Enhancement techniques for abnormality detection using thermal image

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Abstract: Digital thermal imaging is considered as a non-invasive diagnostic tool and a real-time monitoring technique for indicating the physiological changes of the underlying tissue from the superficial thermal signature. A thermal camera can detect temperature variations in the body, as low as 0.1°C. The observed colour pattern depends on the prevailing temperature of the target in a controlled environment. This colour-based thermal pattern is further processed for identifying abnormalities. This process of identification is done by applying various methods such as histogram equalisation, Otsu thresholding and morphologic function. These steps are applied to thermal images of a foot acquired from volunteers and abnormalities were identified. The identification process was based on a threshold obtained from the histogram and it was found to be in the range of 76–80.

1 Introduction

In India, about 80 million people suffer from pre-diabetes and 70 million people have overt diabetes [1]. Pre-diabetes patients can avoid the imminent disease by incorporating a change in their lifestyle and improved physical activity. In gestational diabetes, 50–70% of women with gestational diabetes mellitus (GDM) are at risk of developing Type II diabetes in later years [2]. The mother and fetus can be safeguarded by controlling GDM [3]. It is well-known that diabetes can affect every major organ in the body like the heart, nerves, eyes, kidneys and feet. This current research focuses on the thermal image of a foot in order to identify, if it is a diabetic foot. It also helps in evaluating the healing stage of the wound during the treatment process. Thermography is a non-invasive, non-contact diagnostic tool that uses the heat from our body to aid in making a diagnosis of a disease or disorder in the subject under investigation; it is a completely a safe procedure and known ionising. The thermogram acquires the infrared energy emitted by the subject.

2 Literature review

Simoes *et al.* [4] conducted the study on the abdominal surface temperature in healthy pregnant women. The research was based on specified region of interest (ROI) in a group of pregnant women. The ROI was evaluated to check if the thermal symmetry values were similar to the values of those obtained from healthy non-pregnant women. They observed that there was no change in the variation in the ROI irrespective of women's age. Gati *et al.* [5] found that infrared imaging could be used for studying the fundamental structures and pathological processes. Ng and Sudharsan [6] compared the thermal images with a numerical model and performed several what-if analysis. The study concluded that thermography along with numerical modelling can be used as an adjunct tool for the detection of breast cancer. Mahajan and Madhe [7] used thermal imaging for the detection of thyroid disorders. The study proceeded with the image processing techniques and used feature extraction method for the analysis. The analysis shows that the abnormal area shows temperature variation and can be easily detected using the thermal camera. In this work, the authors propose the use of image processing techniques to identify the threshold values for abnormality detection. Hariprasad and Sharmila [8] observed ulcer detection and its recovery stages using a thermal image and image processing tools. The patients wound captured using thermal camera and find the area and perimeter of the wound. The same patient again captured an image after one week and the image captured. The difference in value indicated the patient healing of wound. However, their research did not relate to temperature variation. Kumar and Sudharsan [9] evaluated the thermal image of a foot using the histogram method. In order to identify the histogram value of an abnormality, a known thermal pattern was generated using a computational fluid dynamic software (Star CCM+). The value was found to be in the range of 76–80. The above analysis was performed for an image having both feet. As the histogram was for the combined feet, the variation between the two and identification of abnormality is not straight forward. Therefore, in this work, the left and right feet were separated and the same methodology applied. This was also repeated with Otsu thresholding and morphological method. This was done to see if the other two methods provided a better understanding or enhancement of interpretation compared to the previous study. To the author's best knowledge, there are no similar studies for comparison and optimisation. It is for this reason a numerical method using CFD study was compared with the histogram method as validation [9].

3 Research methodology

In the existing method, the foot ulcer is predicted by using ROI. Studies in artificial intelligence have progressed rapidly within the last couple of years; modern developments have enabled the efficient treatment of foot injuries in several medical sectors. Although support instruments to evaluate the diabetic foot are in existence, little has been done to reduce the errors in the evaluator's cumulative criteria, and the management of obtained data. The primary drawback with the existing system is that a foot ulcer cannot be predicted exactly. Often, observed skin tones are wrongly diagnosed as diabetic foot.

The proposed method helps to evaluate a diabetic's foot through the introduction of digital image processing techniques. The use of advanced image segmentation techniques and a parameter that adjusts the system's sensibility until the desired results are obtained makes it possible to apply an algorithm to a series of trial images which provides positive results for wound and location detection.

The thermal analysis is processed by the following steps:

- Acquisition of the image using a thermal camera.
- Screening the image using filters.
- Enhance the image.
- Compare the results

The three types of image processing techniques currently evaluated are histogram, Otsu thresholding and morphological function (Fig. 2). The purpose of the research is to detect an abnormality in humans.

This study would help the physician in the evaluation of diabetic's foot, thereby supporting the interpretation of the acquired image to ensure better patient care management. The process of automatic detection of ulcers will greatly reduce physician specific interpretation and thereby democratising the process.

Fig. 1 presents the classification of the thermogram pattern reproduced from [10]. This chart will help the thermographer classify the various conditions of the feet. This interpretation is subjective requiring practice and experience. The current image processing management would greatly enhance the process of classification for medical management.

4 Flowchart and explanation

4.1 Image acquisition

The thermal image quality depends on controllable parameters such as ambient temperature, air flow and lighting. It is necessary to maintain the temperature at 21°C, without air draft and diffused lighting [6]. The uncontrollable factors are patient metabolic rate and patient temperature. This can be indirectly controlled by ensuring the patient is duly rested and acclimatised to the screening environment. The thermal image can be improved further by enhancing the signal-to-noise ratio by ensuring that the patient does not apply any lotion/cosmetics in the scanned region.

4.2 Histogram method

Two sets of images are considered for the analysis-thermal foot image and trial image for training. The trial thermal pattern was generated using a computational fluid dynamic software (Star CCM+).The trial image is generated such that, the colour blue

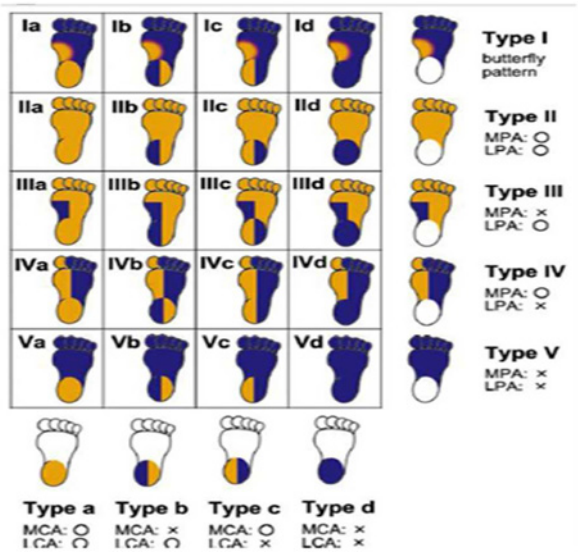

Fig. 1 *Classification of the thermographic patterns [10]*
MPA: medial plantar artery, LPA: lateral calcaneal artery, MCA: medial calcaneal artery, LCA: lateral calcaneal artery. Orange and blue colours denote the higher and lower temperatures, respectively

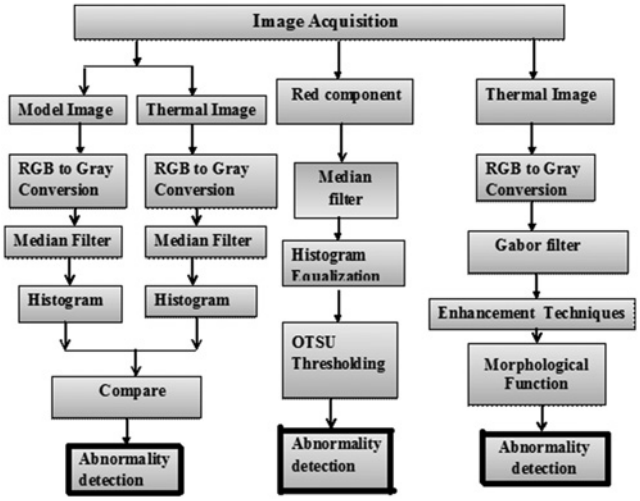

Fig. 2 *Flowchart for the system*

depicts the lowest temperature and extends to the colour red which stands for the highest temperature. The analysis was performed in the numerically generated image and then repeated for the thermal image of the foot [9].

4.2.1 RGB to grey conversion: RGB is converted into grey scale image, which is the intensity image. This conversion occurs by eliminating hue and saturation and retaining luminance.

4.2.2 Noise filtering: The median filter is used in this paper for sorting out salt and pepper noise. It keeps the sharp edges and is a non-linear operation. For every input pixel $p(x, y)$, the value of the pixel is found, its median is identified and the value is assigned to output pixel $q(x, y)$.

After acquiring the image, it is processed using the three types of processing techniques, namely histogram, Otsu thresholding and morphological function.

4.3 Otsu thresholding method

The acquired image is first converted to a grey image. The red component is extracted from the image and filtered using a median filter.

4.3.1 Median filter: The median filter is used in this method for preserving the edges and to remove the salt and pepper noise. The process of the median filter is the replacing of each value with the median value of the neighbouring pixel. It is calculated by first sorting all the pixel values from the window into numerical order, and then replacing the pixel being considered with the middle pixel value. The central pixel is replaced by the median of pixels in the window.

4.3.2 Histogram equalisation: The image is processed using histogram equalisation which helps to adjust the image intensities to enhance contrast.

4.3.3 Otsu thresholding: In image binarisation, Otsu threshold method helps to reduce grey level image to a binary image. In this method, all possible threshold values are iterated to calculate the spread of pixel value on both sides of the threshold value. The purpose is to find out the threshold value for classifying the person as either diabetic or non-diabetic. According to OTSU method, minimising 'within class variance' is equal to maximising 'between class variance' of segmented image. However,

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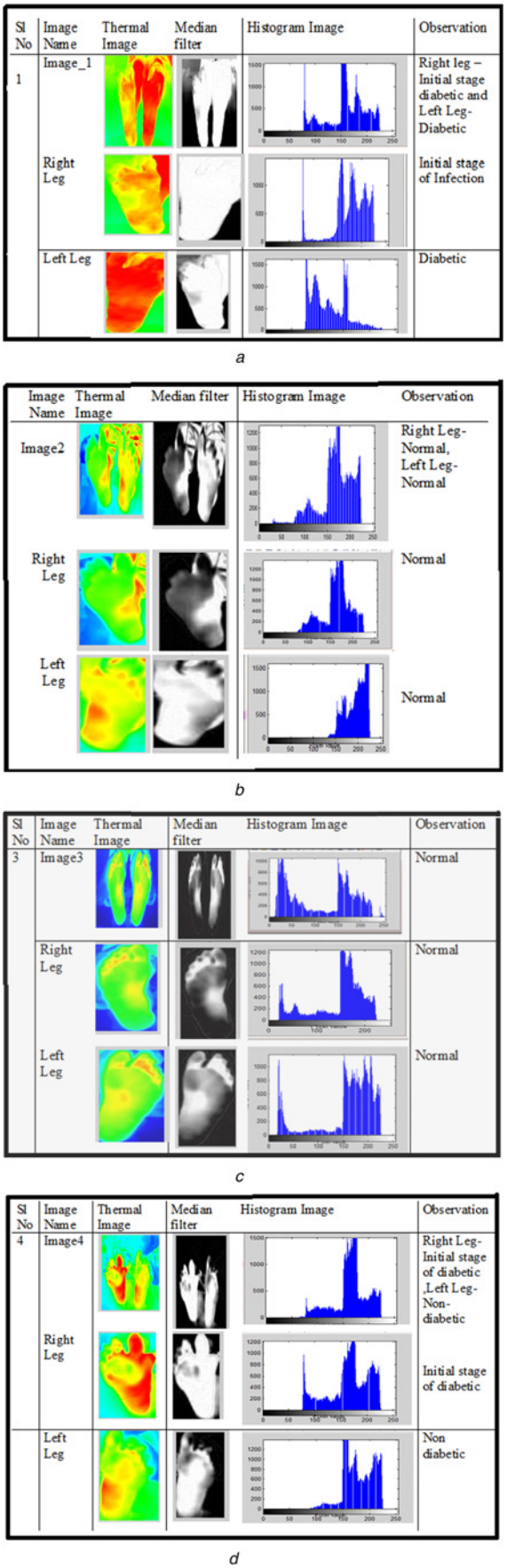


Fig. 3 *Histogram obtained from the thermogram of*
a Image_1
b Image2
c Image3
d Image4

maximising 'between class variance' is less expensive than minimising 'within class variance'.

4.4 Morphological process

4.4.1 Gabor filter: The RGB image is converted to grey image. The captured image is filtered using Gabor filter. The Gabor filter converts the image to discrete value for getting the constant region of the image. Compared to other filters, Gabor filter is primarily used for a low range of values. The filtered image is iterated for five iterations. This helps to extract particular affected area for a clearer view.

4.4.2 Enhancement techniques: In this technique, there are two types – dilation and erosion. Dilation is the process which increases the white content of the image by adding pixels to the boundary of the object. Erosion is used to increase the black content of the image by removing the pixels from the boundary of the object. The small particles in the dilated image are eroded in the erosion process.

4.4.3 Morphological function: A morphological method identifies the shape and features of a diseased area in a given image. The structuring element is placed in all possible positions in the image and it's compared with the corresponding neighbourhood of pixels.

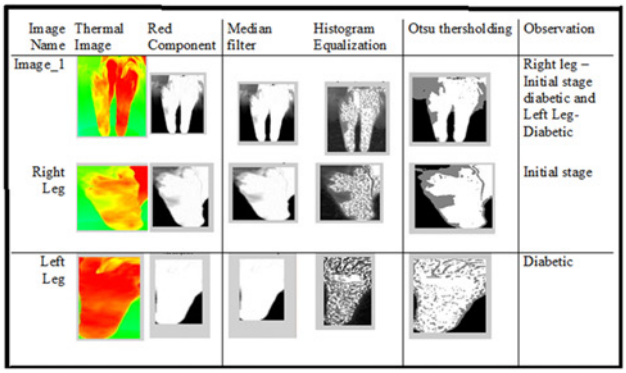
According to the output of the test, it identifies the image that fits or hits the neighbourhood pixels. Erosion strips one layer of both inner and outer boundaries. It avoids small details and enlarges holes and gaps between different regions. The boundaries are finalised by subtracting the eroded image from the original image. $x = f - (f(\Theta)s)$, where f is an image of the regions, s is a 3×3 structuring element, and x is an image of the region boundaries. Dilation adds one layer on both the inner and outer boundaries. It will fill in the gaps between two regions.

5 Result and discussion

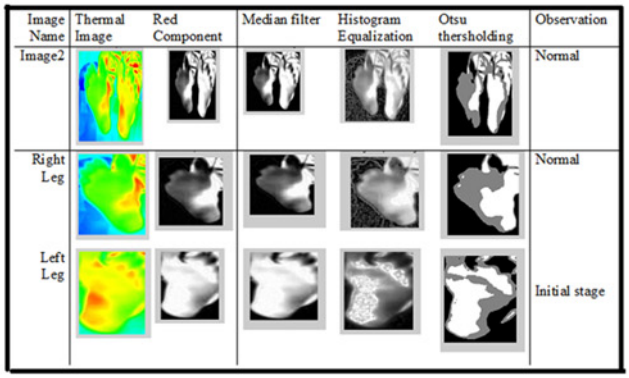
The analysis is done with four sets of foot images. Each foot image is taken separately and the results are observed using three methods and compared.

Table 1 Histogram of normal and abnormal feet are compared and shown the observations

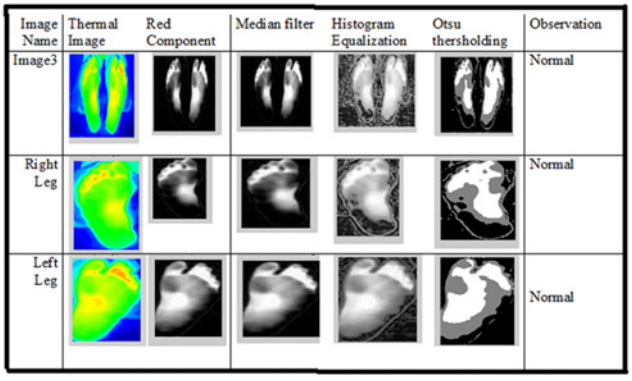
Sl no.	Image	Histogram value	Observation
1	right leg	small range of pixel values in 76	initial stage of infection
	left leg	more pixel values in 76 range	diabetic
	Image_1	considering both legs, the image shown as abnormal	abnormal
2	right leg	small projection in 76	partially diabetic
	left leg	no values in the range of 76	normal
	image 2	considering both legs, the right leg image shows initial stage of infection and left leg as normal	abnormal
3	right leg	no values in the range of 76	normal
	left leg	no values in the range of 76	
	image 3	no values in the range of 76	
4	right leg	small projection in 76	partially diabetic
	left leg	no of pixel in the range of 76 is less	normal
	image 3	considering both legs, the right leg image shows initial stage of infection and left leg as normal	abnormal



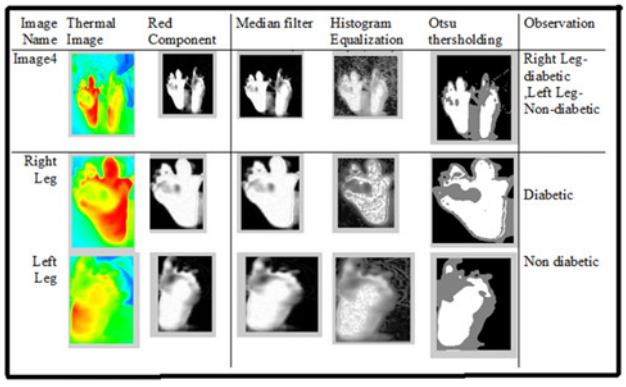
a



b

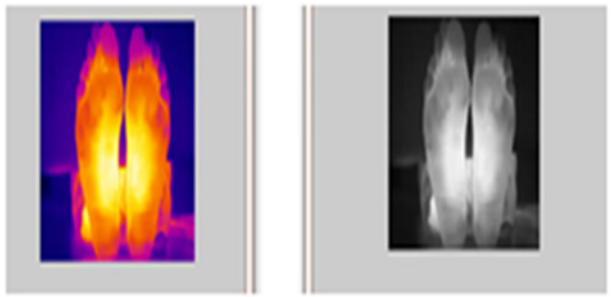


c



d

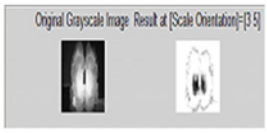
Fig. 4 *Thresholding method in*
a Image_1
b Image2
c Image3
d Image4



a b

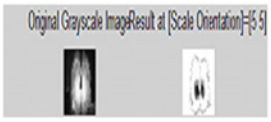
Iteration:1

Iteration:2



Iteration:3

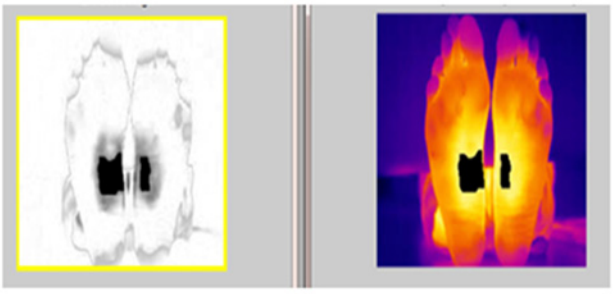
Iteration:4



Iteration:5

c

d



e

Fig. 5 *Morphological Process in*
a Original image
b RGB to grey conversion
c After five iterations of the grey image
d Dilation and erosion in the given image
e Infected area is extracted from the original image

5.1 Histogram method

The process is carried out in four images. In Fig. 3*a*, the output shows the beginning stages of the diabetic foot in the right leg because there is a light projection, as shown in the pixel value of 76. The left leg is seen to be highly diabetic as it shows a huge

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number of pixel values in the area of 76. In Fig. 3*b*, the output shows that both the right and left legs show no infection in the area of 76. So, it can be concluded that the person is non-diabetic. In Fig. 3*c*, the output shows that both the right and left legs show no infection with the pixel value in the area of 76. Hence it can be concluded that the person is non-diabetic. In Fig. 3*d*, the output shows the beginning of diabetes in the right leg because there is a light projection shown in the pixel value of 76. The left leg is seen to be non-diabetic as there is no projection in the histogram (Table 1).

5.2 Otsu thresholding method

The images used in the histogram method are repeated with Otsu thresholding also. So, the images can be analysed and the results are comparable. In Fig. 4*a*, the right leg shows more inflammation compared to the left leg. In Fig. 4*b*, the right leg is seen to be normal and the left leg shows a little inflammation. In Fig. 4*c*, both the right and left legs are normal. In Fig. 4*d*, the right leg shows more inflammation and the left leg is non-diabetic.

5.3 Morphological method

The thermal image (Fig. 5*a*) is converted into grey scale image, and the intensity of the image is noted (Fig. 5*b*). The grey image has undergone by five iterations and all the stages are shown in Fig. 5*c*. After iteration, the figure proceeds with the morphological process. For extracting the abnormal area, the iterated image analyse with the morphological process (dilation and erosion) (Fig. 5*d*). The abnormal part of the image is extracted and it is incorporated with the original image. This helps to identify the affected part without an expert's advice Fig. 5*e*.

6 Conclusion

Thermography can help to identify the stage of the disease by analysing the picture which helps to start early treatment and prevent further damage. Three methods are used for the analysis of the infected foot area. It was found that all three methods are useful. In so far as histogram method is concerned it helps in identifying a diseased foot. However, the other two methods help in extracting the region of interest by enhancing the infected area.

7 Acknowledgment

Images courtesy CGN Research Labs, Thirupathi, www.cgnresearchlabs.com [11].

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