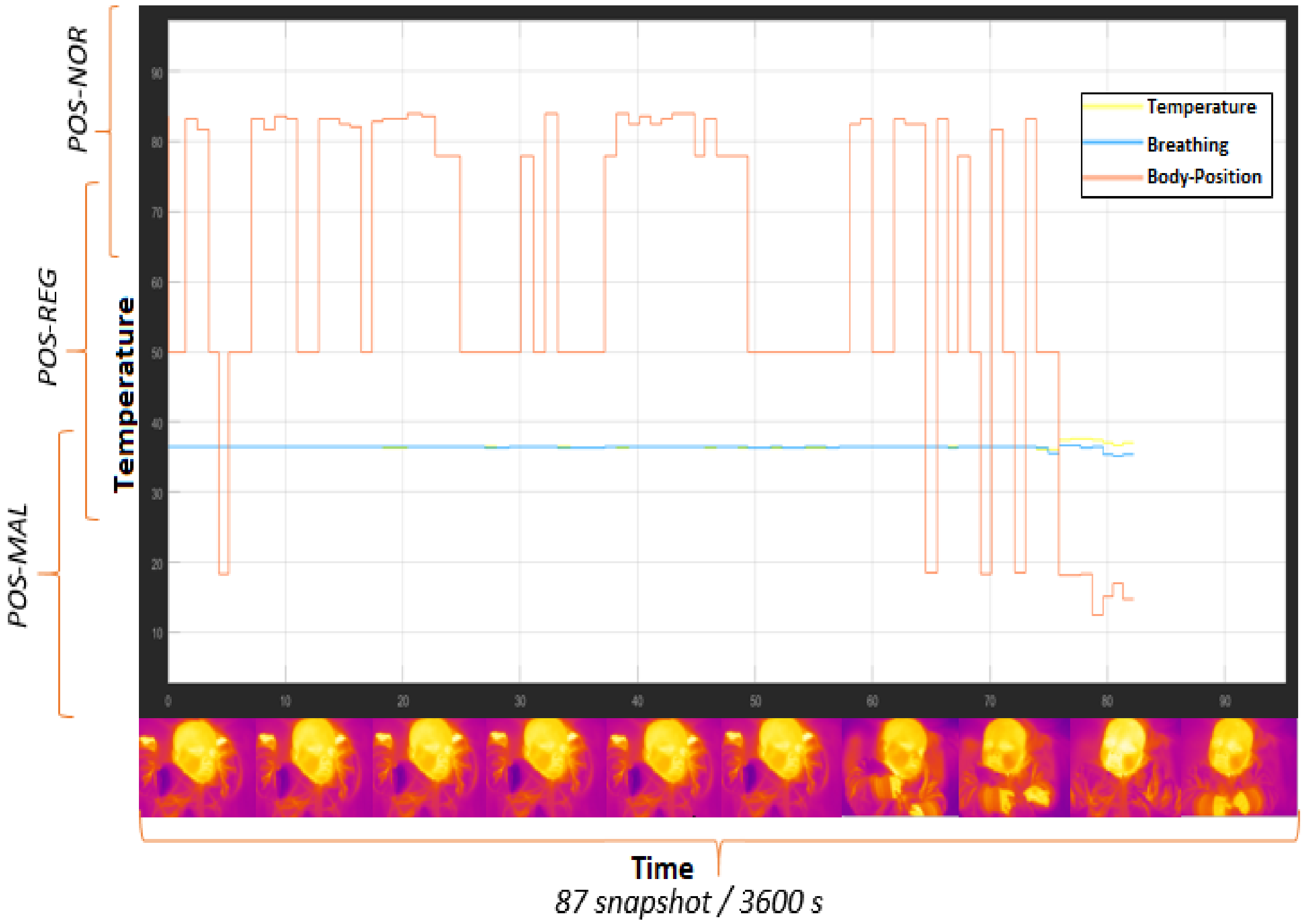

Figure 8. Behavior position of the non-invasive model in subject C.

It was tested that the signs of onset took time to regulate, behavior explained from the normal changes of thermoregulation of the infant. During the validation of the data of Minor C, the model did not present alarming changes, except when the minor began to cry, this change is reflected in the exit signal where there are signs of alarm, despite the fact that the subject was not in a bad position, the temperature changes increased and the respiration ranges decreased, which could be reflected as hyperventilation due to crying.

Comparing the results obtained, with respect to the work published in the journal, International Journal of Control and Automation [26], where they present the monitoring of a minor in 8 different cases regarding the position in which you are sleeping. The proposed model reported the experimental validation in 6 different minors, monitoring slight and severe temperature changes of the real temperature ranges in the skin and temperature ranges that are related to the exhalation and inhalation, physical behaviors of the respiration. In addition, the proposed model monitors activities related to hypothermia and hyperthermia, control of breathing when hyperventilation or stress occurs when children cry, relating these variables to the position in which the child is sleeping.

A detailed analysis of the results obtained was carried out through a confusion matrix of 3x3, which represents the level of success between the position of the child during sleep given by an expert and the predictions given by the proposed method. Additionally, table 8 presents the results of the validation of the algorithm obtained against the concept of the expert, for a sample of 7189 images belonging to the Iron color bar of the 6 minors. In table 4, the main diagonal is observed which represents the agreement given by the concept of the expert and the prediction of the proposed model, the bold values indicate the precision and completeness of the model. The kappa coefficient was also calculated, which is based on comparing the agreement observed in a set of data, with respect to what could happen by mere chance.

Based on the literature [29], the kappa coefficient defines values "<0" as indicative of non-agreement and "0 - 0.20" as a slight concordance, "0.21 -0.40" fair agreement, "0.41 - 0.60" moderate agreement, "0.61 - 0.80" substantial match, and "0.81 - 1" almost perfect match. The kappa coefficient obtained was 0.812, which indicates an high concordance.

Table 4. Confusion matrix and performance measures obtained by predicting the position of the child given by the proposed method compared to the classification given by the expert.

		EXPERT CLASSIFICATION				
		BAD POSITION (PM)	**REGULAR POSITION (PR)**	**NORMAL POSITION (PN)**	**GENERAL CLASSIFICATION**	**ACCURACY**
PROPOSED MODEL	**BAD POSITION (PM)**	900	178	106	1184	**76,014%**
	REGULAR POSTION (PR)	154	2566	102	2822	**90,928%**
	NORMAL POSITION (PN)	178	126	2879	3183	**90,449%**
	GENERAL CLASSIFICATION	1232	2870	3087	7189	
	RECALL	**73,052%**	**89,408%**	**93,262%**		
	OVERALL ACCURACY	**88,26%**				
	KAPPA COEFFICIENT	**0,812**				

DISCUSSION AND CONCLUSION

The use of a diffuse controller allows the non-invasive detection of the extrinsic risk factors of sudden infant death syndrome. The proposed model detects SIMS risk factors, changes in temperature or respiration and infers with the previous two variables the position of the minor during sleep. Additionally, based on the literature, a Kappa value and a general precision value greater than 0.80 is considered an almost perfect match between the predictions of the proposed model compared with the prediction given by the expert [23].

The proposed model presents the ability to save sudden events, episodes that can define the causes of a sudden death or at least the changes that a minor presented while sleeping. What is supported by literature, which define sudden death as: "the death that occurs in a general way during sleep and that is inexplicable, even after an exhaustive investigation of the death scene, the medical history and the autopsy complete [10].

On the other hand, the literature supports that these deaths occur in babies "apparently healthy", but there is still no consensus on the definition of healthy, I emphasize this relationship, since this model seeks to investigate behaviors that may occur while sleeping children and be able to give an approximate meaning to the definition of possible causes of sudden infant death.

According to this research, it can be observed that the temperature range in babies varies according to the position in which they are sleeping and in the same way these ranges can be affected when the child presents strong movements or when the baby cries, as presented during the investigation. Additionally, it was possible to determine that the temperature in the babies stabilizes once they fall asleep, in the 6 minors of the study the initial temperature was regulated after a lapse of time.

The use of the proposed model for several days in children or even a deep examination of thermography, could help in the definition of a clinical parameter that stratifies the risk in neonates. The definition of warning signs and previous diagnosis continues to be an engineering challenge, therefore, a study with a greater number of minors is required to reinforce this hypothesis.

FUTURE WORKS

We can highlight the detection of the eyes and mouth from the database of thermal images obtained in this research. The proposed model could be validated in babies with different pathologies (not healthy), to define a temperature relationship in healthy and unhealthy babies. The proposed model could be used to monitor patients of any age with sleep apnea problems, people with problems of hypoglycemia during sleep (death syndrome in bed) or elderly people with various problems during sleep. The obtaining of a greater number of thermal images (healthy and unhealthy babies), to perform the training of neural networks and compare the proposed method. In future studies this model of non-invasive type could be used for cancer-related research, since different cancer studies with this type of images were found within the literature consulted, since benign and malignant tumors present different ranges of cancer. temperature.

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