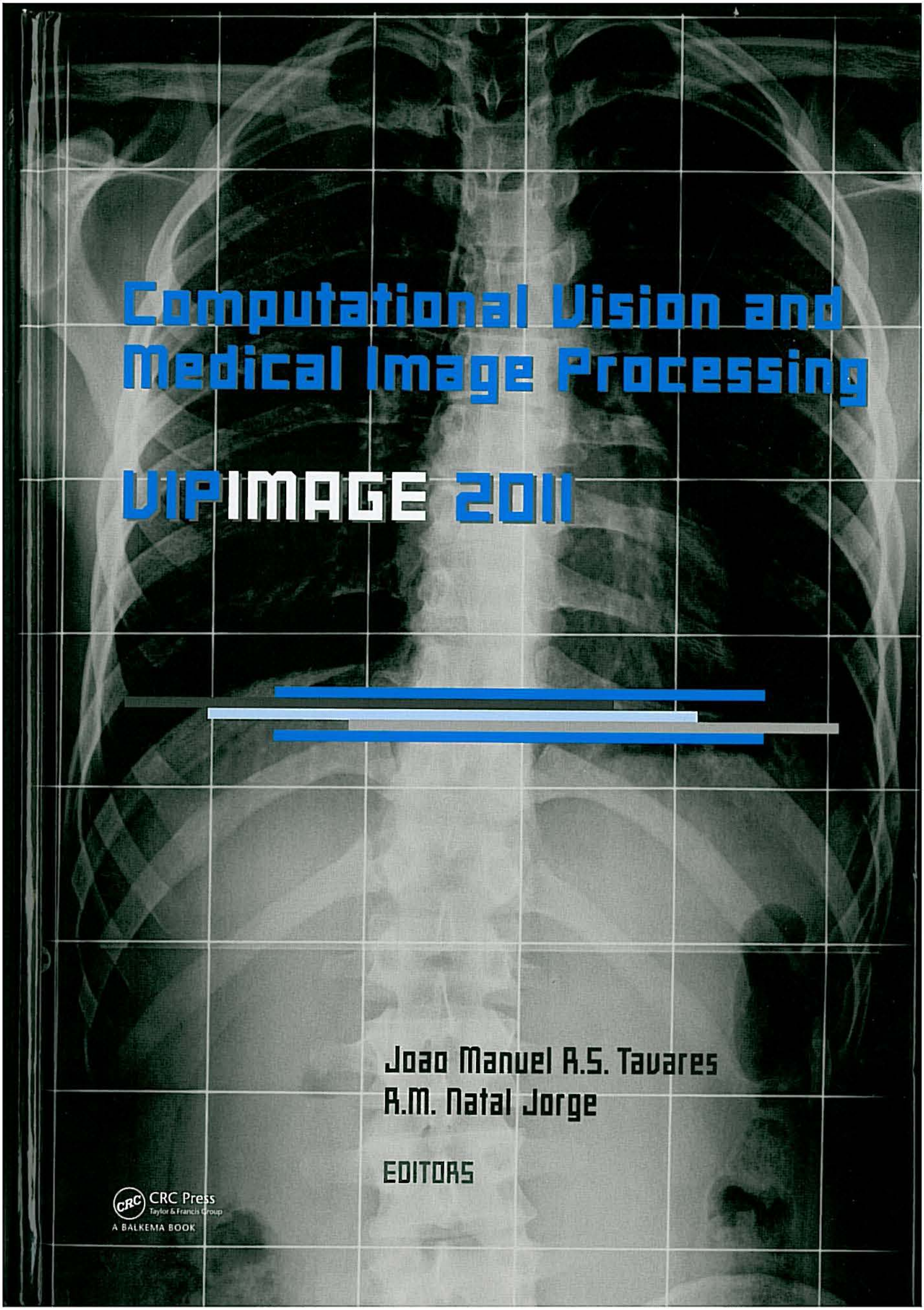

# Computational Vision and Medical Image Processing

## VIPIMAGE 2011


Joao Manuel R.S. Tavares
R.M. Natal Jorge

EDITORS



CRC Press
Taylor & Francis Group
A BALKEMA BOOK

*Computational Vision and Medical Image Processing – Tavares & Natal Jorge (eds)*
*© 2012 Taylor & Francis Group, London, ISBN 978-0-415-68395-1*

# Monitoring feet temperature using thermography

D. Bento & F.C. Monteiro
*Polytechnic Institute of Bragança, ESTiG/IPB, C. Sta. Apolonia, Bragança, Portugal*

A.I. Pereira
*Polytechnic Institute of Bragança, ESTiG/IPB, C. Sta. Apolonia, Bragança, Portugal*
*ALGORITMI, Minho University, Campus de Azurém, Guimarães, Portugal*

ABSTRACT: Studies show that regular monitoring of feet temperature may limit the incidence of disabling conditions such as foot ulcers and lower-limb amputations. Infrared thermometry and liquid crystal thermography were identified as the leading technologies in use today. In this study, we analysed the maximum temperature and tested some mathematical models for the foot temperature distribution.

## 1 INTRODUCTION

Diabetic foot (DF) ulcers are one of the major complications in diabetics, seriously affecting the quality of their lives. The possibility to measure the different aspects of DF and its ulcerative pathology gives to clinicians the chance to both evaluate and weigh up the different components contributing to the genesis and evolution of the cases and to monitor their clinical course as a consequence of the therapeutic interventions. Therefore, it is necessary to establish methods of prevention or early diagnosis for diabetic foot complications (Nishide et al., 2009).

The DF lesions are a combination of several risk factors acting simultaneously and can be triggered by peripheral diabetic neuropathy, peripheral vascular diseases and biomechanical changes. The decrease in sensory function in the foot and limitation of joint mobility are some early signs for the appearance of foot ulcers, meaning high risk of developing inflammations or other complications. These changes can be assessed using various techniques, thus preventing the appearance of ulcers and reducing the risk of foot amputation.

The use of thermal techniques to evaluate diabetic foot has largely remained a research topic (Lavery et al., 2004, Sun et al., 2006, Armstrong et al., 2007, Nagase et al., 2011). The authors believe that thermal techniques can be significantly useful in diabetic foot assessment, with the intent of determining risk of foot ulceration.

Recent advances of physiological imaging techniques have prompted us to use thermography for screening skin temperature, deep tissue edema or fluid collection due to inflammation (Nishide et al., 2009). Infrared thermography is one of the leading technologies in use today. This technology is feasible for temperature monitoring of the foot and can be used as a complement to current practices for foot examinations in diabetes.

In this study, we used thermal plantar images in patients without diabetes to support a mathematical model for foot normal temperature distribution.

## 2 MATERIALS AND METHODS

### 2.1 *Subjects*

This study includes healthy volunteers, recruited from Polytechnic Institute of Bragança, representing a feet healthy population who were between 21 to 43 years old. This preliminary study includes a set of fifteen thermographic images.

### 2.2 *Protocol*

The subjects were guided to keep resting supine position without shoes or socks for 10 minutes, before measurement, to stabilize the feet temperature.

The images were collected by a thermal camera (FLIR 365) positioned at a fixed distance of 1 metre of subject's feet. A plate of rigid foam was placed over the ankles to isolate the temperature of feet from the rest of the body. The total duration of data acquisition process did not exceed 15 minutes.

### 2.3 *Image processing*

Infrared thermography is a real-time temperature measurement technique used to produce a coloured visualization of thermal energy emitted by skin.

However, temperature discrimination threshold, on the foot, could be a difficult process due to the large temperature variation between the feet and the background.

As we can see from Figure 1, the large temperature variation in the image produces small colour variations of skin temperature.

Through the application of image processing techniques it is possible to obtain images with a better contrast of the structures in question. In order to isolate the feet from the background, we apply image segmentation, based on region growing, followed by a histogram expansion using only the temperature values of the feet, obtaining discriminative images, as showed in Figure 2.

### 2.4 *Characterize foot regions*

Interpretation of the colour patterns according to the anatomic temperature distribution is thought to aid in evaluating and diagnosing foot complications.

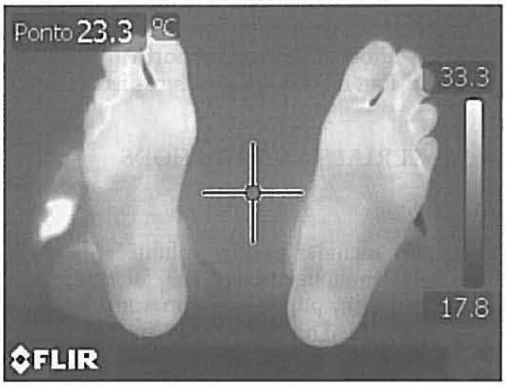


Figure 1. Thermal infrared image.

Figure 2. Improving the temperature discrimination.

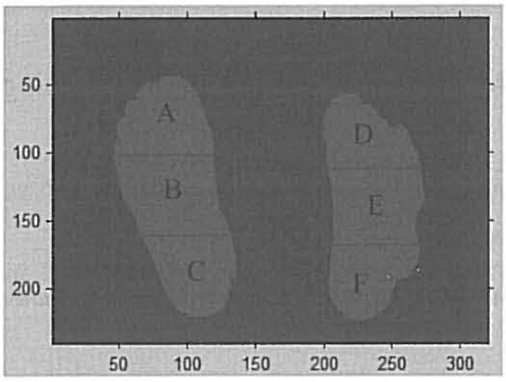


Figure 3. Foot regions.

With the numerical data, obtained through image processing, we defined main areas by measuring each foot (length and width) and divided it in three regions. Considering the left foot, Region A is the upper region; Region B is the central region and the lower region was defined as Region C.

In a similar way, Regions D, E and F were defined for the right foot, as represented in Figure 3.

## 3 NUMERICAL RESULTS AND DISCUSSION

In this study, we used fifteen feet images. Nine of them follow the same pattern for the maximum temperature while the other six do not have a defined pattern.

Figure 4 shows the maximum temperature value, for each region, from the set of nine images which follow a pattern.

We can observe that the maximum temperature value was obtained at Region A and D (the upper regions of the feet) which agrees with other results presented in the literature.

In this preliminary study, we tested three nonlinear mathematical models for the temperature distribution. The parameters $i$, $j$ represent the pixels positions.

$$f_1(x,i,j) = x_1 ij + x_2 i^2 + x_3 j^2 + x_4 i + x_5 j + x_6 \quad (1)$$

$$f_2(x,i,j) = x_1 \sin(x_2 i + x_3) + x_4 \sin(x_5 j + x_6) + x_7 \quad (2)$$

$$f_3(x,i,j) = x_1 \sin^2(x_2 i + x_3) + x_4 \sin^2(x_5 j + x_6) + x_7 \quad (3)$$

It was observed that the best mathematical function that approximates the temperature distribution was the function $f_2$. The evaluation was done using the nonlinear least method combined with $l_1$ penalty method.

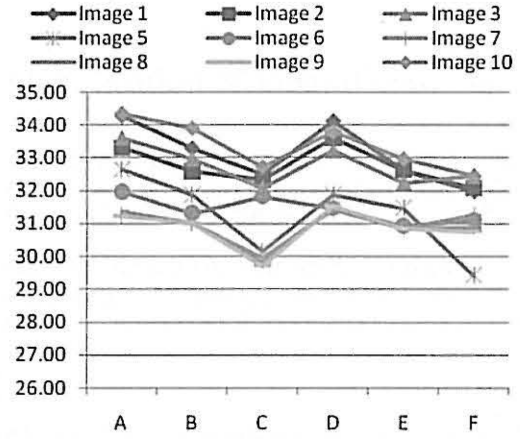


Figure 4. Absolute temperature maximum values.

## 4 CONCLUSIONS AND FUTURE WORK

High temperature gradients between foot regions may predict the onset of neuropathic ulceration, which makes temperature monitoring a way to reduce the risk of ulceration.

In this study, we observed that the temperature maximum value, in general, is obtained in the upper regions of the foot.

A preliminary study indicates that the best mathematical model to approximate the temperature distribution is a sine sum function. Future prospective observation is needed to confirm our mathematical model or some variation of it.

## REFERENCES


Armstrong, D., Holtz-Neiderer, K., Wendel, C. et al., 2007. Skin temperature monitoring reduces the risk for diabetic foot ulceration in high-risk patients, *The American Journal of Medicine* 120: 1042–1046.

Lavery, L., Higgins, K., Lactot, D., Constantinitides, G., Zamorano, R., Armstrong, D., et al., 2004. Home monitoring of foot skin temperatures to prevent ulceration, *Diabetes Care* 27(11): 2642–2647.

Nagase, T., Sanada, H., Takehara, K., Oe, M., Iizaka, S., Ohashi, Y., Oba, M., Kadowaki, T. & Nakagami, G. 2011. Variations of plantar thermographic patterns in normal controls and non-ulcer diabetic patients: novel classification using angiosome concept, *Journal of Plastic, Reconstructive & Aesthetic Surgery* 64(7): 860–866.

Nishide, K., Nagase, T., Oba, M., Oe, M., Ohashi, Y., Iizaka, S., Nakagami, G., Kadowaki, T. & Sanada, H. 2009. Ultrasonographic and thermographic screening for latent imflammation in diabetic foot callus. *Diabetes Research and Clinical Practice* 85(3): 304–309.

Sun, P.C., Lin, H.D., Jao, SH., Ku, Y.C., Chan, R.C. & Cheng, C.K. 2006. Relationship of skin temperature to sympathetic dysfunction in diabetic at-risk feet. *Diabetes Research and Clinical Practice* 73(1): 41–46.