Quantitative Analyses on Human Face Thermograms for Clinical Applications

Jaspreet Singh
Electrical and Instrumentation Engineering Department
Sant Longowal Institute of Engineering and Technology
Sangrur, Punjab, India

Ajat Shatru Arora
Electrical and Instrumentation Engineering Department
Sant Longowal Institute of Engineering and Technology
Sangrur, Punjab, India

***Abstract*— This paper reports the various quantitative analyses on thermal images to extract the useful information in clinical applications for diagnosing the human body. Thermal imaging is a physiological test that measures the surface temperature changes that might be caused by various conditions, for example: fractures, burns, carcinomas, paranasal sinusitis, contusions, lymphomas, breast cancer, dermatological diseases, rheumatoid arthritis, orofacial pain, diabetic foot disease, liver disease, bacterial infections and inflammation. These conditions are commonly associated with regional vasodilation, hyperthermia, hyper-perfusion, hyper-metabolism, and hyper-vascularisation, which generate higher temperature and act as heat source. The various analyses such as: area analysis, thermal profile analysis, level analysis and entropy have been performed on thermal images of human faces.**

Keywords*— Human body thermal imaging; standardization in clinical applications; circle analysis; line analysis; polygon analysis; image thresholding.

I. INTRODUCTION

In 1800, Sir William Herschel discovered the invisible radiations which exist beyond the red light of visible spectrum known as infrared radiations (IR). IR radiations occupy the spectrum between visible and microwave band of electromagnetic spectrum. It covers the wavelengths that range from 0.75μm to 1mm. All objects above absolute zero (or -273.15 degree Celsius) temperature radiate infrared energy [1]. The infrared radiations emanate from the surface of an object is a function of surface temperature and spectral emissivity of that body. Thermography has been used for several decades for diagnosing the abnormalities on the basis of asymmetrical temperature distribution on the human skin. Temperature is a long established indicator of health. In 400 B.C., the Greek physician, Hippocrates, wrote ‘‘In whatever part of the body excess of heat or cold is felt, the disease is there to be discovered [2] .’’ The first clinical application of infrared thermography was documented in 1956, when the asymmetric hot spots and vascularity in thermograms of breasts were reported in breast cancer patients [3]. Thermal imaging camera is a non-contact type instrument which creates and analyzes images by detecting the infrared radiations emitting from an object’s surface. The record generated by thermal imaging camera which represents the temperature distribution of captured view in the form of colored image is known as thermogram.

(a) (b)

Fig. 1 (a) Visual image of human face where each pixel shows natural colour (b) Thermogram of human face where value of each pixel is temperature dependent.

The thermal image shown in figure (1) consists of thermogram and temperature scale commonly known as colour palette which makes the thermogram understandable and self-explanatory. Different colour palettes such as ironbow, arctic, rainbow, lava and gray scale are required for better analysis which is possible with the advent of digital image processing.

II. HUMAN BODY THERMAL IMAGING

A. *Human Skin Infrared Radiation*

The whole IR spectrum can be divided into near IR (0.75-1.4 μm), short-wave IR (1.4-3 μm), medium-wave IR (3-8 μm), long-wave IR (8-12 μm) and far IR (12-1000 μm) [4-8]. For high frequency (short wavelength), the peak wavelength and the absolute temperature is given by Wien’s Displacement law:

$$\lambda_{max} = \frac{b}{T} \tag{1}$$

Where, λ_{max} = Peak wavelength (μm)
b = Wien’s displacement constant; 2897 μm K
T = Temperature in Kelvin

From equation (1), the temperature values at wavelengths of boundaries of fragmented IR region are calculated and illustrated in figure 1. The human body surface temperature varies from 25 to 37 ºC (298.15 to 310.15 K), therefore

λ_{max} (Human body at 25-37 ºC) ≈ 9.71-9.34 μm

So, human body emissions occupy narrow band of long-wave IR which is commonly referred to as human body infrared. The near infrared (NIR) and medium-wave infrared (MWIR) regions occupy the wavelengths between 0.75-1.4μm and 3-8μm respectively which are not traditionally used for human body monitoring and diagnosis.

B. *Physiopathological based understanding of human body*

The functional changes such as temperature, sweatening, metabolic process and hives in the human body are associated with injury or disease. Thermography is an emissive IR imaging modality that measures the surface temperature changes that might be caused by various conditions such as fractures, burns, carcinomas, paranasal sinusitis, contusions, lymphomas, breast cancer, dermatological diseases, rheumatoid arthritis, orofacial pain, diabetic foot disease, liver disease, bacterial infections and inflammation. These conditions are commonly associated with regional vasodilation, hyperthermia, hyper-perfusion, hyper-metabolism, and hyper-vascularisation [9-14], which generate higher temperature and act as heat source.

C. Thermal Imagers in Medicine

The human body IR emissions occupy the narrow band of LWIR which ranges from 9.34-9.71 µm. Therefore, thermal imagers for monitoring and diagnosing the human body are designed to capture LWIR band (8-12 µm). These cameras are mounted on a portable camera stand with the provision of horizontal and vertical movement. Some companies also provide the thermal imaging workstation which employs dedicated computer for processing and analyzing the thermograms with pre-loaded software and actuators for adjusting the height, tilt, horizontal movement and vertical movement with the help of remote control.

Fig. 2 Thermal Imaging Workstation (www.spectronir.com)

In clinical applications, rainbow type palette is preferred because it represents the small temperature differences with different colors (in isotherm sequences) unlike uses continuous sequences of colors such as grey scale and ironbow.

D. Standardization of thermal imaging in medicine

In medical applications, some standards are to be followed by thermographers to produce a correct, reproducible and reliable temperature record. In 1970’s, the quantitation and archiving of thermograms became available with the advancement in digital image processing which resulted an increased awareness for the need of standardization of thermography [15]. Some papers were published by European Association of Thermology in last two decades of twentieth century which contained many elements of standardization for various thermographic clinical applications including: breast diseases, locomotor (or muscular) diseases and skin temperature measurements in drug trials [16-18].

The International Electro-technical Commission (IEC) and International Organization for Standardization (ISO) collaboratively have published standard, “Particular requirements for the basic safety and essential performance of screening thermographs for human febrile temperature screening” in September 2008. Many performance characteristics, installation and calibration required by thermal imager and ambient conditions to separate out febrile individuals from afebrile are provided in this publication [19]. The criteria used to classify the normal and febrile human is 1ºC elevation in human face temperature from threshold temperature with 0.98 emissivity value for dry human skin. A second document was published by SPRING in March 2009, recommended the mode of deployment, implementation and operational guidelines regarding the use of thermography for human identification [20]. These standards provide the correct and effective use of thermal camera in medicine and set out the minimal technical performances required for fever screening.

III. METHODOLOGY

In clinical applications, thermography is used only for monitoring the superficial organs which included the applications such as: breast cancer, ocular diseases, musculoskeletal disorders, paranasal sinusitis and mass fever screening [21-25]. For different applications, different body parts are monitored with thermography with respective consideration to environmental conditions and subject’s posture. But in this study, the thermal images of human faces were taken with a thermal imaging camera (MobIR M8) that was placed at 4 feet away from a subject. The thermal imaging camera was placed on a stand for stationary imaging. In animate, surface temperature is a function of various parameters including: blood flow, metabolic reactions, environmental conditions, and many more. The blood flow rate and metabolic reactions taken place inside the human body varies from one to other. If there is any abnormality inside our body, then the rate of these parameters will be different which further change the body temperature. These parameters are very difficult to control intentionally. But the environmental conditions (room temperature, humidity and radiations) can be controlled according to our requirements. So, a great attention is required for considering these parameters while performing measurements on animates. In this experiment, room temperature was maintained at 18 $\pm$ 2 °C. The subjects were asked to be in resting and sitting posture for 15 minutes in controlled environment before acquiring the thermal images.

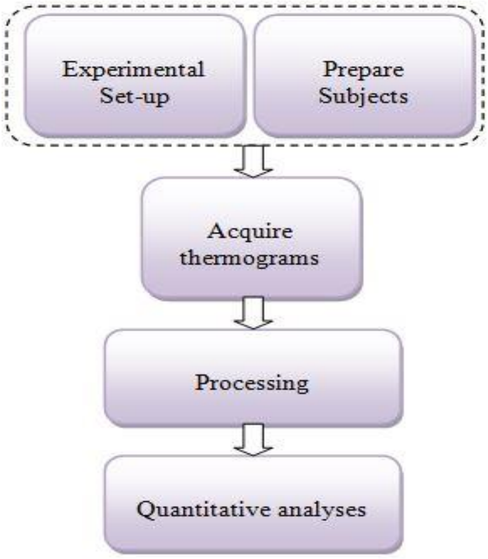


Fig. 3 Process flow diagram

The subjects were advised for looking forward towards the camera and there should be no and there should be no other heat source in the camera view because that may change the temperature scale range of a thermal imager.

IV. EXTRACTING THE REGION OF INTEREST

In this experiment, the region of interest (ROI) is human face which is to be extracted and perform analyses. As the thermograms are acquired with a close view, the maximum active area in the thermal image is covered by a face (where the human body and face is acting as heat source and considered as active region and background considered as passive region of the thermal image. Here, an algorithm has been prepared which crop the face region from the thermogram using largest square matrix. The various techniques and processes used in this algorithm are explained in detail.

A. *Otsu's Thresholding*

In this method, Otsu's thresholding is used to convert the colored thermogram into binary image. It separates the two classes by threshold value't'. It relies on a very simple idea: Find the threshold't' (intensity value in a gray scale image) that minimizes the weighted within-class variance which is same as maximizing the between-class variance. The weighted sum within-class variance is given by:

$$\sigma_w^2(t) = q_1(t)*\sigma_1^2(t) + q_2(t)*\sigma_2^2(t) \quad (2)$$

Where $q_1(t)$ & $q_2(t)$ = Class probabilities
$\sigma_1(t)$ & $\sigma_2(t)$ = Individual Class Variances

In this experiment, calculation of all the possible threshold values, choice of threshold which minimizes the within class variance and separating the background and foreground are done automatically using MATLAB.

B. *Morphological Operations*

Morphology is a broad set of operations that process the images based on shapes represented by structuring element. Morphological operations apply a structuring element to an input image and create an output image of the same size. Here, morphological operations are used for filling holes or small gaps surrounded by ones in a binary image.

C. *Largest Square in Binary Image*

The binary image consists of only 0's and 1's where face covers most of the active area (containing all 1's). To select the face region, an algorithm is used which finds the largest square of containing all ones. The algorithm is based on a concept: Find the minimum value from the last square of four elements of a matrix, replace the lower index element with this minimum value plus one and repeat this procedure for all other element by decreasing columns and rows. In this way, a new matrix of same size will be formed where each element (act as first element of a square) shows the square size. The visual representation of the algorithm for extracting the region of interest is shown in fig. 4.

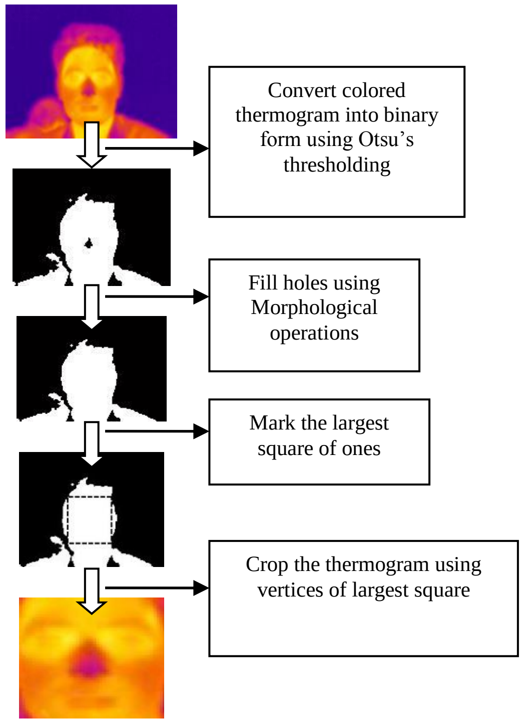


Fig. 4 Visual representation of algorithm for cropping ROI

V. QUANTITATIVE ANALYSES

A. *Area Analysis*

Mean Temperature: The mean temperature over the regions by marking the different shapes such as circles and polygons are calculated by MATLAB. The human face has been divided into five parts: forehead, two cheeks, nose and lower portion including lips and chin. These segments are marked using the imaging tool. The mean temperature of these parts is calculated by performing circle and polygon analysis. As shown in fig. 5, nose is represented by polygon and all others by circles/ellipse.

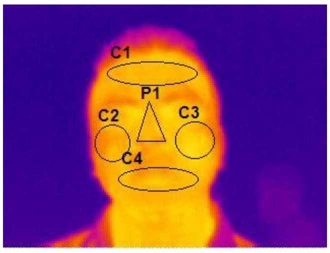


Fig. 5 Marked segments on human face

The mean temperature over the marked region is calculated by adding all the temperature values and divided by number of points in that region. The mean temperature is depicted by a mathematical expression is given below:

$$\bar{x}=\frac{\sum fx}{n} \tag{3}$$

Where n = number of points in marked region
fx = temperature at point 'x'

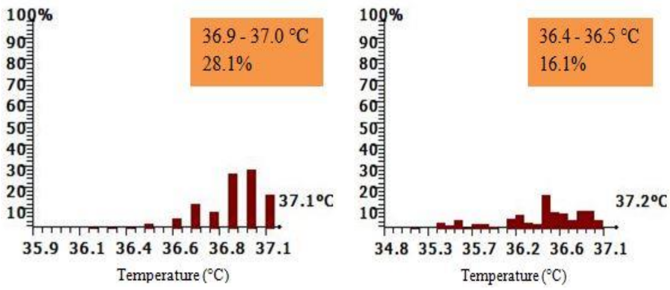
Table-1: Mean temperature over different regions	
Region	Mean Temperature (°C)
C1(Forehead)	36.8
C2(Right Cheek)	36.4
C3(Left Cheek)	37.4
C4(Lower portion)	36.6
P1(Nose)	36.8

Histogram: The histograms are graphical representation of the various temperature values and their occurrence in the particular region. These help to analyze the temperature variations and temperature distribution in the region of interest. The histograms of forehead and right cheek are shown in fig. 6 which illustrates the several temperatures present over the region with peaks of different heights and the maximum peak details are also highlighted on the histogram. The x-axis of the histogram represents the temperature in degree Celsius and y-axis represents the occurrence of temperature in percentage. The histograms are represented by peaks having heights corresponding to the frequency of occurrence of temperature range.

Variance: Variance is a measure of statistical dispersions about the mean of the distribution [26, 28]. The variance σ2 is the second central moment of a distribution and is defined as:

$$\sigma 2=\frac{\sum f(x-\bar{x})^2}{n} \tag{4}$$

Median: In statistics, the median is the numerical value which separates the higher half of the probability distribution. Thus, more difference in the value of median for organs and more will be the asymmetric temperature distribution; whereas the value almost remains same for the normal thermograms [26-28].



(a) *(b)*

Fig. 6 (a) Histogram-C1 (Forehead) (b) Histogram-C2 (Right Cheek)

Kurtosis: Kurtosis is any measure of the "Peakedness". Kurtosis, 'K' measures the flatness or peakness of a distribution relative to a normal distribution. Kurtosis is also termed as the fourth standardized moment and is mathematically represented as,

$$K=\left\{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\frac{P(i,j)-\mu}{\sigma}\right)^4-3\right\} \tag{5}$$

Skewness: In statistics, Skewness is a measure of the asymmetric distribution. It can be positive or negative, or even undefined. Skewness, 'S' characterizes the degree of asymmetric pixel distribution in the specified window around its sample mean [26, 28]. Skewness is given as:

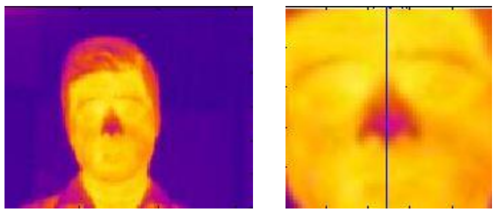
$$S=\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\frac{P(i,j)-\mu}{\sigma}\right)^3 \tag{6}$$

B. Line Analysis

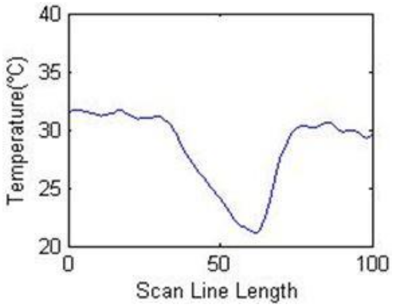
The temperature variations between different parts of a face can be shown by line analysis. As shown in figure 7(b), a line is marked on a thermal image. The vertical line 'L' starts from centre of forehead to lips via crossing the nose is marked. The profile of temperature variations is shown in figure 7(c). The Subject has large variations in temperature profile which is shown in figure 7(c) where the nose has lowest temperature. The large variations in temperature profile of Subject shows the abnormality.

C. Point Analysis

Commonly, it is used to extract the point information based on maximum and minimum temperature. Point analyses are used to locate the hot spots and cold spots on the thermograms which provide better diagnosing for body organs.



(a) (b)



(c)

Fig. 7 (a) Human face thermogram (b) Vertical line marked through the nose (c) Shows large variation in temperature profile of a subject

Fig. 8 Shows maximum and minimum temperature on the thermogram

D. Texture Analysis

The texture analysis can also help to classify the asymmetrical temperature distribution in specified region which provides better diagnosis in clinical applications.

Entropy: It is the measure of uncertainty in the information contained in the specified region of an image. It measures how much disorder is there in the system. Hence, entropy is a useful tool for detecting the asymmetries in the thermogram. For normal temperature distribution in the region, the value of entropy remains to be same [28]. It is given as:

$$H(X) = -\sum_{k=0}^{L-1} P_{rk}(\log_2 P_{rk}) \quad (7)$$

Where P_{rk} = probability of the k-th gray level

L = total number of gray levels

VI. RESULT AND DISCUSSION

The thermograms of 18 subjects were acquired at room temperature 18 ±2 °C and various analyses were performed.

TABLE I. RESULTS OF QUANTITATIVE ANALYSES

SUB.	REGIONAL TEMPERATURE				TEMPERATURE DIFFERENCE			ENTROPY
	T_F	T_C	T_N	T_L	Δ_{FN}	Δ_{CN}	Δ_{LN}	
1	35.3	34.7	34.9	35.6	0.4	-0.2	0.7	0.0139
2	31.3	27.7	26.3	29.5	5.0	1.4	3.2	0.0125
3	33.9	31.1	25.1	32.7	8.8	6.0	7.6	0.2343
4	28.9	28.2	31.4	29.2	-2.5	-3.2	-2.2	0.0077
5	27.7	25.9	25.6	27.4	2.1	0.3	1.8	0.0075
6	32.8	30.5	26.2	31.2	6.6	4.3	5.0	0.1752
7	32.9	30.9	24.8	30.9	8.1	6.1	6.1	0.2739
8	31.2	30.1	28.2	30.8	3.0	1.9	2.6	0.0298
9	33.3	31.7	30.4	32.9	2.9	1.3	2.5	0.0184
10	34.2	31.4	29.2	32.9	5.0	2.2	3.7	0.0144
11	32.4	29.8	25.6	31.0	6.8	4.2	5.4	0.0560
12	30.9	29.3	23.6	29.9	7.3	5.7	6.3	0.1552
13	29.5	28.0	23.7	30.4	5.8	4.3	6.7	0.0802
14	30.1	27.6	27.4	29.4	2.7	0.2	2.0	0.0072
15	30.5	29.6	27.1	29.2	3.4	2.5	2.1	0.0330
16	30.4	28.2	27.4	30.4	3.0	0.8	3.0	0.0273
17	29.3	29.0	30.3	28.9	-1.0	-1.3	-1.4	0.0122
18	35.0	33.5	30.9	33.9	4.1	2.6	3.0	0.0113

Where T_F = mean temperature of forehead

T_N = mean temperature of nose

T_C = mean temperature of cheek

T_L = mean temperature of lower portion including lips and chin

Δ_{FN} = regional temperature difference between fore-head and nose

Δ_{CN} = regional temperature difference between Cheeks and nose

Δ_{LN} = regional temperature difference between lower portion and nose

Normally, there is symmetrical temperature distribution over the body surface. But if there is asymmetrical temperature distribution over any region that means there is some problem regarding that region. In this experimentation, these abnormalities are marked by calculating temperature difference between different marked regions on a face and by performing texture analysis on ROI. The mean temperature over the regions (nose, cheeks, lower to nose and forehead) has been calculated using the algorithm. The asymmetrical temperature distribution on the nose can be easily marked with these quantitative analyses. The highlighted subjects in TABLE II were having asymmetrical temperature distribution which is depicted with large value of regional temperature differences and with large value of entropy.

VII. CONCLUSION

This paper explores the various quantitative analyses for extracting the useful information from human body thermogram. Furthermore, these are diagnosing tools for identifying the diseases related to superficial organs. The basic methodology for acquiring the thermal data from human subjects with the consideration of international standards is also presented in this paper. The largest square algorithm for extracting the ROI provides the reliable and accurate results. The quantitative analyses help to identify the asymmetrical temperature distribution on the human face represented with large value of entropy and large regional temperature differences.

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