Infrared Physics & Technology 81 (2017) 250–261

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Regular article

Human emotions detection based on a smart-thermal system of thermographic images

Irving A. Cruz-Albarran, Juan P. Benitez-Rangel, Roque A. Osornio-Rios, Luis A. Morales-Hernandez *

Mecatrónica/Facultad de Ingeniería, Campus San Juan del Rio, Universidad Autónoma de Querétaro, Rio Moctezuma 249, Col. San Cayetano, 76807 San Juan del Rio, Querétaro, Mexico

HIGHLIGHTS

- A study on thermal behavior of anger, disgust, fear, joy and sadness is carried out.
- A self-calibrated system to have the same thermal trend for each subject is proposed.
- A diagnostic of emotion through a top-down hierarchical classifier is done.
- Biomarkers are proposed through temperature changes.

ARTICLE INFO

Article history:
Received 17 August 2016
Revised 19 November 2016
Accepted 4 January 2017
Available online 11 January 2017

Keywords:
Infrared thermography
Emotion
Region of Interest
Diagnostic
Self-calibration and biomarker

ABSTRACT

This work presents a noninvasive methodology to obtain biomedical thermal imaging which provide relevant information that may assist in the diagnosis of emotions. Biomedical thermal images of the facial expressions of 44 subjects were captured experiencing joy, disgust, anger, fear and sadness. The analysis of these thermograms was carried out through its thermal value not with its intensity value. Regions of interest were obtained through image processing techniques that allow to differentiate between the subject and the background, having only the subject, the centers of each region of interest were obtained in order to get the same region of the face for each subject. Through the thermal analysis a biomarker for each region of interest was obtained, these biomarkers can diagnose when an emotion takes place. Because each subject tends to react differently to the same stimuli, a self-calibration phase is proposed, its function is to have the same thermal trend for each subject in order to make a decision so that the five emotions can be correctly diagnosed through a top-down hierarchical classifier. As a final result, a smart-thermal system that diagnose emotions was obtained and it was tested on twenty-five subjects (625 thermograms). The results of this test were 89.9% successful.

1. Introduction

Nowadays, noninvasive systems to monitor and diagnose health problems have been booming. Infrared thermography (IRT) is a technology that allows measuring the radiation of energy that a body emits in a noninvasive way and without the limitations arising from the use of invasive sensors [1]. Therefore, the use of IRT has been increased as a solution to analyze different problems in different fields of human knowledge [2]. Specifically, humans are an important case of study where many investigations have emerged [2–7] because the temperature is one of the most common health indicators [8]. In this context, emotions play an important role in the life of living beings considering that the main function of any emotion is to mobilize the body to quickly deal with interpersonal encounter. According to Ekman, emotions can be classified into six main categories: happiness, sadness, surprise, disgust, anger and fear [9].

In recent years, some emotions have been studied through IRT, because when an emotion occurs a change in facial temperature appears due to the blood flow that the body emits through blood vessels in the subcutaneous area [10], this change can be qualified and quantified through IRT. For example, research focused on the emotion of joy, in other words, when a subject is smiling, it has been found that the temperature of the nose and forehead decreases during this event [11,12]. Di Giacinto et al. [13] examined the emotion of fear in patients with both posttraumatic stress disorder (PTSD) with mild symptoms and those who do not develop symptoms. It was found that the facial temperature in patients with PTSD is lower compared to those who are controlled.

* Corresponding author.
E-mail addresses: icruz@hspdigital.org (I.A. Cruz-Albarran), benitez@uaq.mx (J.P. Benitez-Rangel), raosornio@hspdigital.org (R.A. Osornio-Rios), lamorales@hspdigital.org (L.A. Morales-Hernandez).

http://dx.doi.org/10.1016/j.infrared.2017.01.002
1350-4495/

Merla and Romani [14] studied the facial temperature changes during stress, fear and pleasure, and it was found that discomfort of stress in revealed by sweating especially around the mouth, pain or fear causes the overall decrease in facial temperature and arousal generates an increase in the temperature of the forehead, lips and nose; Ioannou et al. [15] did research on the feeling of guilt in children and concluded that the facial temperature decreases, however, the most visible change is on the tip of the nose. Ioannou et al. [10] studied a wide range of emotions, such as fear [16], empathy [17,18] stress [19], however, not all studies are conducted with humans, some of them have been conducted on animals [20,21]. So far, studies of emotions through IRT presented above show results of monitoring temperature in different regions of interest (ROI's), however, none of them presents the diagnostic phase, that is to say, they do not have any automatic system that is capable of identifying any emotion and on the other hand, the analysis of these studies is done manually. However, IRT is not the only way in which emotions have been studied and classified, over the time, different techniques have been applied, for example, Maglogiannis et al. [22] presented a method for classifying emotions based on edge detection and measurement of gradients in the region of the eyes and mouth, Murad and Malkawi [23] presented a neuro/fuzzy system that makes use of fourteen human factors measurable highlighting the electroencephalogram (EEG), heart rate (HR), blood pressure (systolic and diastolic) and response of skin conductance (SCR), however, it has the disadvantage that the sensors used are invasive and due to the amount of information gotten from them, an enormous computational load occurs. Kim et al. [24] conducted a review on the use of EEG to detect emotions and they show that there are still many elements to be improved, such as: a model relating the EEG with cognitive emotional process and the interaction between properties of the EEG. Finally, Wang and Ji [25] presented a review of current research on the analysis of the affective components of direct video (audio and visual characteristics) and it was concluded that there should be more emphasis on using non-intrusive sensors for acquiring physiological signals as well as combining sensors in different ways to measure spontaneous responses of users. However, these analyzes should be customized to attack the specific emotional preferences of each subject. The study of emotions is an ongoing open research topic, yet, there is no a non-invasive system based on IRT that has the ability of being self-calibrated for each subject and at the same time can diagnose the emotion that appears in that moment, bearing in mind that every human being expresses their emotions differently [23]. Some emotions such as disgust and sadness have not been studied. Therefore, knowing the advantages of IRT, it would be desirable to have a smart-thermal system capable of self-calibrating depending on the subject under study in order to diagnose what emotion is happening at the time.

This paper presents a methodology to obtain a noninvasive smart-thermal system based on the analysis of biomedical infrared images that can diagnose basic emotions: joy, disgust, anger, fear and sadness. Such emotions show a different thermal facial behavior due to the blood flow that radiates through the blood vessels when an emotion occurs, therefore, in this study the quantification of the change in facial temperature was registered in the different ROI's in order to propose a biomarker as a response to these emotions. However, subjects have different reactions to the same stimulus, therefore, a stage of self-calibration in the system is proposed in order to have the correct diagnose when one of the five basic emotions occur.

2. Methodology

An outline of this system methodology is shown in Fig. 1. It is important to say that for this study there were taken into account factors for the use of infrared thermography in humans [8] due to the input of the system were subjects. In the Smart-Thermal System Methodology there are two paths, in path 1, a first thermogram at baseline is taken, ROI's are analyzed in order to obtain reference temperatures for the classifier at the baseline, then in path 2, a thermogram with an induced emotion is taken, ROI's are analyzed and these temperatures pass to the calibration step in order to have the same thermal trend for each subject, the new values of temperature go to the classifier, according to the reference and induced emotion temperatures, the classifier can diagnose which of the five emotions studied in this work is presented or if there is no emotion, which is the expected output of this system.

2.1. Protocol to take pictures through IRT

As it was mention, the aim of this study is to propose a methodology to obtain a noninvasive smart-thermal system that can diagnose five basic emotions (joy, disgust, anger, fear and sadness) for only one subject at a time through the analysis of thermograms. All the thermograms used in the experiments were divided into training and testing sets based on thermal facial expression categories, not subjects. As a result, the training and testing sets contained multiple samples of each subject in each expression category. As previously shown, thermograms are one of the most important things in the system for both the training stage and testing stage, for this reason they should be obtained in the best way. The procedure and process of how the thermograms were taken are shown in the following steps.

2.1.1. Subjects

The study was conducted in a group of 44 subjects (students) from the Autonomous University of Queretaro, 8 women and 36 men, with an average age of 26.5 and a standard deviation of 7.02. This study was performed in the area of Integral Health Nursing in the Faculty of Nursing of the same school, the scene is recreated in Fig. 2. The invitation to participate in the study during five days was conducted openly; those who accepted signed a letter of informed consent. The study was conducted with the support of a group of experts from the Psychology area of the National Autonomous University of Mexico. In this way, the requirements of standard medical procedures were followed. Exclusion criteria that were selected to be part of the study included: not to wear glasses during thermographic shots, be free from any disease that could cause changes in body temperature, avoid the use of lotions, creams cosmetics and deodorant, not to shave the face that day, not to drink alcohol 24 h before, not to have caffeinated drinks 3 h before, avoid smoke 2 h before, not to exercise an hour before and finally, not to obstruct face area with hair.

2.1.2. Environmental factors

The schedule was from 8:00 to 15:00 h, each participant was assigned a turn, 30 min per subject during 5 days, since each emotion was studied in a different day. Based on the recommendations showed by Fernández-Cuevas et al. [8], the room where the study was carried out had a dimension of 2.5×3 m. with a low incidence of natural light to thereby maintain a uniform temperature that oscillated between 20 ± 2 °C, however, to achieve this objective, it was necessary to use an air conditioner. The relative humidity oscillated from 45 to 60%.

2.1.3. Technological equipment

For the thermograms, a FLIR A310 camera was used, which has a thermal sensitivity of 0.05 at 30 °C, an infrared resolution of 320×240 pixels, and a spectral range between 7.5 and 13 μm; for this reason, this camera works in the Far-Infrared range. In this work, IRT is mention being aware that is Far-IRT. This camera was

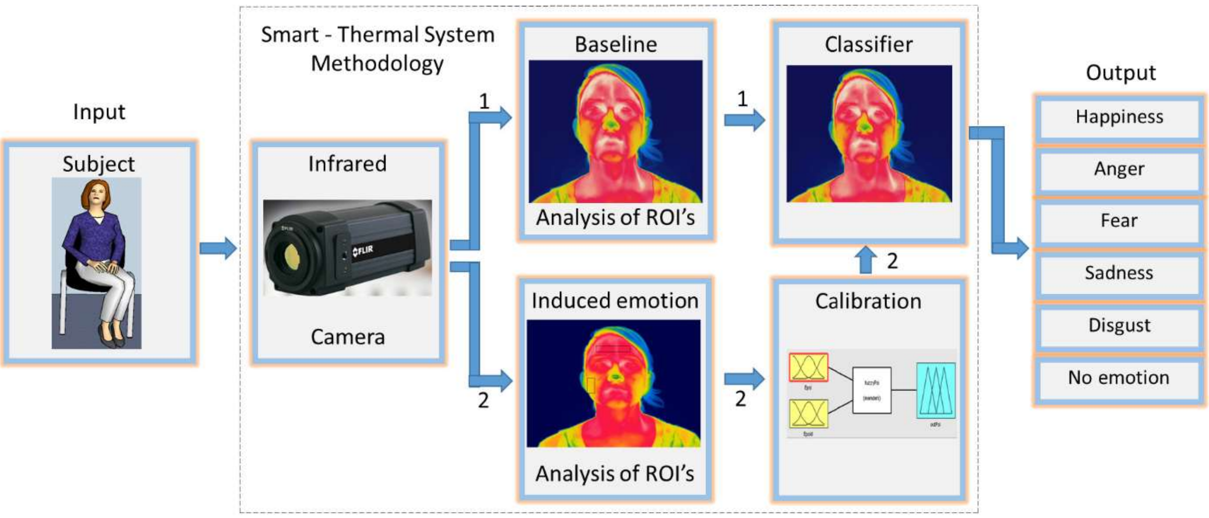

Fig. 1. Proposed methodology for smart-thermal system.

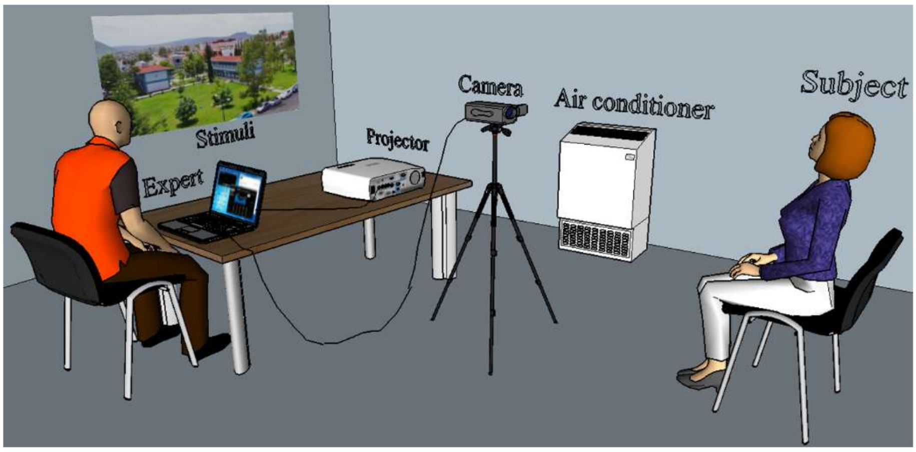

Fig. 2. Scene for thermogram acquisition.

installed on a tripod at a height of 1.2 m. and at a distance of 1.2 m from the subject under study. This camera was previously calibrated in [26] regarding an RTD, the difference between both instruments of measurement was of ±1 °C. The processing of thermograms was done using a computer Dell Inspiron with Intel (R) Core (TM) i7-3537 CPU @ 2.00 GHz processor. To show stimulants a Canon projector was required.

2.1.4. Stimuli

The method to induce the five emotions studied in this work was through a visual stimulus, specifically, through videos, because videos is one the most effective methods to induce emotions [27], to ensure that, videos were selected with the help of a group of experts from the Psychology area. For each emotion there was only one video which was presented to each subject, each video lasted 8 min. The content of the videos was different according to the emotion to trigger, i.e., to induce joy there were funny scenes, to induce fear there were tenebrous scenes, to induce disgust there were revolting scenes, to induce sadness there were affected scenes and to induce anger there were scenes when the subjects don't get what they want.

2.1.5. Procedure to take thermograms

The biomedical thermographic IR images (thermogram) of the subjects were obtained in five sessions, one for each emotion. The protocol A-B-A [28] tested by the group of experts was used to carry out the study which was always under their supervision; A when the subject is on the baseline, it lasted 2 min, B when the emotion is induced, it lasted all the time while the video was on, and A when the subject returns to the baseline, it also lasted 2 min. It's important to say that thermograms of each of the five emotions were taken in the following sequence:

When the subject arrived, he came into the room and sat in front of IRT camera. He waited 15 min in order to stabilize its body temperature [29] and also to obtain a baseline status. After 15 min, the ambient temperature was taken as well as the relative humidity with an Air Quality meter brand Fluke; in addition, the reflected temperature for the subject was taken by an infrared laser brand Fluke. Then, these parameters were inserted in the software used for thermogram acquisition in order to self-adjust the camera to thereby obtain a correct measurement, the emissivity factor used was 0.98 [30]. Finally, before starting the study, the distance of 1.2 m between the camera and the subject was verified.

Once the above steps were made the protocol started with A. With the subject sitting in front of the IR camera, without movement, a thermogram was performed every 10 s for 2 min in order to capture the physiological behavior of the patient at the baseline. After that, according to the protocol the step B was carried out. Depending on which emotion was studying a visual stimulus (video) was presented in order to induce the emotion, during the transmission of the video a thermogram was performed every 10 s along the time that the video lasted. Finally, step A, patients were asked to perform a relaxation technique based on diaphragmatic breathing [31] to bring them back to their baseline during two minutes, similarly, during that time one thermogram every 10 s for two minutes was taken.

Once the step shown was completed, all the thermograms used in the present study were obtained. Fig. 8 provides three example sets of the five thermogram facial expressions of joy, disgust, anger, fear and sadness. The number of thermograms used to make the three different steps (trend, training and test) were:

A total of 15,840 thermograms were taken during all the study. To do each step (trend, training and test) some thermograms were selected as depicted below:

To make the trend of each emotion a total of 3520 thermograms were analyzed. 704 for joy, 704 for disgust, 704 for anger, 704 for fear and 704 for sadness. For each subject and each emotion, a thermogram of each 30 s of the video was analyzed to get the thermal change in ROI's.

During the training phase, 440 thermograms were used; 88 for joy, 88 for disgust, 88 for anger, 88 are fear and 88 for sadness. For each subject and each emotion, two thermograms were taken into consideration, the thermogram at the baseline and the thermogram when the emotion is induced.

To test the system 625 thermograms were used, 125 for joy, 125 for disgust, 125 for anger, 125 are fear and 125 for sadness. For each subject and each emotion, five thermograms were taken into account, four when an emotion is induced and one at the baseline.

2.2. Detection and analysis of ROI's

This section presents how the ROI's for each thermogram are obtained, step by step which techniques and methods are used to get that goal. It also presents how the data analysis of each ROI is done.

2.2.1. Detection of ROI's

For detection of the ROI's, the methodology presented in Fig. 3 was followed.

After the acquisition of the thermogram with the protocol shown in Section 2.1, the thermal matrix was obtained through the equation proposed by Jadin et al. [32].

$$T_r = T_{\min} + \left(\frac{T_{gray}}{T_{mgv}}(T_{\max} - T_{\min})\right) \quad (1)$$

where T_r is the thermal value of the thermogram, $T_{\max}$ and $T_{\min}$ represents the maxim and the minim value of the temperature in the thermogram in °C, T_{gray} is the intensity of the pixel at some point in the gray scale thermogram and T_{mgv} is the highest intensity value in the gray scale thermogram.

The temperature range in the thermograms was 22–36 °C, this represents the lowest and the highest temperature in each thermogram. From these temperatures and with the thermal matrix of the original thermogram a threshold to remove the background in each thermogram is proposed as shown in Eq. (2).

$$P_{val} = \begin{cases} 255 & 32\ ^\circ\mathrm{C} < T_r < 36\ ^\circ\mathrm{C} \\ 0 & others \end{cases} \quad (2)$$

where P_{val} is the thresholding value and T_r is the thermal value in some point in the thermogram.

Based on thresholding, it was possible to obtain the width of the face, which is represented by D. According to the width of the head the height from forehead to maxillary is obtained, with this the centers of the regions to be studied were obtained, similar to those that were presented by Shih [33], as shown in Fig. 4:

As shown in Fig. 5, it is possible to obtain the center of the ROI's through the application of the equations in Fig. 4.

Finally, with the detection of the centers of the ROI's the area of the biomarker was obtained, for better visualization, these are presented in a color thermogram as shown in Fig. 6.

2.2.2. Analysis of ROI's

As mentioned in Section 2.1, a total of 440 thermograms were used for the training system, 88 for joy, 88 for disgust, 88 for anger, 88 for fear and 88 for sadness. For each subject and each emotion, only two thermograms were considered, one at the baseline and the last one when the emotion is induced.

As each ROI has a number of pixels, the mean and the deviation standard of each was calculated for both thermograms in order to obtain temperature in each one. Having the temperature in each ROI, the thermal difference between the thermogram where the emotion was induced and the thermogram at baseline was done, that is to say, the difference between the final state and the baseline (3). It's important to say that this procedure was done for each emotion on each subject.

$$\Delta_t = T_f - T_i \quad (3)$$

where Δ_t is the temperature change, T_f final temperature, that is to say, when the emotion is induced and T_i is temperature at baseline.

The reference temperature (baseline) considered in this work was between 31 and 36 °C for all the regions of the face, similar to those mentioned by Ioannou et al. [10].

2.3. Calibration

Calibration of the system is based on a fuzzy logic model as shown in Fig. 7.

2.3.1. Inputs

Eight inputs are used, four for the baseline subject ($Forehead_i$, $Cheeks_i$, $Nose_i$ y $Maxillary_i$) and four when the emotion is induced ($Forehead_f$, $Cheeks_f$, $Nose_f$ y $Maxillary_f$), each of the four variables refers to each ROI (forehead, cheeks, nose and maxillary) at baseline and final state, respectively, each one is divided into three groups, "low", "normal" and "high". The first four, with the subscript i, represents how the temperature must change: "low" must be assigned if the temperature has to be decreased; if it has to be increased "high" must be assigned, and "normal" if it needs no change. The last four, with the subscript f, were assigned by means of the comparison between both baseline and induced emotion thermogram, if the temperature increase "high" is assigned, if the temperature decrease "low" is assigned and if it remains without change the command "normal" is required.

2.3.2. Outputs

Eight outputs are used, Forehead increases (F_I), Forehead decreases (F_D), Cheeks increases (M_I), Cheeks decreases (M_D), Nose increases (N_I), Nose decreases (N_D), Maxillary increases (MA_I) and Maxillary decreases (MA_D), which represent whether ROI should increase or decrease its temperature.

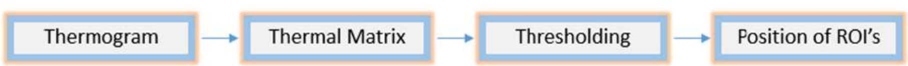

Fig. 3. Methodology to detection of ROI's.

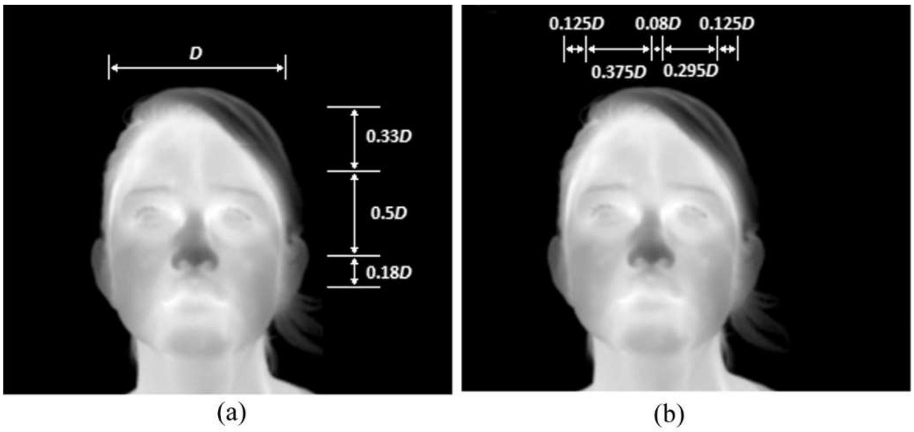

Fig. 4. Estimation of centers of the ROI's (a) vertical (b) horizontal.

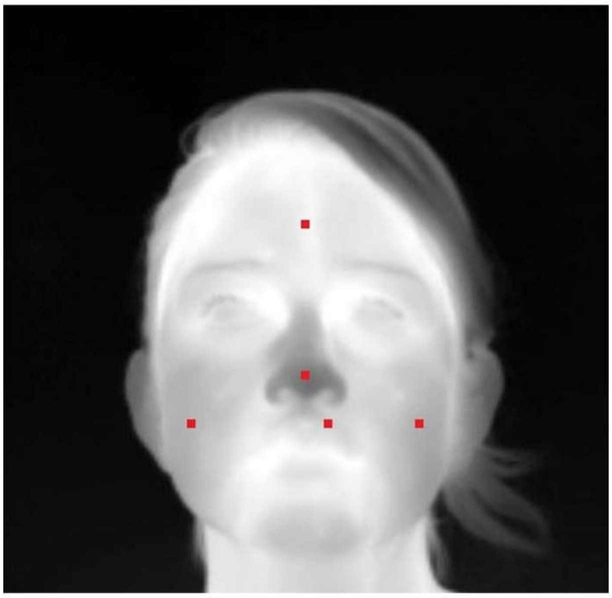

Fig. 5. Centers of the ROI's detected.

2.3.3. Rules

The inference machine is composed of a collection of forty rules in IF-THEN form. As an example, assuming that only the temperature of the nose and maxillary are modified and based on Table 2, it can be assumed that the joy emotion is present, so that the following rule could be applied, IF the Nose temperature is "Low" and Maxillary temperature is "High" THEN calibrate Region is "Decrease maxillary". Another example, IF Nose temperature is "Low", Maxillary temperature is "Low" and Cheeks temperature is "Low" THEN calibrate Region is "Increase cheeks". So, all the rules in the inference machine were done in this way.

MATLAB Fuzzy Logic toolbox was used for the implementation of Fuzzy Logic System. Fuzzy logic System implemented shows the ROI where there should have been a difference in temperature. With this or these regions obtained, the calibration is as follows:

If the system shows that the temperature must be increased in any region of interest, then the Eq. (4) that applies is:

$$T_{fin} = T_f - (2 * (-\Delta_t)) \tag{4}$$

where T_{fin} is the final temperature calibrated, T_f is the ROI temperature when an emotion is induced an Δ_t is the temperature difference found by (3).

On the contrary, if the system shows that the temperature in some ROI must have decreased the Eq. (5) that applies is:

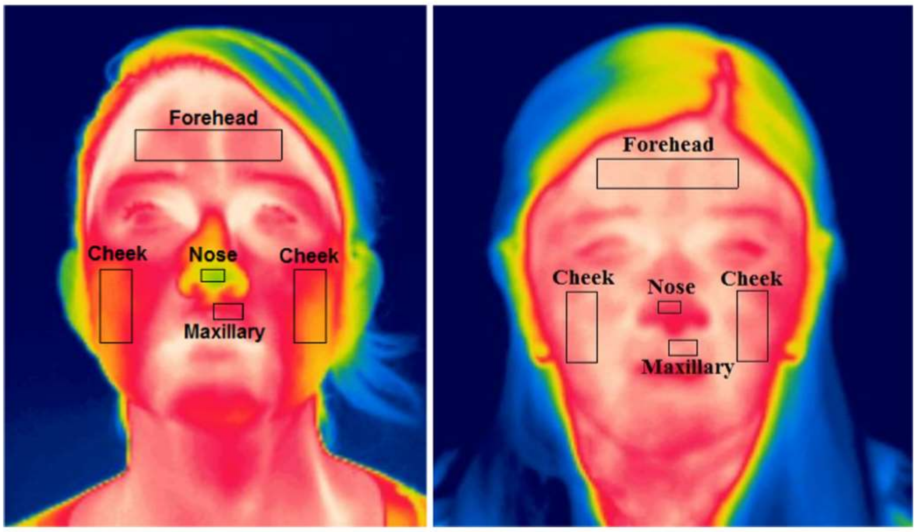

Fig. 6. Biomarker based on ROI's for thermal analysis.

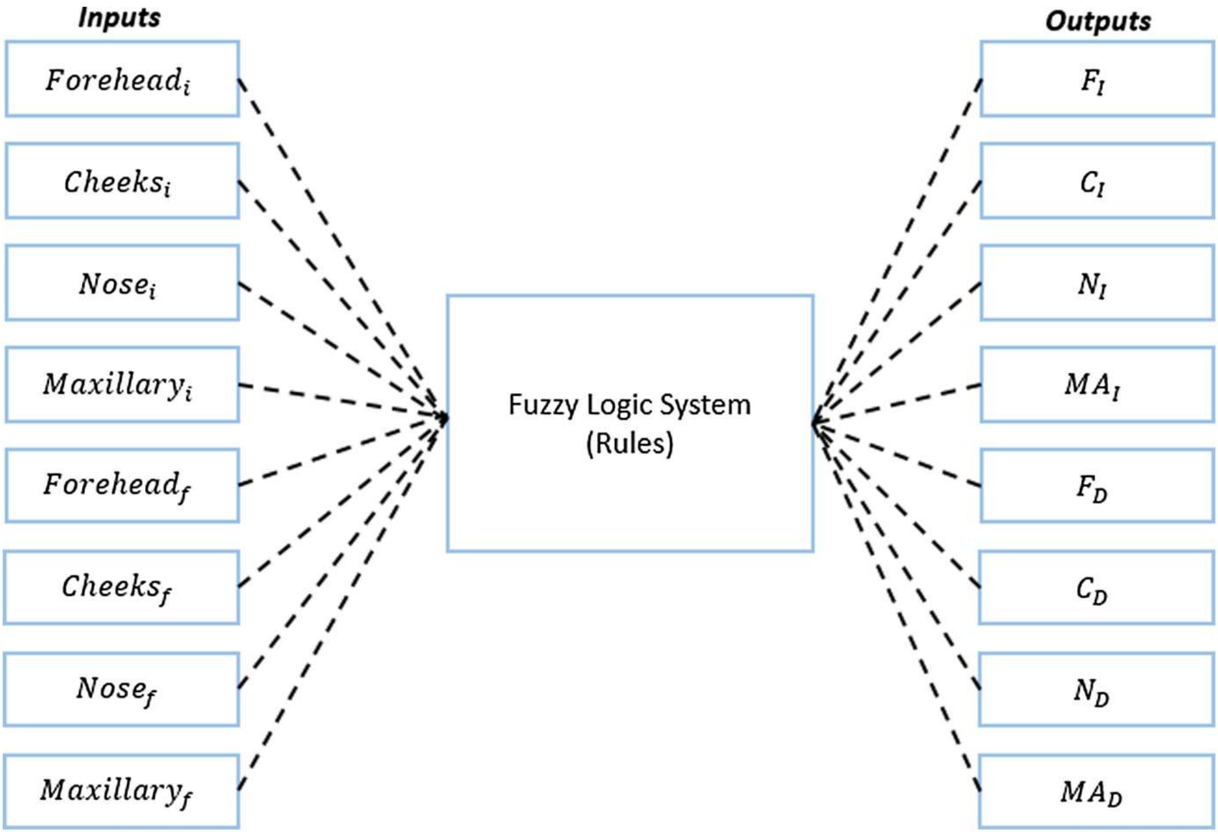

Fig. 7. Fuzzy logic system to self-calibrate.

$$T_{fin} = T_f - (2 * (\Delta_t)) \tag{5}$$

If the ROI does not change and it must have changed, the Eq. (6) that applies is:

$$T_{fin} = \begin{cases} T_f + (2 * (\Delta_t)) \\ T_f - (2 * (\Delta_t)) \end{cases} \tag{6}$$

The equation takes the positive sign if the ROI must have increased and the negative sign if the ROI must have decreased, where $\Delta_t = 0.2$.

With the final temperature calculated, we can differentiate between the baseline and when the emotion is presented. The inputs for the classifier will be the final temperature calibrated and the temperature at the baseline, so, with both temperatures,

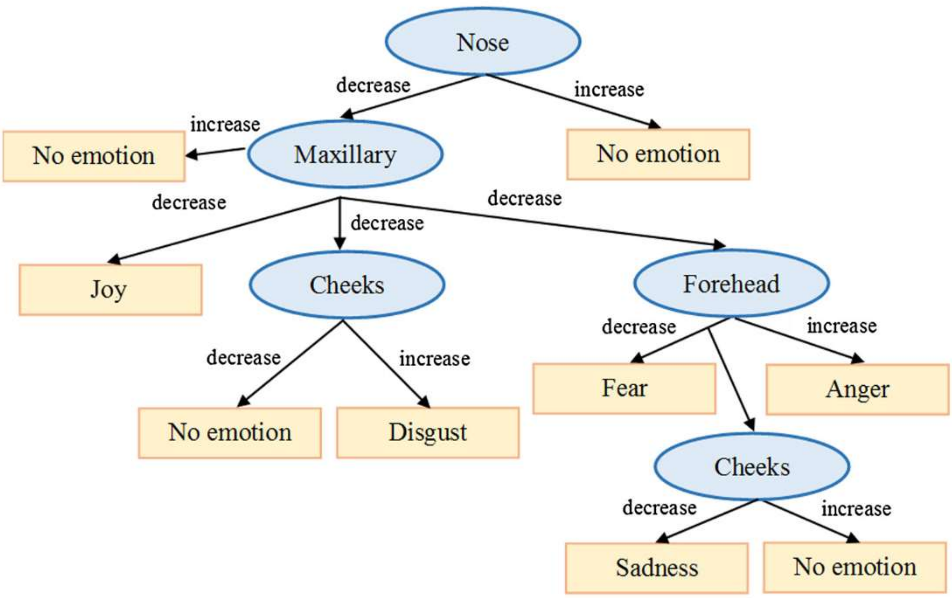

Fig. 8. Top-down hierarchical classifier to classify emotions.

subjects can know if the final temperature increases or decreases in order to diagnose what emotion occurs.

2.4. Top-down hierarchical classifier

According to Ioannou et al. [10] small thermal changes of ±0.1 °C to ±0.2 °C are considered insignificant, for this reason, the ROI's whose thermal change is below this threshold in the majority of the subjects were despised, and the ROI's with a thermal change above the same threshold were chosen. Correlating the thermal behavior pattern and the thermal threshold Table 2 is obtained. Having the thermal trend of these emotions (Table 2) is possible to implement a top-down hierarchical classifier (Fig. 8) as a classifier in order to achieve the goal of diagnosing which emotion is present. In the top-down hierarchical classifier, the ROI's chosen are decision nodes, the split function is the thermal change, if it increases or decreases, and finally the result is the emotion studied in this work or no motion.

2.5. Validation

An important step is the validation. This is done by the group of experts of the Psychology area of the National Autonomous University of Mexico through the facial expression of emotion, due to expressions are an important indicator of emotion and they are expressed and recognized similarly worldwide [34], to get this goal, this group was present during all the study in order to support the study.

3. Experimental results

When an emotion is induced a gradual change according to the baseline occurs, this, as mentioned previously, is due to blood flow that radiates through the blood vessels when an emotion takes place. Fig. 9 shows some examples of the thermograms obtained. Table 1 shows the average temperatures of the 44 subjects under study, in each ROI's and for each emotion. However, any small change in temperature represents that an emotion has happened, sometimes small fluctuations of ±0.1 to ±0.2 are considered insignificant and consequently may not affect the value of the final status [10], so that any change above this range is treated as a change in facial temperature because an emotion takes place.

In Table 1, the average baseline temperature (T_i) can be seen, and the induced state (T_f) with respect to each ROI's emotion, similarly the temperature difference (Δ_t) on these states is shown,

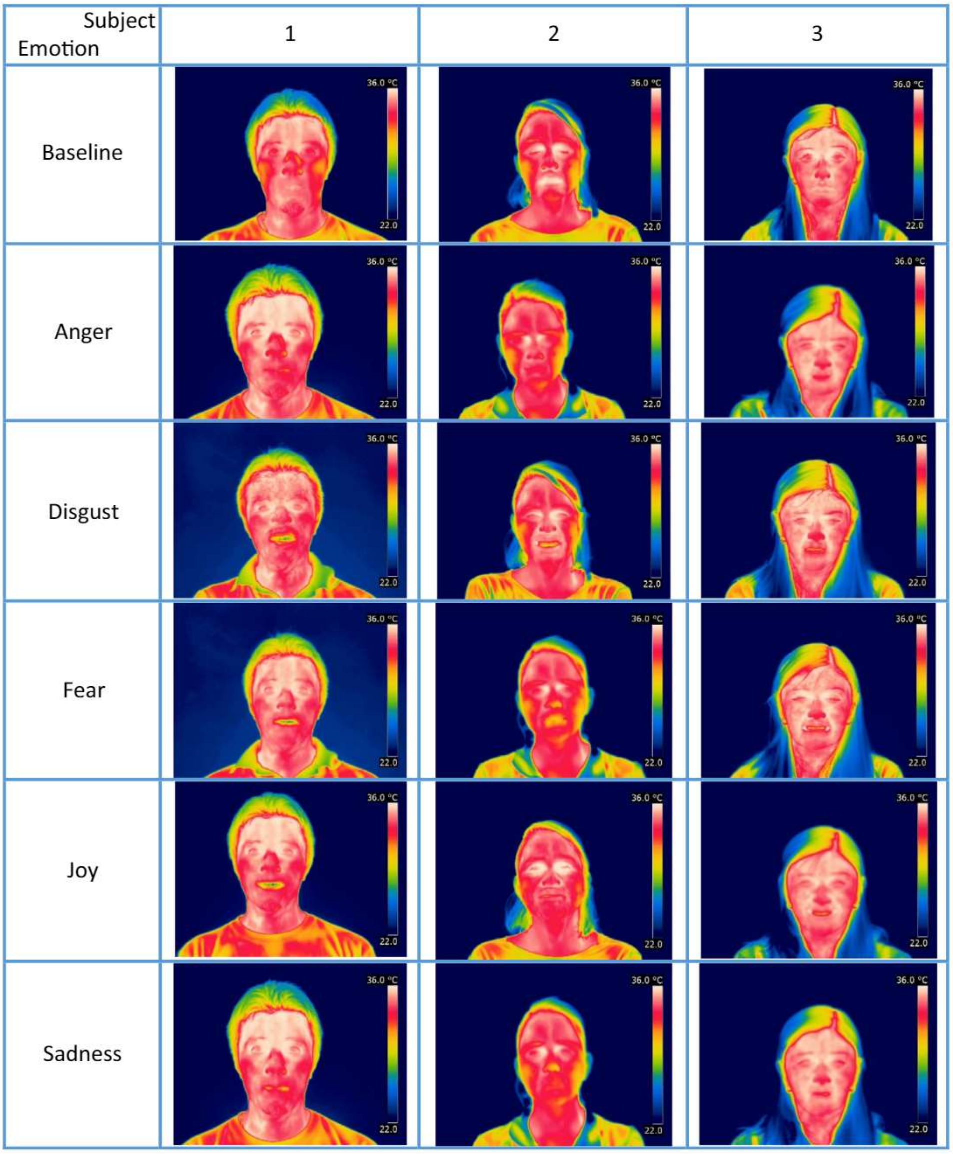

Fig. 9. Examples of thermograms in baseline and with induced emotion.

Table 1
Mean temperature of ROI's for each emotion.

Emotion \ ROI		Cheeks		Forehead		Nose		Maxillary	
		$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
Anger	T_i	*	*	33.40	0.28	33.57	0.18	34.44	0.21
	T_f	*	*	33.52	0.27	32.02	0.24	33.43	0.29
	Δ_t	*	*	0.12	-0.01	-1.55	0.06	-1.01	0.08
Disgust	T_i	32.84	0.41	*	*	33.93	0.22	34.67	0.20
	T_f	33.2	0.49	*	*	33.62	0.21	34.42	0.20
	Δ_t	0.36	0.08	*	*	-0.31	-0.01	-0.25	0.00
Fear	T_i	*	*	34.85	0.21	34.14	0.16	34.72	0.19
	T_f	*	*	35.94	0.22	33.72	0.19	34.35	0.23
	Δ_t	*	*	0.09	0.01	-0.42	0.03	-0.37	0.04
Joy	T_i	*	*	*	*	33.72	0.18	34.59	0.18
	T_f	*	*	*	*	33.24	0.17	34.50	0.17
	Δ_t	*	*	*	*	-0.48	-0.01	-0.09	-0.01
Sadness	T_i	32.75	0.27	34.67	0.42	33.67	0.18	34.50	0.23
	T_f	33.01	0.25	34.58	0.38	32.63	0.23	33.99	0.24
	Δ_t	0.26	-0.02	-0.09	-0.04	-1.04	-0.05	-0.51	0.01

* ROI without significant temperature change

increases in temperature are marked in red and decreases are blue, some changes do not seem significant, however, this is because the tendency to increase or decrease will not always be the same for everyone, since the reaction is different in each subject (see Fig. 10). Speaking of temperature, the Joy analysis clearly shows the decrease in the nose and maxillary compared to the initial state, however, in some cases these increases (Fig. 10(a)). When showing disgust, the cheek area clearly shows an increasing trend, showing few cases of decrease or stability, the decrease of temperature is remarkable on maxillary and nose area, although there are some cases in which increases are also present as in (Fig. 10(b)). Referring to Fear, temperature on the forehead, maxillary and nose decreases, however, in all of them there is a small portion that increases its temperature, leaving only the nose some cases at stable state (Fig. 10(c)). In Anger, forehead temperature tends to increase, although there are cases where decreases or remains stable, while on the maxillary and nose temperature decreases (Fig. 10(d)). Finally, in Sadness, the region of cheeks presents a clear increasing trend, there are some cases of decrease, forehead tends to decrease, although minority there are cases of increase and stable state, nose and maxillary have a clear tendency to decrease (Fig. 10(e)). It is scientifically proven that each subject has different reactions to the same stimulus, it is therefore necessary to calibrate the system for everyone in order to obtain a reliable result [23].

Summarizing, based on the analysis previously done and in the review presented by Ioannou et al. [10] thermal trend in selected ROI's when one of the five basic emotions occur is presented (Table 2), nothing that neither disgust nor sadness has been studied yet.

Within the tendency of increase or decrease of temperature in the different ROI's, a similar pattern for the temperature change in a time lag occurs. In the case of Joy (Fig. 11(a)), to be an easy emotion to induce, changes develop rapidly, within 1–2 min period a change of 0.5 ± 0.3 °C for both the nose and the maxillary is shown. In the Disgust (Fig. 11(b)) for the same period of time (1–2 min), the decrease in the nose around at 0.2 ± 0.2 °C, being the same for the increase in the cheeks. Fear (Fig. 11(c)), the decrease of temperature for the period of time 1–2 min on the nose was between 0.5 ± 0.3 °C, for forehead and maxillary these changes are lower, oscillating between 0.3 ± 0.2. In Anger (Fig. 11(d)), in the regions of the nose and maxillary the most notable changes are in the range of 1–2 min, ranging from 0.3 ± 0.3 °C, however, forehead significant temperature increase is shown after 3 min with an increase of 0.2 ± 0.2 °C. Finally, in Sadness (Fig. 11(e)), the most notable change is present in the nose within 1–2 min with a range of 0.5 ± 0.5 °C, for the maxillary and cheeks significant change occurs after 2 min, with a range of between 0.3 ± 0.2 °C, being forehead the ROI where the temperature change is slower, which happens after 3 min, with an oscillation between the 0.2 ± 0.2 °C. For cases where subjects react inversely to the trend shown in Table 2 temperatures show the same rate of change to those shown above, but in reverse. Similarly, it is vital that some subjects are more expressive and show major changes. Doing an analysis of the results it can be seen that even when there are no temperature changes occurring in a ROI or reverse the expected behavior, the system is designed to look at this problem, therefore, the system presents good results.

Based on the trends of temperature change when an emotion takes place (Table 2) a classifier of emotions was proposed and implemented. For the evaluation of the classifier a total of 625 thermograms were considered, 425 with any emotion induced and 200 without emotion, this amount of thermograms are 8 from women and 17 from men, the accuracy of the classifier was divided into gender as shown in Tables 3 and 4, for each emotion, the correct assignments are presented in bold.

The error of the classifier is due to inaccurate location of the ROI's as a result of the geometry orientation of the face, however, the performance is reduced to acceptable levels. When there is no emotion present, the performance of the classifier has an accuracy of 100% because no ROI has a significant temperature difference. The final accuracy of the system is presented in Table 5.

The system has a final accuracy of 89.90%, the final variation of both men and women does not show a significant difference, therefore, the system works in the same way for both genders.

4. Discussion

In this paper, a series of studies were conducted in subjects of different ages and different gender, standard visual stimuli were applied in order to induce five basic emotions: joy, disgust, anger,

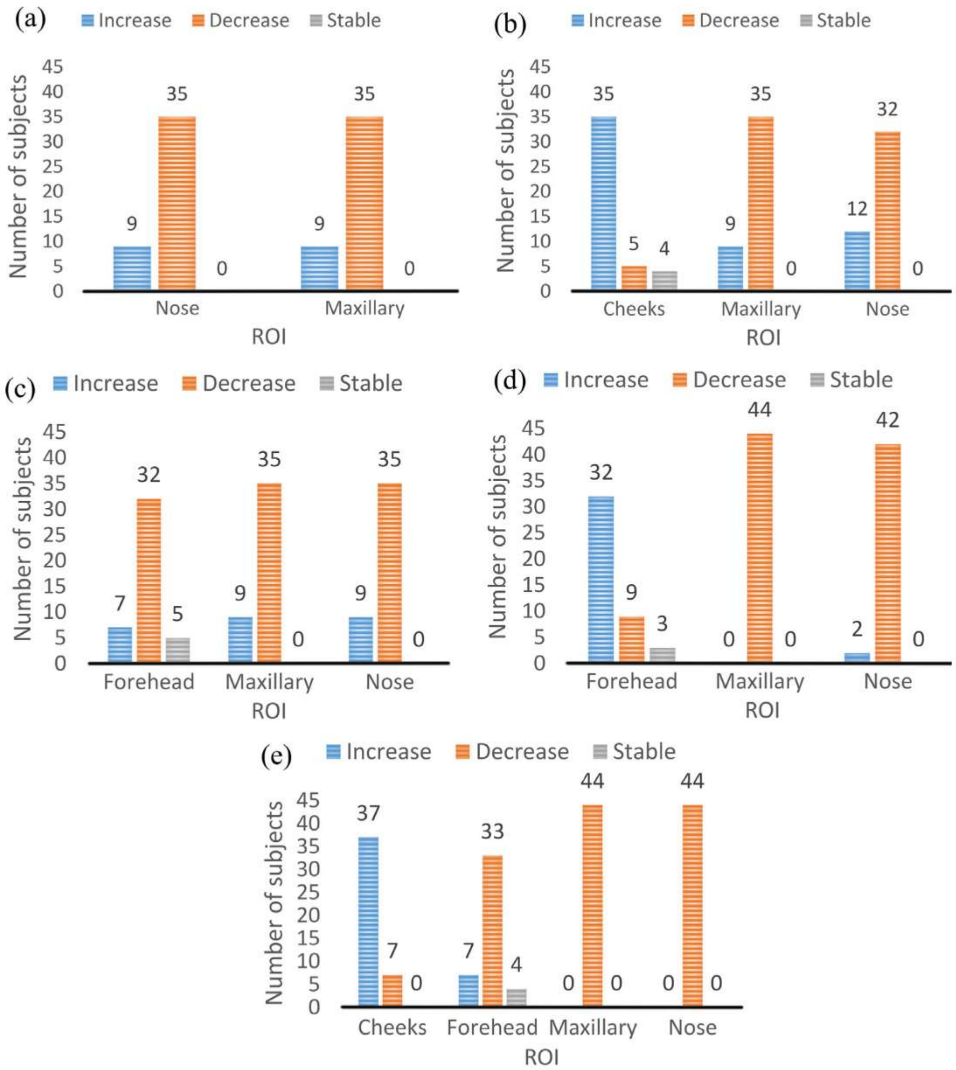

Fig. 10. Thermal tendency of ROI's (a) joy, (b) disgust, (c) fear, (d) anger, (e) sadness.

Table 2
Thermal trend for each ROI's for each emotion.

	Emotions				
	Fear	Joy	Anger	Disgust	Sadness
Regions					
Nose	↓	↓	↓	↓	↓
Cheeks	*	*	*	↑	↑
Forehead	↓	*	↑	*	↓
Maxillary	↓	↓	↓	↓	↓

* ROI without significant temperature change.

fear and sadness. Infrared thermography was used during the emotion induction process to quantify temperature changes that occur on the facial region. It is scientifically proven that each subject reacts differently to the same stimuli, for this reason, in this paper a method of calibration that can detect how every subject reacts to various stimuli is proposed. In summary, this paper proposes a smart-thermal system to detect emotions, working through the quantification of changes in temperature in order to obtain a biomarker in each ROI that achieves the diagnosis of five basic emotions.

As shown in the introduction, nowadays there are many works on the study of emotions through IRT, some of them are based on the qualitative analysis of the thermograms and others present a quantitative analysis of them. The obtained results allow validating the conclusion reached by Murad and Malkawi [23] that each subject reacts differently to a similar stimulus, however, it could also be observed that the vast majority of subjects show a clear trend to react similarly, therefore, on that basis, it could create a shift pattern that shows whether the temperature increases or decreases in some ROI's to every emotion studied. Salazar-Lopez

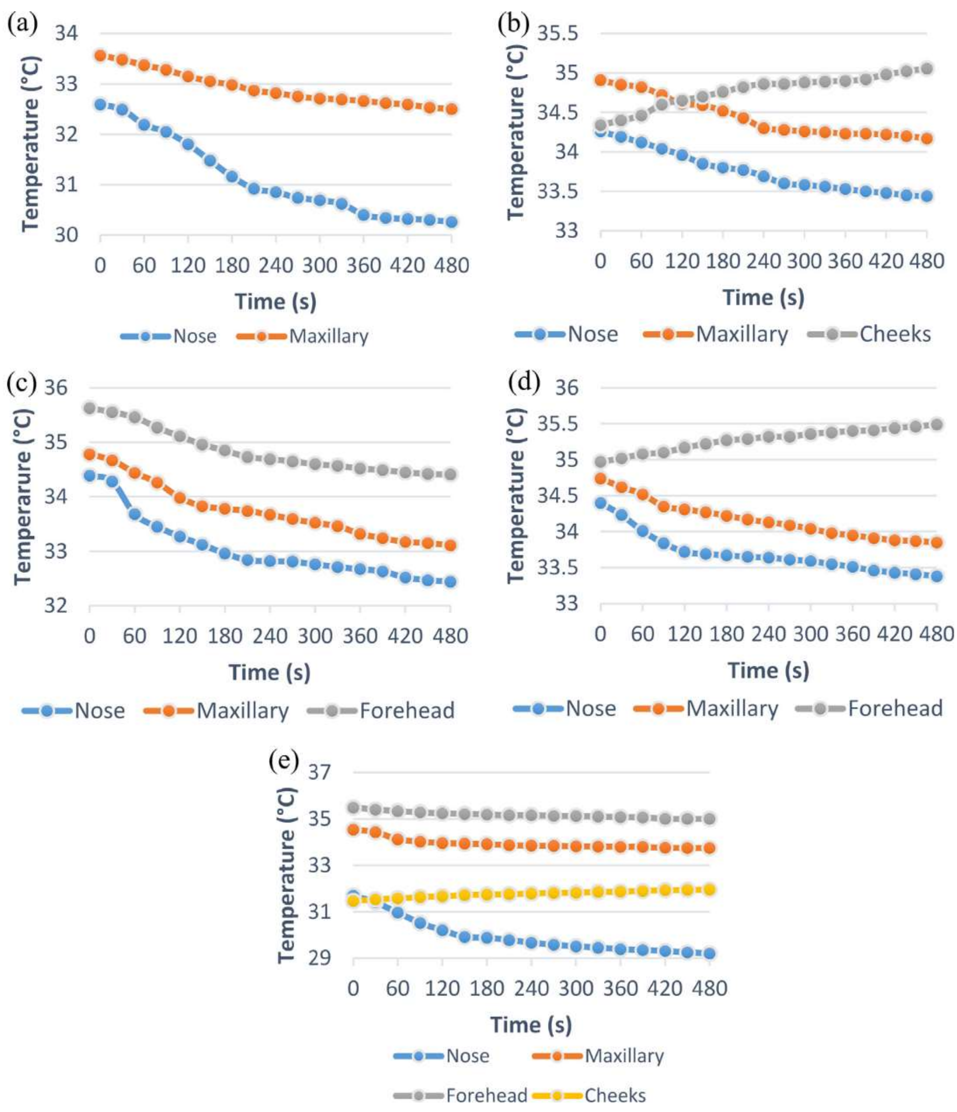

Fig. 11. Progress of temperature changes in ROI's (a) joy, (b) disgust, (c) fear, (d) anger, (e) sadness.

Table 3
Confusion matrix for 8 women.

		Emotion (classifier)							
		Anger	Disgust	Fear	Joy	Sadness	No emotion	Total	Accuracy (%)
Emotion (real value)	Anger	**25**	0	6	0	1	0	32	78.12
	Disgust	0	**30**	0	0	2	0	32	93.75
	Fear	7	0	**25**	0	0	0	32	78.12
	Joy	0	1	0	**31**	0	0	32	96.87
	Sadness	0	4	0	0	**28**	0	32	87.5
	No emotion	0	0	0	0	0	**40**	32	100
Total		32	35	31	31	31	40		
Accuracy (%)		78.12	85.71	80.64	100	90.32	100		
						Women accuracy			89.5

et al. [11] and Nakanishi and Imai-Matsumura [12] found that temperature decrease in nose and forehead during joy. When fear occurs, Di Giacinto et al. [13] and Merla and Romani [14] found the overall decrease in facial temperature. The conclusions for the emotions that hadn't been studied are that during disgust, the temperature in nose and maxillary decrease while cheeks increase, sadness alters all the ROI's studied, nose, forehead and maxillary decrease and only cheeks increase. As it is shown, the results of this study contrast with other studies, however, these studies need an expert to analyze the data of each thermogram, but nevertheless it is important to highlight that the system proposed in this work is automatic, namely, analyze the thermal changes and returns a result of which emotion is present in the subject, all without the need of an expert. Murad and Malkawi

Table 4
Confusion matrix for 17 men.

		Emotion (classifier)							
		Anger	Disgust	Fear	Joy	Sadness	No emotion	Total	Accuracy (%)
Emotion (real value)	Anger	**54**	0	11	0	3	0	68	79.41
	Disgust	0	**61**	0	0	7	0	68	89.70
	Fear	12	0	**56**	0	0	0	68	82.35
	Joy	0	0	2	**66**	0	0	68	97.05
	Sadness	0	6	0	0	**62**	0	68	91.17
	No emotion	0	0	0	0	0	**85**	85	100
Total		66	67	69	66	72	85		
Accuracy (%)		81.81	91.04	81.15	100	86.11	100		
						Men accuracy			90.3

Table 5
Final system accuracy.

	N	Accuracy
Men	8	90.3
Women	17	89.5
Total	25	89.90%

[23] also presented an intelligent system that detects emotions, however, they used fourteen invasive sensors to get the human data.

Despite the good results presented in the paper, it would be desirable to have a system that could detect the face even if it is not in front of the camera or it presents a geometric change. Therefore, having the advantage of using IRT as a noninvasive system, it can predict future studies correlating IRT with emotions, and which in turn are seen as intelligent systems.

5. Conclusion

This paper presents the development, test and implementation of a smart-thermal system, which was successful in 89.9%. It has the capability of monitoring biomedical thermal images, detect ROI's (forehead, cheeks, nose and maxillary) and diagnose emotions through a biomarker that automatically analyzes temperature. The proven system is capable of self-calibrating for each subject in order to be able to diagnose correctly the five emotions studied in this work, which are: joy, fear, anger, disgust and sadness. For the first three emotions, its behavior was well identified however, for the last two emotions his behavior had not yet been studied through IRT, therefore, the quantification of those changes was carried out, allowing the proposal of a table showing the trend of increase and decrease in temperature. This paper shows that the quantification of temperature changes that occurred in the different ROI's can be cataloged as a biomarker, which provides accurate information to diagnose an emotion, however, these biomarkers can also be considered by experts in the medical field as additional information so that together with other techniques facilitate the diagnosis of emotional problems.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

The authors wish to thank Benjamin Dominguez Trejo and David Alejandro Rodriguez Medina from the Psychology area of the National Autonomous University of Mexico for supporting this study. Also, first author would like to thank CONACYT for the scholarship (CVU: 515431) given.

References

[1] D. Cardone, P. Pinti, A. Merla, Thermal infrared imaging-based computational psychophysiology for psychometrics, Comput. Math. Methods Med. 2015 (2015) 1–8, http://dx.doi.org/10.1155/2015/984353.
[2] A. Kylili, P.A. Fokaides, P. Christou, S.A. Kalogirou, Infrared thermography (IRT) applications for building diagnostics: a review, Appl. Energy 134 (2014) 531–549, http://dx.doi.org/10.1016/j.apenergy.2014.08.005.
[3] B.B. Lahiri, S. Bagavathiappan, T. Jayakumar, J. Philip, Medical applications of infrared thermography: a review, Infrared Phys. Technol. 55 (2012) 221–235, http://dx.doi.org/10.1016/j.infrared.2012.03.007.
[4] H. Peregrina-Barreto, L.a. Morales-Hernandez, J.J. Rangel-Magdaleno, J.G. Avina-Cervantes, J.M. Ramirez-Cortes, R. Morales-Caporal, Quantitative estimation of temperature variations in plantar angiosomes: a study case for diabetic foot, Comput. Math. Methods Med. (2014) 585306, http://dx.doi.org/10.1155/2014/585306.
[5] J.I. Priego Quesada, A.G. Lucas-Cuevas, M. Gil-Calvo, J.V. Giménez, I. Aparicio, R. M. Cibrián Ortiz de Anda, R. Salvador Palmer, S. Llana-Belloch, P. Pérez-Soriano, Effects of graduated compression stockings on skin temperature after running, J. Therm. Biol. 52 (2015) 130–136, http://dx.doi.org/10.1016/j.jtherbio.2015.06.005.
[6] G. Tanda, Skin temperature measurements by infrared thermography during running exercise, Exp. Therm. Fluid Sci. 71 (2016) 103–113, http://dx.doi.org/10.1016/j.expthermflusci.2015.10.006.
[7] D. Hernandez-Contreras, H. Peregrina-Barreto, J. Rangel-Magdaleno, J. Gonzalez-Bernal, Narrative review: diabetic foot and infrared thermography, Infrared Phys. Technol. 78 (2016) 105–117, http://dx.doi.org/10.1016/j.infrared.2016.07.013.
[8] I. Fernández-Cuevas, J.C. Bouzas, J. Arnáiz Lastras, P.M. Gómez Carmona, S. Piñonosa Cano, M.Á. García-Concepción, M. Sillero-Quintana, Classification of factors influencing the use of infrared thermography in humans: a review, Infrared Phys. Technol. 71 (2015) 28–55, http://dx.doi.org/10.1016/j.infrared.2015.02.007.
[9] P. Ekman, Basic emotions, in: T. In Dalgleish, M.J. Power (Eds.), Handbook of Cognition and Emotion, John Wiley & Sons Ltd., New York, NY, 1999, pp. 45–60.
[10] S. Ioannou, V. Gallese, A. Merla, Thermal infrared imaging in psychophysiology: potentialities and limits, Psychophysiology 51 (2014) 951–963, http://dx.doi.org/10.1111/psyp.12243.
[11] E. Salazar-López, E. Domínguez, V. Juárez Ramos, J. de la Fuente, A. Meins, O. Iborra, G. Gálvez, M.A. Rodríguez-Artacho, E. Gómez-Milán, The mental and subjective skin: emotion, empathy, feelings and thermography, Conscious. Cogn. 34 (2015) 149–162, http://dx.doi.org/10.1016/j.concog.2015.04.003.
[12] R. Nakanishi, K. Imai-Matsumura, Facial skin temperature decreases in infants with joyful expression, Infant Behav. Dev. 31 (2008) 137–144, http://dx.doi.org/10.1016/j.infbeh.2007.09.001.
[13] A. Di Giacinto, M. Brunetti, G. Sepede, A. Ferretti, A. Merla, Thermal signature of fear conditioning in mild post traumatic stress disorder, Neuroscience 266 (2014) 216–223, http://dx.doi.org/10.1016/j.neuroscience.2014.02.009.
[14] A. Merla, G.L. Romani, Thermal signatures of emotional arousal: a functional infrared imaging study, in: Proceedings of the 29th Annual International Conference of the IEEE EMBS, 2007, pp. 247–249.
[15] S. Ioannou, S. Ebisch, T. Aureli, D. Bafunno, H.A. Ioannides, D. Cardone, B. Manini, G.L. Romani, V. Gallese, A. Merla, The autonomic signature of guilt in children: a thermal infrared imaging study, PLoS One 8 (2013), http://dx.doi.org/10.1371/journal.pone.0079440.
[16] D. Shastri, A. Merla, P. Tsiamyrtzis, I. Pavlidis, Imaging facial signs of neurophysiological responses, IEEE Trans. Biomed. Eng. 56 (2009) 477–484, http://dx.doi.org/10.1109/TBME.2008.2003265.
[17] S.J. Ebisch, T. Aureli, D. Bafunno, D. Cardone, G.L. Romani, A. Merla, Mother and child in synchrony: thermal facial imprints of autonomic contagion, Biol. Psychol. 89 (2012) 123–129, http://dx.doi.org/10.1016/j.biopsycho.2011.09.018.

[18] B. Manini, D. Cardone, S.J.H. Ebisch, D. Bafunno, T. Aureli, A. Merla, Mom feels what her child feels: thermal signatures of vicarious autonomic response while watching children in a stressful situation, Front. Hum. Neurosci. 7 (299) (2013) 1–10, http://dx.doi.org/10.3389/fnhum.2013.00299.

[19] I. Pavlidis, P. Tsiamyrtzis, D. Shastri, a. Wesley, Y. Zhou, P. Lindner, P. Buddharaju, R. Joseph, A. Mandapati, B. Dunkin, B. Bass, Fast by nature - how stress patterns define human experience and performance in dexterous tasks, Sci. Rep. 2 (2012) 1–9, http://dx.doi.org/10.1038/srep00305, 305.

[20] K. Kuraoka, K. Nakamura, The use of nasal skin temperature measurements in studying emotion in macaque monkeys, Physiol. Behav. 102 (2011) 347–355, http://dx.doi.org/10.1016/j.physbeh.2010.11.029.

[21] D.M.L. Vianna, P. Carrive, Changes in cutaneous and body temperature during and after conditioned fear to context in the rat, Eur. J. Neurosci. 21 (2005) 2505–2512, http://dx.doi.org/10.1111/j.1460-9568.2005.04073.x.

[22] I. Maglogiannis, D. Vouyioukas, C. Aggelopoulos, Face detection and recognition of natural human emotion using Markov random fields, Pers. Ubiquitous Comput. 13 (2009) 95–101, http://dx.doi.org/10.1007/s00779-007-0165-0.

[23] U. Murad, M. Malkawi, Artificial neuro fuzzy logic system for detecting human emotions, in: IEEE CITS 2012 - 2012 Int. Conf. Comput. Inf. Telecommun. Syst, 2012, pp. 1–13, http://dx.doi.org/10.1109/CITS.2012.6220388.

[24] M.-K. Kim, M. Kim, E. Oh, S.-P. Kim, A review on the computational methods for emotional state estimation from the human EEG, Comput. Math. Methods Med. (2013) 1–13, http://dx.doi.org/10.1155/2013/573734, 573734.

[25] S. Wang, Q. Ji, Video affective content analysis: a survey of state of the art methods, IEEE Trans. Affect. Comput. 3045 (2015), http://dx.doi.org/10.1109/TAFFC.2015.2432791, 1–1.

[26] A.G. Garcia-ramirez, L.A. Morales-hernandez, R.A. Osornio-rios, J.P. Benitez-rangel, A. Garcia-perez, R.D.J. Romero-troncoso, Fault detection in induction motors and the impact on the kinematic chain through thermographic analysis, Electric Power Syst. Res. 114 (2014) 1–9, http://dx.doi.org/10.1016/j.epsr.2014.03.031.

[27] A. Schaefer, F.F. Nils, X. Sanchez, P. Philippot, Assessing the effectiveness of a large database of emotion-eliciting films: a new tool for emotion researchers, Cogn. Emot. 24 (2010) 1153–1172, http://dx.doi.org/10.1080/02699930903274322.

[28] B. Domínguez Trejo, G. Ruvalcaba Palacios, M. López Lena, Pain, emotions, and social-well-being in Mexico, in: Handbook of Happiness Research in Latin America, first ed., Mariano Rojas, 2016, pp. 489–514.

[29] IACT, Thermology guidelines, standars and protocols in clinical thermography imaging, Int. Acad. Clin. Thermol. IACT. (2002) 1–9.

[30] V. Bernard, E. Staffa, V. Mornstein, A. Bourek, Infrared camera assessment of skin surface temperature e effect of emissivity, Physica Med. 29 (2013) 583–591, http://dx.doi.org/10.1016/j.ejmp.2012.09.003.

[31] K. Consolo, S. Fusner, S. Staib, Effects of diaphragmatic breathing on stress levels of nursing students, Teach. Learn. Nurs. 3 (2008) 67–71, http://dx.doi.org/10.1016/j.teln.2007.10.003.

[32] M.S. Jadin, S. Taib, K.H. Ghazali, Feature extraction and classification for detecting the thermal faults in electrical installations, Measurement 57 (2014) 15–24, http://dx.doi.org/10.1016/j.measurement.2014.07.010.

[33] F. Shih, Automatic extraction of head and face boundaries and facial features, Inf. Sci. (Ny) 158 (2004) 117–130, http://dx.doi.org/10.1016/j.ins.2003.03.002.

[34] A. Young, D. Perrett, A. Calder, R. Sprengelmeyer, P. Ekman, Facial expressions of emotion: stimuli and tests (FEEST), Psychol. Man. (2002).