Towards the Diabetic Foot Ulcers Classification with Infrared Thermal Images

by R. Vardasca*, L. Vaz**, C. Magalhães**, A. Seixas***, ****, J. Mendes*

* LABIOMEP, INEGI-LAETA, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias S/N 4200-465 Porto, Portugal, rvardasca@fe.up.pt
** Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias S/N 4200-465 Porto, Portugal
*** Escola Superior de Saúde, Universidade Fernando Pessoa, Rua Carlos da Maia, 296, 4200-150 Porto, Portugal
**** LABIOMEP, CIFI2D, Faculdade de Desporto, Universidade do Porto, R. Dr. Plácido da Costa, 91, 4200-450 Porto, Portugal

Abstract

Diabetes Mellitus is a top 10 deadly health condition worldwide, one of its consequences is the diabetic foot ulcers (DFU) that in severe cases can lead to amputations and death. Preventive measures are required, a rise in skin temperature is one of the early signs of a DFU formation. Infrared thermal images were taken from 56 DFU patients at early stage, being processed and classified using an intelligent data method (k- Nearest Neighbour), an accuracy of 92.5% was achieved. A larger sample is required to improve the results, so it can be used at daily practice for DFU prevention.

1. Introduction

According to the International Diabetes Federation [1] a total of 485 million people is affected with Diabetes Mellitus (DM) worldwide and 1 in 2 remains undiagnosed. It is known that in their lifetime, 25% of the DM patients develop Diabetic Foot Ulcers (DFU), which may lead to minor and major amputations and consequently death [2]. It is also known that patients that developed DFU have a great probability (40%) of developing them again [3]. Measures are required to early identify the formation of DFU, so health professionals can act promptly and with success.

The DFU are associated with neuropathy and/or peripheral artery disease in the lower extremity of people with diabetes [4], this affects the skin temperature and is object of being monitored with infrared thermal imaging (IRT). IRT in medicine is a non-invasive, non-ionizing, fast, safe and remote imaging method that records the skin surface thermal energy emitted transforming it in temperature maps, providing real-time physiology data [5]. A formation of a DFU is normally associated with a rise in temperature, being this an early sign [6, 7].

The artificial intelligence computational classification methods have been employed in medical IRT since 2002 with several applications, being the k-Nearest Neighbour (k-NN) the technique that provided better results [8].

2. Methodology

A total of 56 DFU early stage patients were examined at the specialized diabetic foot centre, Centro Hospitalar do Porto, EPE. The images were collected after the participants signed the informed consent and the procedure have been explained to them, being the study approved by the hospital ethical committee. Regions of Interest (ROI) were defined in the areas were more often the DFU occur at the plantar foot (Figure 1). The data collection followed the international guidelines [9,10] using a 10 minutes' acclimatization period and the room being acclimatized in a temperature around 22ºC with relative humidity of <50%. The Infrared camera used to capture the images was the FLIR A325sc, with a FPA sensor of 320x240, a Non-Equivalent Temperature Difference (NETD) of <50mK at 30ºC and a measurement uncertainty of ±2% of the overall reading.

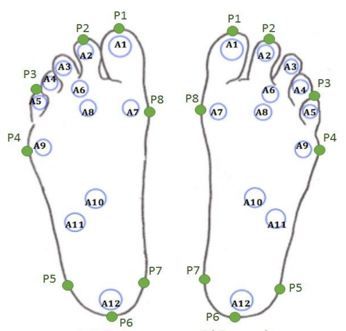

Fig. 1. The regions of interest (ROI) used to analyse the plantar feet thermal images.

A computational tool was developed in C# programming language to read the images, place the ROIs and extract the mean temperature, median temperature and standard deviation per ROI, the affected ROIs were signed, this was then stored in a PostgreSQL database in that was used by another developed tool to classify the data, for quality assurance an open-source suite of machine learning software Weka (https://www.cs.waikato.ac.nz/ml/weka/) was used to compare the obtained results. The Figure 2 presents the solution infrastructure.

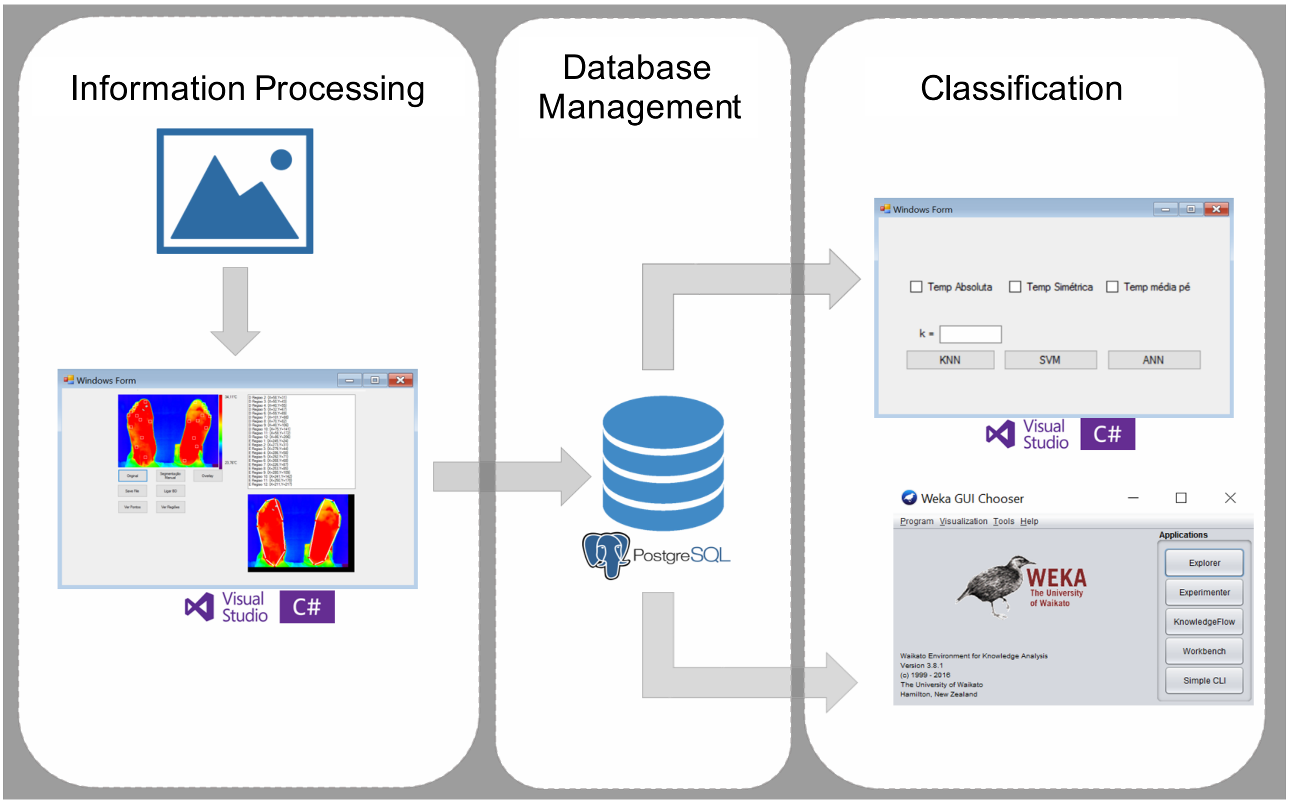

Fig. 2. The infrastructure of the images analysis and data classification.

The temperature in degrees Celsius (T) is obtained from the radiometric value (S) and the Planck constants R1, R2, B, F and O, which are obtained from the proprietary thermal image files. The temperature is calculated by equation 1.

$$T(^{\circ}C) = \frac{B}{\ln\left(\frac{R1}{R2.(S+O)}+F\right)} - 273.15 \tag{1}$$

The developed system can be divided into five main parts: the localization and extraction of metadata from binary files, image processing, identification of regions of interest (ROI), structuring and populating the database, and finally, the development of a tool to allow automatic classification. In order to assess the quality of the results obtained from the classification process, a similar operation with the same data was performed in parallel using the Weka framework. The determination of the ROIs is presented in the Figure 3, where the image is loaded, an overlay with control points based in the model (Figure 1) is displayed over the thermal image, it can be adjusted with the mouse for adequate placement and based on it, the ROIs are placed automatically and the mean, median and standard deviation is extracted from each ROI to be used as input for classification.

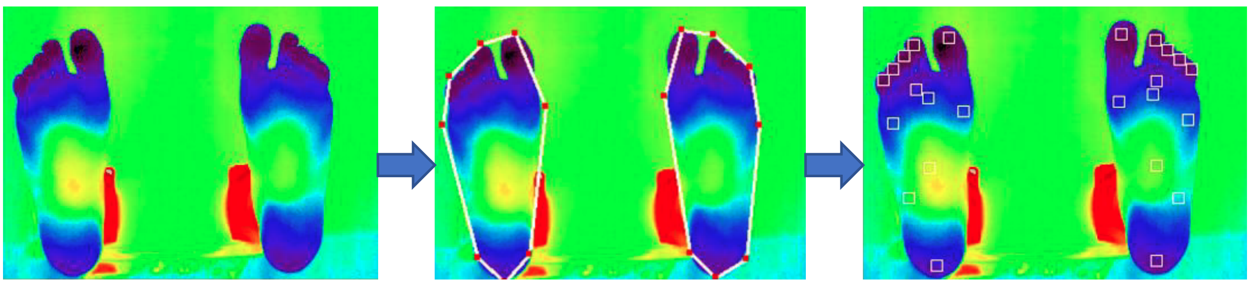

Fig. 3. The ROIs determination process.

3. Results

The thermal parameters (mean, median and standard deviation) per ROI were successfully obtained from each ROI of the processed images, to verify the correct classification it was matched with the clinical classification of the location of DFU at each image. For producing the classification results, based in the distribution of the thermal parameter it was verified that only the k-NN classifier could be used given the low disparity of the data (Figure 4), the positive prediction of ANN and SVM methods was 0% and the negative prediction was 100%. The obtained classifications accuracy from the k-NN operator using the mean and median absolute values of the ROIs is shown at table 1.

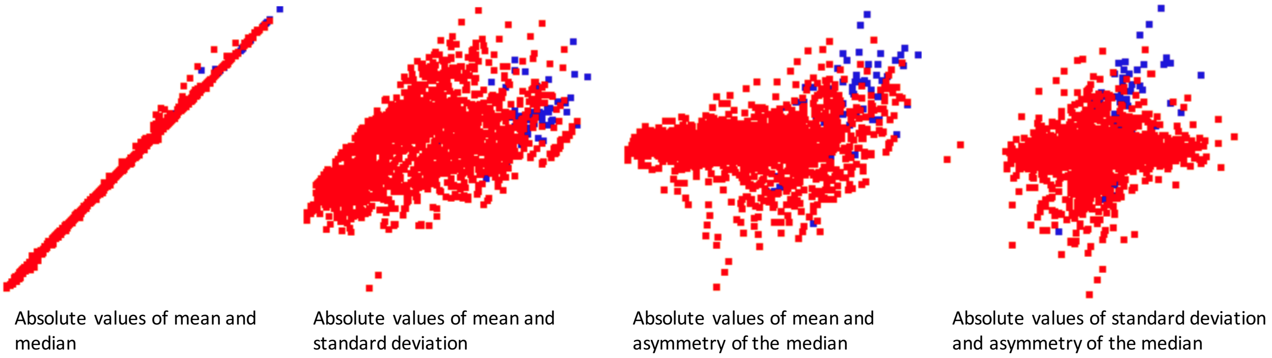

Fig. 4. The dataset distribution of the thermal parameters selected for classification.

Table 1. Results from the data classification accuracy using the k-NN method for the absolute means and medians.

k	Developed program		Weka	
	accuracy	positive prediction	accuracy	positive prediction
1	90.8%	28%	91.2%	6.5%
3	92.1%	14.3%	93.4%	9.7%
5	92.5%	20%	92.3%	6.5%
7	92.5%	20%	92.1%	9.7%

The configuration of the classifier that obtained better classification from the developed program was the 5 number of k-NN classes, with an accuracy of 92.5%. With the same dataset, from the Weka framework the best performance was provided from 3 number of k-NN classes, with an accuracy of 93.4%.

4. Discussion

The developed classification solution has presented higher accuracy for 5 or more classes, 92.5%. Classification through k-NN shows very acceptable results. The accuracy value obtained with the developed program is very close to the value obtained in the Weka program.

However, due to the fact that in the program created more ways of calculating the distances between the various elements were implemented than in the Weka, a higher positive prediction was obtained with the developed program.

Since it was not possible to create a representation of the data where a two-dimensional separation was verified, it was not possible to develop the SVM and ANN classifiers, as initially planned. A test performed in the Weka for these classifiers justified this impossibility, due to the fact that a positive precision of 0% and a negative precision of 100% was obtained.

In either case, the negative accuracy obtained is always greater than the positive precision. This is due to the fact that few images of feet with ulcers have been tested, in the elements for the classification there are more samples of ROIs without ulcer than of ROIs with ulcers.

5. Conclusion

The developed application allowed to classify DFU at ROIs with high accuracy. With a larger number of samples, it is expected that this accuracy rises and it could be implemented at specialized units on daily practice for early DFU identification, which would lead to prompt care and would avoid any further costs and consequences for the patient.

6. Acknowledgments

The authors gratefully acknowledge the partial funding of project NORTE-01-0145-FEDER-000022 - SciTech - Science and Technology for Competitive and Sustainable Industries, co-financed by Programa Operacional Regional do Norte (NORTE2020), through Fundo Europeu de Desenvolvimento Regional (FEDER) and of project LAETA - UID/EMS/50022/2013.

REFERENCES

[1] International Diabetes Federation. Diabetes Atlas, 8th edition. Retrieved December 30, 2017 and available at: http://www.diabetesatlas.org/

[2] Singh N., Armstrong DG. Lipsky, B.A. Preventing foot ulcers in patients with diabetes. Jama 2005; 293:217-228.

[3] Bus SA., Waaijman R., Arts M., de Haart M., Busch-Westbroek T., van Baal J., Nollet F. Effect of custom-made footwear on foot ulcer recurrence in diabetes: A multicenter randomized controlled trial. Diabetes Care 2013; 36:4109-4116.

[4] Bakker K., Apelqvist J., Lipsky BA., Van Netten JJ., Schaper NC. The 2015 iwgdf guidance documents on prevention and management of foot problems in diabetes: Development of an evidence-based global consensus. Retrieved December 30, 2017 and available at: http://www.iwgdf.org/files/2015/website_development.pdf

[5] Ring EFJ., Ammer K. Infrared thermal imaging in medicine. Physiological measurement 2012; 33(3): R33-R46.

[6] Armstrong DG., Holtz-Neiderer K., Wendel C., Mohler MJ., Kimbriel HR., Lavery LA. (2007). Skin temperature monitoring reduces the risk for diabetic foot ulceration in high-risk patients. The American journal of medicine 2007; 120(12):1042-1046.

[7] Ring EFJ. Thermal Imaging Today and Its Relevance to Diabetes. Journal of Diabetes Science and Technology 2010; 4(4):857-862.

[8] Vardasca R., Vaz L., Mendes J. Classification and decision making with infrared medical thermal imaging, Classification in BioApps: Automation of Decision Making, Dey N., Ashour AS., Borra S. (Eds.), in Studies in Lecture Notes in Computational Vision and Biomechanics book series. Springer 2018; chapter 4:79-104.

[9] Ammer K. The Glamorgan Protocol for recording and evaluation of thermal images of the human body. Thermology international 2008; 18(4):125-144.

[10] Ring EFJ., Ammer K. The technique of infrared imaging in medicine. Thermology international 2000; 10(1):7-14.