A QUANTITATIVE INDEX FOR CLASSIFICATION OF PLANTAR THERMAL CHANGES IN THE DIABETIC FOOD

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ABSTRACT

One of the main complications caused by diabetes mellitus is the development of diabetic foot, which in turn, can lead to ulcerations. Because ulceration risks are linked to an increase in plantar temperatures, recent approaches analyze thermal changes. These approaches try to identify spatial patterns of temperature that could be characteristic of a diabetic group. However, this is a difficult task since thermal patterns have wide variations resulting on complex classification. Moreover, the measurement of contralateral plantar temperatures is important to determine whether there is an abnormal difference but, this only provides information when thermal changes are asymmetric and in absence of ulceration or amputation. Therefore, in this proposed work quantitative index for measuring the thermal change in the plantar region of participants diagnosed diabetes mellitus regards to a reliable reference (control) or regards to the contralateral foot (as usual). Also, a classification of the thermal changes based on a quantitative index is proposed. Such classifications demonstrate the wide diversity of spatial distributions in the diabetic foot but also demonstrate that it is possible to identify common characteristics. An automatic process, based on the analysis of plantar angiosomes and image processing, is presented to quantify these thermal changes and to provide valuable information to the medical expert.

1. INTRODUCTION

1.1 General

The term digital image refers to processing of a two-dimensional picture by a digital computer. In a broader context, it implies digital processing of any two- dimensional data. A digital image is an array of real or complex numbers represented by a finite number of bits. An image given in the form of a transparency, slide, photograph or an X-ray is first digitized and stored as a matrix of binary digits in computer memory. This digitized image can then be processed and/or displayed on a high-resolution television monitor. For display, the image is stored in a rapid-access buffer memory, which refreshes the monitor at a rate of 25 frames per second to produce a visually continuous display. It has been recognized that the main causes of ulceration are diabetic neuropathy and vascular disease of both the macro- and microcirculation.1 Uncontrolled diabetes leads to various complications affecting the eyes, kidneys, heart, nerves, and feet.

Indeed, foot complications are one of the most frequent problems of diabetes mellitus and key contributors to medical costs, as 50% of all inpatient admissions due to diabetes are due to foot complications. The two main causes of diabetic complications are decreased blood supply and loss of sensation in the feet. In the proposed system by using the angiosome concept and by measuring their temperature, it is possible to detect thermal changes even in the early stages.

2. THERMAL ANALYSIS FOR DIABETIC FOOT

2.1 Acquisition Protocol

This chapter concerns the acquisition protocol that will be used in the clinical study, and is also related to the description of the image processing of the plantar foot thermal images realized for this project.

The arrangement of the elements is presented in Figure 1 Remember that the distance between the camera and the feet was chosen to 1.1 m.

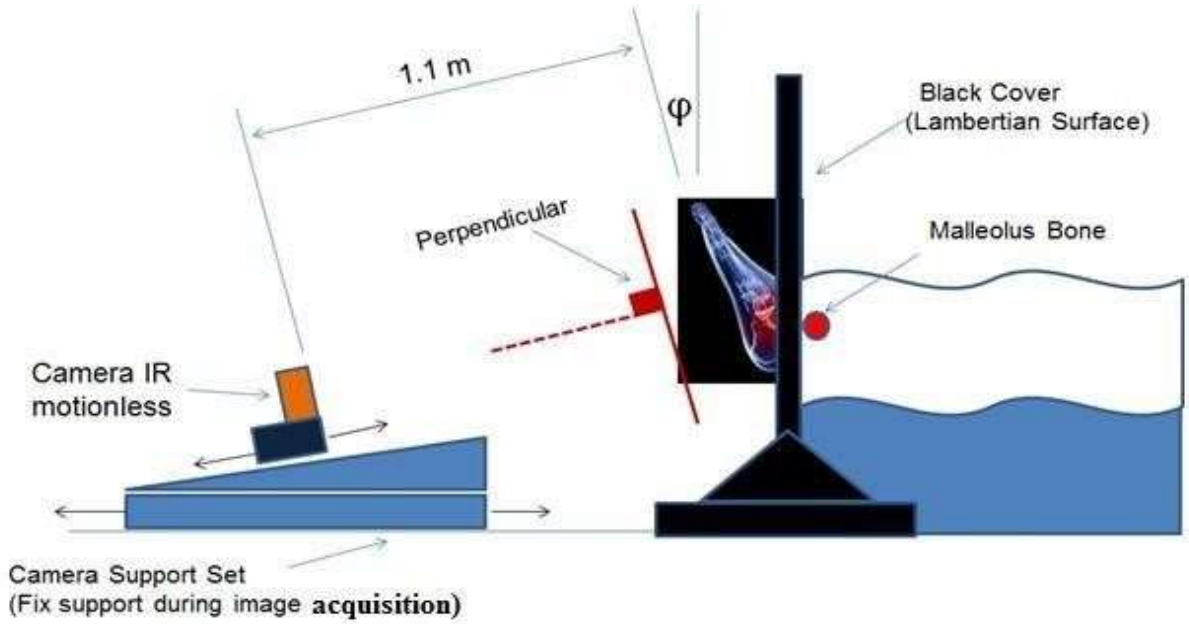

Fig -1 Arrangement of elements for image acquisition

Thermal reflections are a common source of problems in interpreting infrared thermal images. In particular, smooth surfaces like glass, metals or wet surfaces, but also brick and concrete may easily give rise to reflections of infrared radiation from often uncared sources. If unnoticed, these thermal reflections may give rise to misinterpretations of the object temperature. For perfect diffusely scattering surfaces, the Lambertian reflectance is the property that defines an ideal diffusely reflecting surface.

The apparent brightness of such a surface to an observer is the same regardless of the observer's angle of view. More technically, figure 4.2 shows the surface's luminance is isotropic, and the luminous intensity obeys Lambert's cosine law.

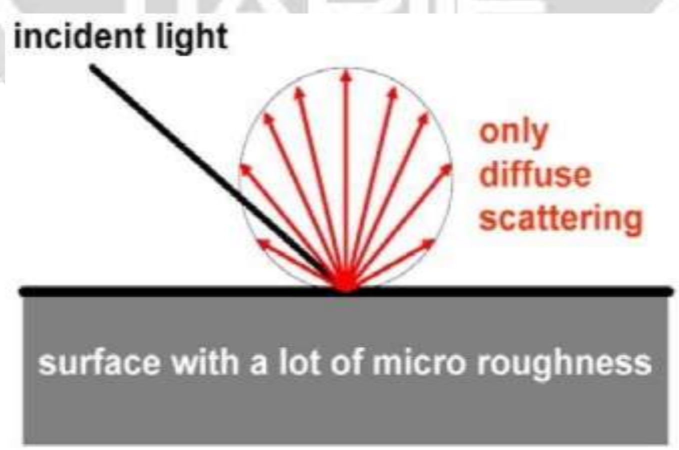

Fig -2 Lambertian Surface

Not all rough surfaces are Lambertian reflectors, but this is often a good approximation when the characteristics of the surface are unknown. The polyurethane foam has a surface roughness estimated in 0.8.

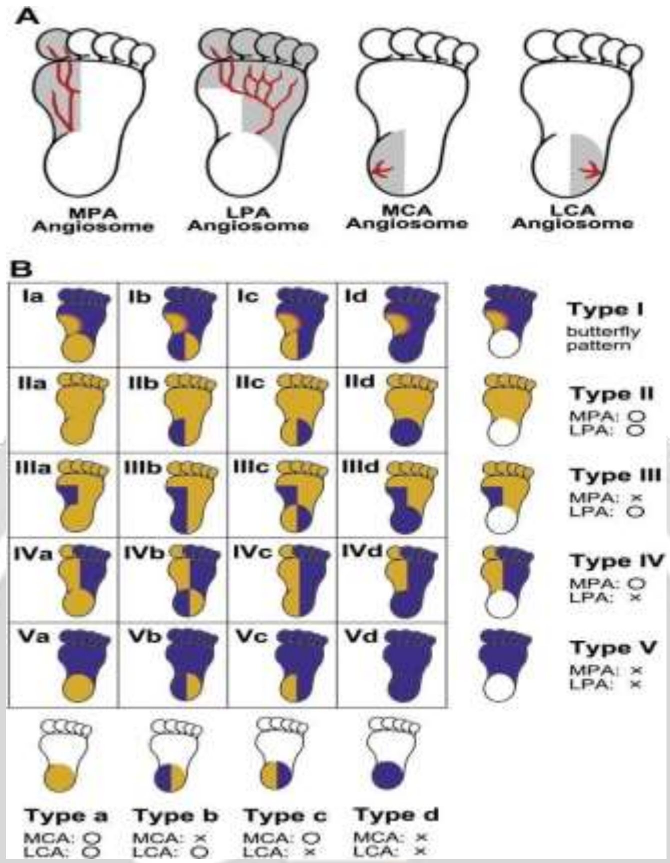

Fig -3 Four Plantar Angiosomes

2.2 Thermographic Classification of Plantar Based in Angiosomes

Variations of plantar thermographic patterns in normal controls and non-ulcer diabetic patients were studied. Thermometry of the plantar skin temperature has been one of the important parameters for assessing ulceration risks in diabetic patients. Recent progress of infrared thermographic technology allows us to obtain imaging of temperature distribution of the whole plantar skin. The plantar thermal is divided into four types of angiosomes it shows in the figure Note that the MPA and the LPA angiosomes are overlapped in the hallux. Orange colour indicates higher temperature, and blue colour indicates lower temperature. To build up the classification framework, they separated the whole plantar area into the distal area and the heel. They distinguished five different patterns in the distal area. The most typical 'bilateral butterfly pattern' was designated as type I. The other four patterns were defined according to the viabilities of the MPA and LPA angiosomes:

- Type I: corresponds to the 'bilateral butterfly pattern'.
- Type II: represents the condition when both the MPA and LPA angiosomes are intact.
- Type III: represents the condition when the MPA is occluded and the LPA angiosome is intact (the MPA angiosome is nourished by choke vessels from the adjacent angiosomes, and, thus, possibly shows lower temperature).
- Type IV: represents the situation when the LPA is occluded and the MPA angiosome is intact.
- Type V: represents the condition when both the MPA and LPA are occluded and both angiosomes are nourished by choke vessels. They similarly distinguished four different patterns in the heel area:
- Type a: represents the condition when both the MCA and LCA angiosomes are intact.
- Type b: represents the condition when the MCA is occluded.

- Type c: represents the condition when LCA is occluded.
- Typed: represents the condition when both the MCA and LCA are occluded.

They finally crossed the five distal patterns and the four heel patterns, just like the vertical and horizontal axes of a two-dimensional space, obtaining the conceptual classification with the 20 different categories from Ia to Vd. In the normal group, thermographic patterns of more than 65% of feet were allocated to the two typical categories, including the ‘butterfly pattern’ among the 20 categories, whereas 225 feet (87.2%) of the diabetic groups were variously allocated to 18 out of the 20 categories. This is the first study which describes detailed plantar thermographic patterns, showing wider variations in the diabetic patients than in the normal subjects.

Thermography will be one of the screening options to assess circulatory status in both daily foot care and surgical intervention. If it is possible to identify that blood supply of a particular angiosome is compromised by thermography in DM patients, physicians can pay more attention to prevent diabetic ulcer formation in this part in the clinical practice of foot care. Observation of the thermographic pattern according to this classification may give an important clue as a screening tool for searching for the foot angiosomes with damaged source arteries, and, thereby, avoiding such kinds of unfavourable surgical outcomes.

3. RESULT AND ANALYSIS

3.1 Thermal Image Extraction

According to previous studies, the temperature variation between corresponding regions in both feet usually does not vary beyond 1°C; a difference greater than 2.2°C is considered as abnormal. The ranges established by were considered in order to determine whether the plantar temperature is normal. Moreover, research results presented by about plantar temperature were taken into account. That study concluded that patients with diabetes type 2 with and without neuropathy have a plantar temperature of 32.2 ± 0.94°C and 30.7 ± 1.07°C, respectively.

The goal in this work is to identify differences between corresponding areas of the right and left foot in order to obtain quantitative information about the plantar temperature distribution. Furthermore, it addressed the early detection of hot spots in an initial phase (small areas) with the aim of preventing their expansion and future complications. Both estimations could be useful for the specialist in early risk detection. The thermal images used in this work correspond to patients diagnosed with diabetes type 2 and neuropathy.

It shows one of the obtained images, which is divided into two sections corresponding to the right and left foot. These images are processed in order to classify their pixels. All the pixels from each image are processed and classified in order to make the limits among the temperature regions clear. As it was described in, there are eight classes with a representative temperature and an associated colour, and all the pixels are classified.

Fig -4 Thermal Feet image

The importance of this process lies on the fact that in the original images it is difficult to determine where a colour starts or ends due to the large number of colours. The figure 6.1 proposed classification process provides an estimated number of pixels (area) for every temperature class. Every time a pixel is classified as belonging to a class, the counter associated with that class is increased. Since only the foot area is relevant for the analysis, the remaining temperatures are considered background and they are not taken into account for the measurement. Thus, the classes C_1 to C_7 comprise the total foot area (a_{total}). In this way, the foot is off the background, as it can be observed. where the background is uniform and the regions are well defined in their corresponding classes. In this case, the entire feet were processed by way of example and to provide a better perspective of the classification process. For practical purposes, in this methodology the pixel classification is as follows.

Once the feet are separated in their corresponding images, they are again divided into four subsections, one per angiosome. Observing the original MPA angiosome image of the left foot, it can be supposed that the colour corresponding to the C_5 class has the greatest area. However, it is difficult to establish the limit among the coloured regions in a clear way because of the similitude among some colours. A visual comparison between the MPA angiosome of both feet could be even more complicated; therefore, it is important to go beyond the visual perception and make a quantitative comparison of the temperature distribution. Once the pixel classification has been made, it is possible to clearly observe the area that covers certain temperature associated with a class.

3.2 Colour Classification

In this work, a methodology that determines and analyzes temperature differences is proposed to detect abnormal temperature increase in the diabetic foot. The plantar area is analyzed by taking into account the angiosome concept since the blood flow in these regions accurately reflects the temperature variation. In the angiosome, temperature estimation is calculated by identifying the present colour regions, which at the same time are characterized and related to a temperature value. Thus, temperature differentiation between corresponding angiosomes can be achieved.

Moreover, this process enables the localization of the area that covers each temperature; thereby, it also allows the detection of abnormal hot spots at the interior of the angiosome. To perform the colour characterization and obtained the feet image extraction to determine and find the hot spot detected in the areas. The figure 6.2 shows the feet image extraction.

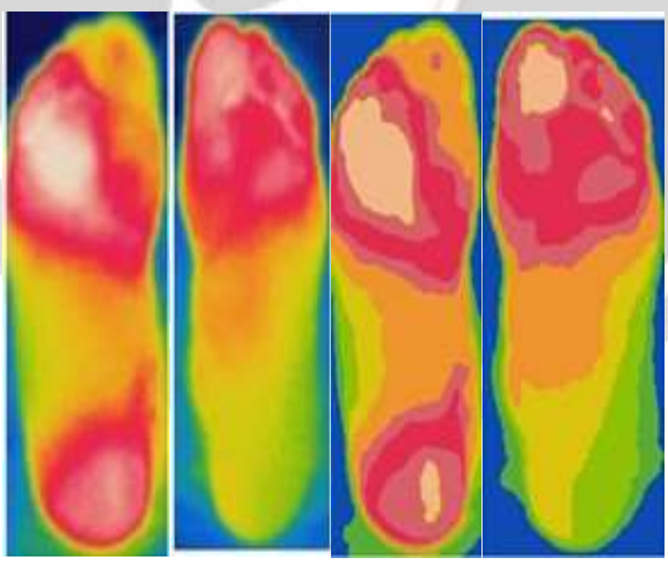

Fig -5 Feet image extraction

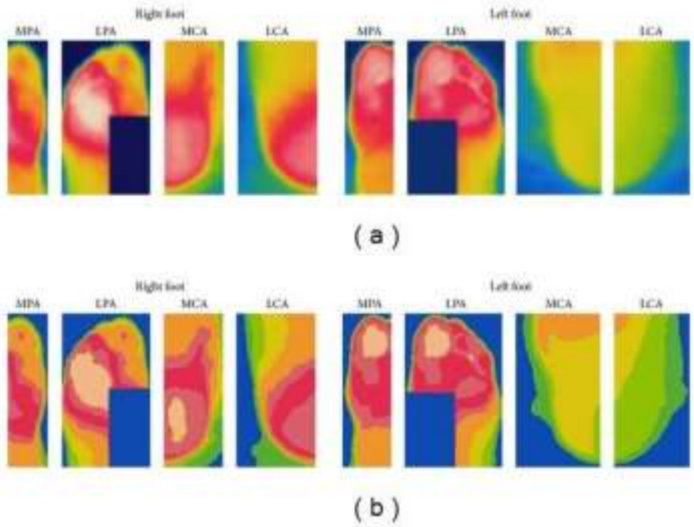

Fig -6 Angiosome images of their colour classification

The areas of each angiosome in are shown in the figure 6. The areas are translated into percentages and based on this data, it determined which classes have the larger area in the same angiosome of both feet. In the MPA angiosome analysis, it is observed that the majority of the angiosome area is divided among classes C_4, C_5, and C_6 for the left foot that is, a temperature interval of [31, 34) °C. For the right foot, the class C_4 is the predominant one with an interval of [31, 32) °C. In the LPA plot, it is observed that the foot temperatures are more distributed, being C_5 and C_6 the largest classes for the left foot, while C_4 is the largest for the right foot. Then, the temperature intervals in the LPA angiosome are [32, 34) and [31, 32) °C for the left and right foot, respectively.

For the calcaneal angiosomes (MCA and LCA), the temperature distribution has a more drastic variation respect to MPA and LPA. The MCA angiosome temperature in the left foot with a predominant class C_3 is lower ([30,31) °C) than in the right foot with a predominant class C_6 ([33,34) °C), as shown in. LCA temperature is also very different, being C_2 ((29, 30) °C) in the left foot and, C_4 ([31, 32) °C) the right foot, the predominant classes.

While there is an important amount of scientific reports about temperature analysis in the diabetic foot, most of them rely on qualitative analysis. However, it is not always simple to estimate the abnormal temperature differences by visual inspection of the thermogram.

The aim of the proposed methodology is to bring precise information about such differences by facilitating the detection of possible risks regions and their evolution to the medical specialist. Although not all the regions with abnormal temperature will become an ulcer, their monitoring is very important as they represent high-risk regions. It is significant to remark that this methodology is not a diagnostic tool but a tool that brings complementary information to be evaluated by the medical specialist in order to facilitate early detection of ulceration risks.

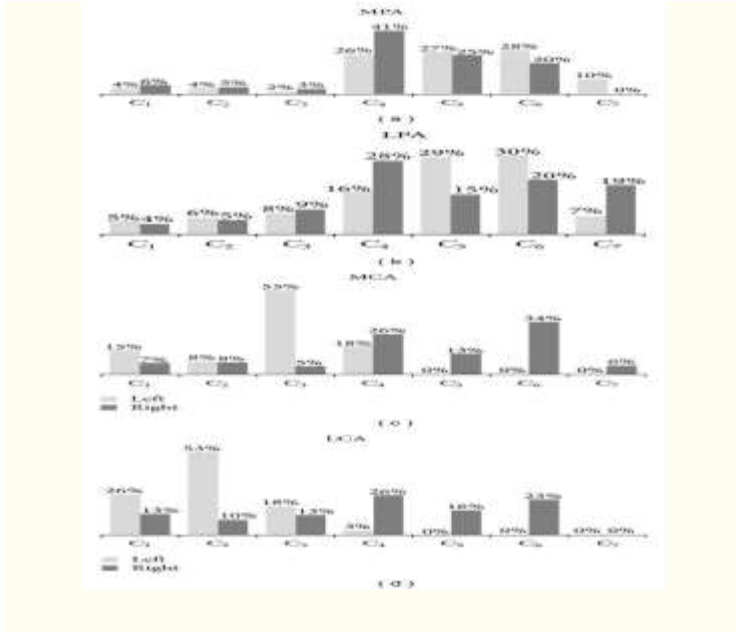

Fig -7 Graphical representation of the area (as percentage) that covers each temperature class in the angiosome

3.3 Simulation Output

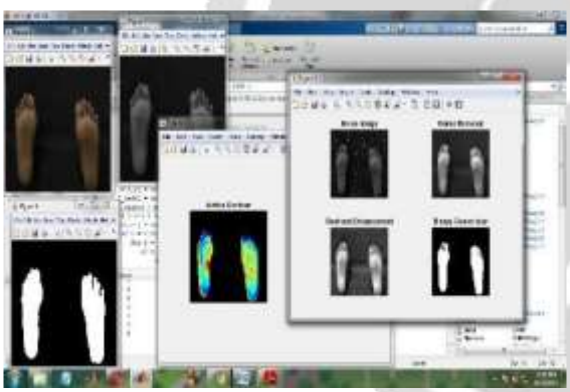

Fig -8 Simulation output

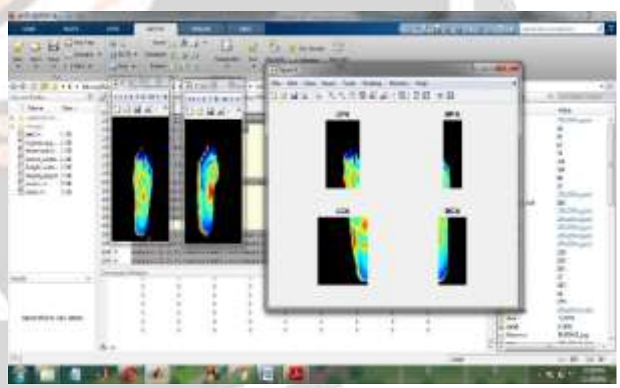

Fig -9 Simulation output

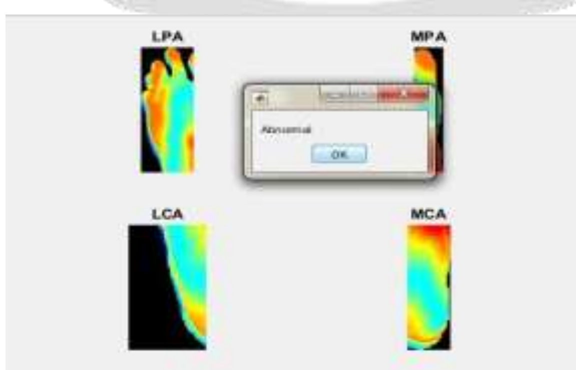

Fig -10 Simulation output

4. CONCLUSION

Thermal imaging and image analysis are useful tools in the medicine field applied to the study of diseases such as diabetes. Temperature distribution in the plantar area contains relevant information about the condition of diabetic foot and ulceration risks. In this work, a methodology was presented aiming at providing quantitative information about abnormal temperature differences in symmetric regions between feet and inside of the same foot. The methodology took into account the temperature differences, their distribution, and area. As a first analysis, differences between symmetric areas in both feet were studied since it is known that symmetric regions in the body have similar temperatures. For this, the plantar area was divided into four main regions (angiosomes) and the temperatures inside those regions were grouped in classes according to a color similitude criterion. An index (ET) based on the relation between the class with larger area and its adjacent classes was proposed in order to estimate a representative temperature for each angiosome. Thus, it was possible to obtain an estimated difference (ETD) between symmetric regions which obtained an accurate measure to determine whether there is an abnormal difference or not. A second analysis was performed to study the temperatures inside the angiosomes with the aim of detecting the presence of small abnormal areas (hot spots). For that reason, it proposed a hot spot estimator (HSE) that relates the representative temperature of the angiosome with the higher temperature on it. This estimator was capable to detect the presence of abnormal regions in initial phase that, for their small area, were not detected by the estimator ETD. In this way, it was possible to analyze the whole plantar area by bringing quantitative information to determine the presence of regions in possible risk of ulceration.

5. REFERENCES

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