# Automatic Analysis of Plantar Foot Thermal Images in at-Risk Type II Diabetes by Using an Infrared Camera

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*Abstract*— **Temperature of the plantar foot surface is an important feature in type II diabetes as abnormal temperature variations can be an early sign of foot diseases. In this paper, automatic way to analyze these temperature variations is presented by using an infrared camera. A robust acquisition protocol is proposed and an image processing software is developed. Three types of analysis are performed. First, the mean plantar foot temperature of both feet results from a segmentation procedure based on the Chan and Vese active contour method. Second, the point-to-point absolute mean difference between the 2 feet is assessed by using a rigid registration method. Third, significant hyperthermia regions such that the point-to-point absolute difference is greater than 2.2°C are highlighted. All these measures are fully automatic and do not need manual intervention. 82 type II diabetic subjects in a pre-ulcerative state were recruited in the Dos de Mayo hospital (HNDM) in Lima, Peru. These persons were classified in two risk groups of developing an ulcer based on a medical exam: a medium risk group, and a high risk group. Results show that the mean temperature of the plantar foot surface is higher of 1ºC in the high risk group compared to the medium risk group. The mean point-to-point absolute difference shows identical values in the 2 groups. Finally, 9 subjects out of the 82 ones show significant hyperthermia of one foot compared to the other (6 in the medium risk group and 3 in the high risk group). It is expected that the new opportunity to automatically analyze foot temperature in hospitals or in diabetic health centers will help in reducing foot ulcer occurrence for type II diabetic persons.**

*Keywords*— **Diabetic foot, thermal imaging, thermography, automatic procedure, hyperthermia.**

## I. INTRODUCTION

Diabetes is a major public health problem that mainly concerns eyes, cardiovascular system, kidneys and feet. It is a rapidly growing problem as it will affect 500 millions of people worldwide in 2030 compared to 350 million nowadays [1][5]. Concerning foot complications, the annual incidence of foot ulceration is of 2%. Approximately 15% of foot ulceration will lead to a lower-limb amputation [8]. It is more than necessary to develop new ways to reduce this dramatic figure.

In diabetic foot, the occurrence of an ulcer is often associated with a foot temperature elevation. Temperature monitoring could be a complementary diagnostic method in prevention of major foot complications, but cannot replace any of the current steps in modern diabetes care. Early diagnosis and early treatment are crucial for the healing of diabetic foot lesions and resources for rapid interventions must therefore be available to take care of a higher number of suspected foot complications [8]. Unfortunately, temperature is difficult to assess in current diabetic foot therapy as it consists in a manual palpation of foot temperature. It is therefore too subtle to be detected in this way. For this reason, some works concern the use or the development of dedicated systems in that purpose as described below.

In diabetic foot, occurrence of an ulcer is often associated with hyperthermia. Hyperthermia is defined as a temperature greater than 2.2ºC in a given region of one foot compared to the same region of the contralateral foot [2]; the TempTouch Thermometer was used and it was shown that the occurrence of an ulcer can be reduced by 30%.

In [12], wider variations of the plantar foot patterns in thermal images acquired with an IR camera were found in ischemic patients compared to normal subjects.

In [6], using a thermal camera, the relationship between the mean temperature of the plantar foot surface and a risk index that associates neuropathic signs to pre-ulcerative skin was studied: an increase of temperature in line with the risk level was clearly demonstrated.

In [13], an infrared thermal imaging for the detection of diabetic foot complication was proposed. Here the various ROIs were manually annotated by an expert.

In this communication, we propose to analyze the plantar foot surface temperature in diabetic foot by using a thermal camera and to automatically derive from the image thermal parameters. The variations of these parameters will be studied as the risk of ulcer increases. The risk index results in the use of a by-risk classification following a foot examination in hospital conducted by a specialized medical doctor. The following parameters will be automatically calculated from the images: mean temperature of each foot, the mean point-to-point absolute difference between the 2 feet, and finally hyperthermia, if any, will be pointed out.

## II. MATERIALS AND METHODS

### A. Subjects

A transversal clinical study has been conducted in the Hospital National Dos de Mayo (HNDM) in Lima from the



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1st of February 2013 to the 30th of June 2013, with a population of type II diabetes before a possible ulceration occurs.

The type II diabetic patients who came from outside the hospital for a regular exam in the diabetes service of the HNDM were first taken in charge by experimented nurses. Exclusion criteria have been defined, such as patients with ulcer, neurodegenerative diseases, in the pediatric age, and so on [11]. These criteria are comparable to those used in other similar studies [2][12].

82 individuals were recruited from the Diabetic Foot Unit in HNDM. Clinical data, including age, gender, time of diabetes diagnosis (TOD), and body mass index (BMI), were collected during the exam (Table 1).

Table 1 Patient characteristics and by-risk classification

| Patient Characteristics | | | |
|---|---|---|---|
| Variables | General | Risk | |
| | | Medium | High |
| Sample num. | 82 | 49 | 33 |
| Age (yr) | 63.45 ± 10.53 | 62.55 ± 10.86 | 64.79 ± 10.03 |
| Gender (F/M) | 54 / 28 | 34 / 15 | 20 / 13 |
| TOD (yr) | 10.25 ± 8.60 | 6.97 ± 5.83 | 15.11 ± 9.77 |
| Weight (kg) | 69.4 ± 13.74 | 70.4 ± 12.92 | 67.9 ± 14.96 |
| Height(cm) | 152.74 ± 9.73 | 152.3 ± 10.27 | 153.3 ± 8.99 |
| BMI (kg/m²) | 29.7 ± 5.09 | 30.3 ± 4.74 | 28.7 ± 5.49 |

Following this, the same medical doctor conducted a barefoot medical exam that lasted about 30 minutes from which a by-risk classification [7] resulted (Table 1):

- Low risk: people with no ischemia, nor neuropathy;
- Medium risk: first signs of ischemia or neuropathy;
- High risk: strong signs of neuropathy or ischemia.

Few patients of the low risk category were observed. They were not included in the study.

*B. Acquisition protocol*

The proposed acquisition protocol has already been described in [11]. The key points are that after a medical exam, the patient should be given sufficient time to equilibrate with the ambient temperature [4][6], the exam room temperature must be well controlled, and any external infrared radiation must not affect the measurements. A black cover assimilated to a Lambertian surface was used to ensure a homogeneous background and carefully isolate feet from the rest of the body during image acquisition. This black cover was a polyurethane foam with density = 19.2 Kg/m$^3$; tensile strength = 34.5-51.7 kPa; of 80×80 cm$^2$; of 6 cm of thickness. Two holes were also present in the black cover in which the patient feet could go through it. These holes were two circles of 7 cm of diameter each, and separated of 20 cm.

In view of required specification, a FLIR i5 thermal camera was chosen. Five intrinsic parameters were taken into account: resolution, sensitivity, accuracy, spectral range, and emissivity. Regarding sensitivity, figure 1 shows one acquired image of a homogeneous background and its histogram: the standard deviation over the image is $\sigma = 0.06$ °C. It means than any thermal variation above 3σ, *i.e.* 0.2°C, can be highlighted. It is more than necessary regarding the present study. Price was also a selection criterion in order to permit this technology to be widespread in future.

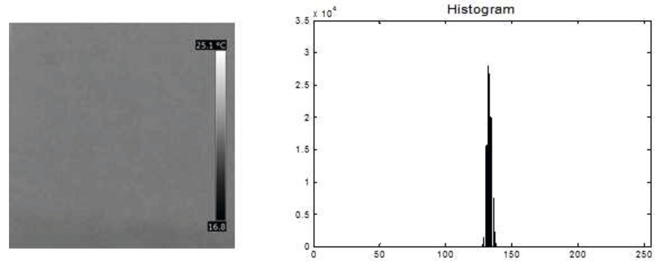



Fig. 1 Accuracy of the FLIR i5 camera

Figure 2 shows an image obtained using the proposed image acquisition protocol. As seen, the plantar foot clearly appears as a white surface on a homogeneous dark background. The image temperature varies from 21.2°C (room temperature) to 33.5°C (hottest point of the plantar foot).

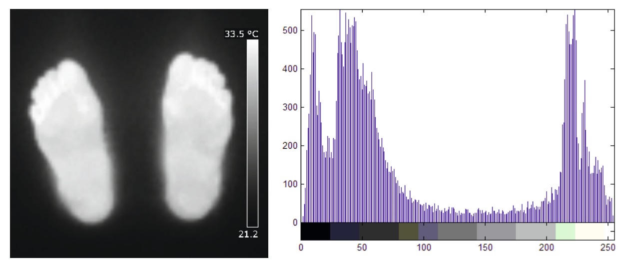



Fig. 2 Thermal image and its histogram

*C. Automatic Image Processing*

The original image as that presented in figure 2 is divided so that two images are obtained, one for each foot. The minimum of the Radon transform in the vertical direction is the chosen separation value between the 2 feet. The label on the right side of the image is removed. The right foot is considered as the reference foot. The left foot is vertically flipped in order to look like the right foot. Afterwards, the process of segmentation is carried out. For segmenting the 2 feet, the Chan and Vese active contour algorithm is implemented [9] in order to find the contour of the feet (Figure 3). This algorithm was chosen because feet contours are not sharp. The number of iterations is of 300, and the value of the internal algorithm parameter is 0.2.

Results obtained after this segmentation step are of high quality. The mean temperature of the right foot and that of the left foot can be assessed automatically from the proposed image algorithm. For image in Figure 3, for example, the mean right temperature is equal to 31.71 °C.

The following step is registration of the two feet; a straightforward rigid registration method, efficient and easy to implement, called the iterative closest point [10], is applied to minimize the distance between the two contours (Figure 4).

Fig. 3 Region and contour of the right foot

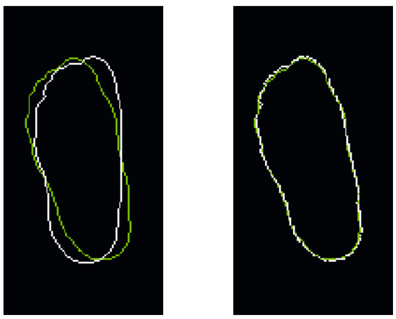


Fig. 4 ICP-based rigid registration
Left: original contours. Right: registered left contour

The point-to-point absolute temperature difference between the right and the left feet is calculated for each pixel and is presented in Figure 5. It varies from 0°C (for the background and some parts of the plantar foot surface) to 2.99°C (only parts of the plantar foot surface). Because of feet asymmetry, registration is not always optimal and some foot zones are withdrawn. The mean of this image is calculated and is named $|\Delta T|$.

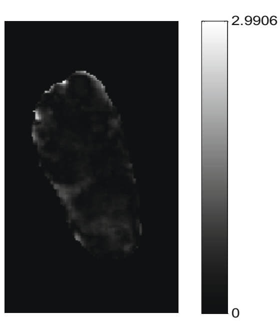



Fig. 5 Image of the point-to-point absolute temperature difference between the 2 feet (°C)

Temperature of corresponding points of the right and left feet do not usually differ more than 1°C in diabetic foot. It was determined that values greater than 2.2°C are in hyperthermia [2]; one has to keep in mind that hyperthermia can be an early sign of ulcer. The percentage of hyperthermia plantar foot points is called HT%. When HT% is greater than 1%, it roughly corresponds to a disk of 1 cm of diameter. It is also the smallest area at-risk for the foot. This limit was therefore chosen to be an alert sign. Such a region is denoted significant hyperthermia region. One example is presented in Figure 6.

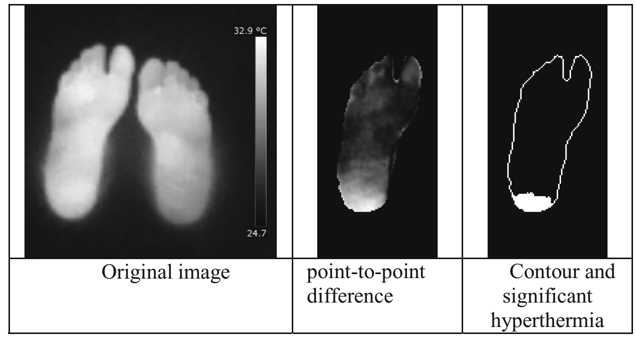



Fig. 6 Original image (left), the point-to-point absolute temperature difference between the 2 feet image (middle), the contour and a significant hyperthermia region (right) of the right foot

## III. Results

Table 2 presents means and standard deviations of the age, time of diagnosis (TOD), and body mass index (BMI) in the medium and high risk groups. To assess if a difference occurs between these two by-risk groups, a Student t-test was performed on the age, TOD, and BMI. The TOD is significantly lower in the medium risk group than in the high risk group (6.97 ± 9.77 years versus 15.11 ± 5.83 years). It means that TOD is an important feature regarding the by-risk classification.

Table 2 Parameters of interest: age, TOD and BMI using the by-risk classification and related t values

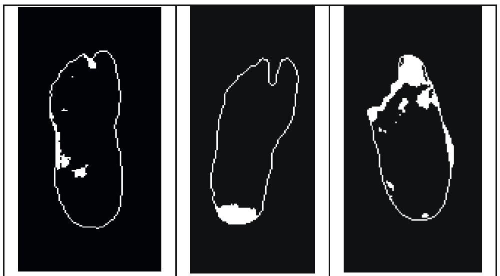
| | Risk | | | | | |
|---|---|---|---|---|---|---|
| | Medium | | | High | | |
| | Age | | TOD | | BMI | |
| Mean | 62.55 | 64.79 | 6.97 | 15.11 | 30.37 | 28.76 |
| STD | 10.03 | 10.86 | 9.77 | 5.83 | 5.49 | 4.74 |
| t value | 0.96 | | 4.29 | | -1.37 | |

The mean temperature of the plantar foot surface of the left (ML) and right (MR) feet was calculated as well as $|\Delta T|$, the point-to-point mean absolute temperature difference between the two feet. Table 3 shows the ML, MR and $|\Delta T|$ parameters. A Student t-test was performed with a level of significance of 5% on these three parameters. Results show that the mean temperature is significantly higher in the high risk group compared to the medium risk group. For the medium group, the mean temperature is around 31 ± 2 °C, and increases for high risk to a value close to 32 ± 2 °C. If this result is confirmed by other clinical tests, it may be of a great help for the early diagnosis of diabetic foot: from the medium risk to high risk, the plantar foot temperature is increased by 1°C.

Finally, the significant hyperthermia regions are highlighted. 9 persons out of the 82 patients of the study show significant hyperthermia. Among them, 6 persons are from the medium risk group, and 3 from the high risk group. 3 images are presented in Figure 7. This hyperthermia alert may be of a substantial help because it is an early sign of foot ulcers.

Table 3 ML, MR and $|\Delta T|$ using the by-risk classification and related t values

| | Risk | | | | | |
|---|---|---|---|---|---|---|
| | Medium | | | High | | |
| | ML | | MR | | \|ΔT\| | |
| Mean | 30.98 | 31.83 | 30.91 | 31.73 | 0.57 | 0.53 |
| STD | 2.03 | 1.65 | 2.16 | 1.76 | 0.27 | 0.24 |
| t value | 2.09 | | 1.88 | | -0.70 | |



| IR_700 | IR_896 | IR_992 |
|---|---|---|

Fig. 7 Three feet with significant hyperthermia

## IV. Conclusions and perspectives

The overall objective of the study is to develop new strategies to reduce the occurrence of ulcers using thermography. A dedicated and automatic image processing method was proposed. It is composed of two steps: segmentation and registration. From these steps, mean temperature of each foot, the point-to-point absolute mean temperature difference between the right and left feet can be assed, and significant hyperthermia regions can be detected.

A transversal clinical study was conducted including a population of 82 type II diabetic patients before a possible ulceration occurs. For the medium risk group, the mean temperature is 31°C, and increases for high risk to a value close to 32°C. It was found that around 10% of these persons coming in the hospital for an ordinary consultation in the diabetes service have a significant region of hyperthermia. It would be interesting to know if this thermal analysis using an IR camera along with the proposed automatic software could help medical doctors in hospital or in medical centers.

Several perspectives of this work will be advanced in a near future. The polyurethane foam makes positioning a patient for the image acquisition a long and difficult process, especially for old people (see paragraph II-B). It is expected to develop an image segmentation method that could be operational without this polyurethane foam. It that case, the segmentation of the plantar foot is a difficult task.

A longitudinal study, similar to that proposed in [2], will take place soon in the Hospital National Dos de Mayo, Lima. The general objective will be to evaluate the potential of this proposed technology, *i.e.* using an IR camera in ulcer prevention for type II diabetic foot.

Finally, an at-home system can now be developed thanks to new technologies that recently appeared in mobile technologies [14].

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