Identification and Evaluation on Diabetic Foot Injury by Computer Vision

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Abstract— **The diabetic foot is one of the most devastating complications related to diabetic. Its significant transcendence is related to a higher incidence and amputation percentage as well as deaths. Given the fact that laboratory diagnoses trials are both limited and expensive, the most typical alternative is still based on the disease's signs and symptoms. Therefore, the attending physician fills out a questionnaire based on its support instrumental measurements and its own observation (it could be method but not so sure). The aforementioned questionnaire will provide the foundation for the diagnose that also depends on the criteria and the consultant's experience. However, for some variables such as the laceration (injury or wound) and –or-location the previous dependency is not acceptable.**

This paper aims to become the first link to optimize the diabetic's foot evaluation through the introduction of digital image processing techniques.

Because of the use of advanced object segmentation techniques and a parameter that adjusts the system's sensibility until obtaining the desired results it was possible to apply an algorithm to a series of trial images provided positive results for wound and location detection.

Keywords— Digital image processing; diabetic foot; image segmentation; software detection

I. INTRODUCTION (*HEADING 1*)

During the last couple of years, diabetes (Diabetes Mellitus) has taken the leading position amongst human chronicle diseases with a wide array of complications as well as an impressive ability of deterioration and destruction [1]. The diabetic foot is one of the most frequent and devastating complications [2]. According to the World Health Organization (WHO) the diabetic foot syndrome is defined by the presence of ulcers, infections, and/ or gangrene associated to the diabetic neuropathy, and different levels of peripheral vascular disease, as a result of the complex interaction of several maintained hyperglycemic (excessive amount of sugar) induced factors.

Nowadays, diabetic's foot complications are common and they represent a very serious health problem in Mexico because of its frequency as well as its expensive treatment and difficulties in handling.

It has been described that between 13-25% of the diabetics have developed diabetic's foot [2]. It is relevant because of the high percentage of amputations. Furthermore, 40 to 50% diabetics develop foot ulcers through life; amongst those we consider that in 20% of the cases it is the cause of a limb's amputation [2] [3] [4]. Following an amputation we have a 13-40% mortality rate during the first year, increasing to 65% after 3 years, and between 39-80% at 5 years[5].

Currently a typical evaluation of diabetic's foot is based on the disease's signs and symptoms. Generally, the specialist performs a valuation of the neuropathic and ischemic symptoms by monofilament Semmens-Weinstein y el Doppler, respectively. As for the rest of the variables, the physician evaluates according to its observation. Based on those results the physician fills a questionnaire and emits a diagnosis. [6][7][8] Because of that most of the diagnosis relays on the criteria en physicians' expertise, providing an incorrect assessment considering variables such as the area and location of the lesions.[9]

Relevant studies in the artificial intelligence have progressed within the last couple of years, allowing the development of artificial vision systems that have benefited several medical sectors. Although there have been developments for support instruments to evaluate the diabetic foot, little has been done to reduce the error on the evaluator's criteria, and the obtained data management. [10][11] The introduction of digital image processing for detection and evaluation of ulcers and wounds aims to become the first link to optimize the results of the diabetic's foot. [12][13]

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II. Materials And Methods

A. Artificial Vision

Artificial vision, also known as computerized vision, is a subfield of artificial intelligence that is defined as an integral focused attempt of the algorithm development that will allow a machine to simulate, to some extent, the biological vision process.

Digital image processing (DIP) is an artificial vision subfield that is related to the manipulation of digital images with the objective to identify and give interpretation to relevant information within them. New technologies development for image acquiring as well as computer processing tools has created for this knowledge branch an interesting and a constantly developed field. [14]

A critical decision made at the time of selecting the appropriate algorithm is the one about the technology that will be used. There are multiple tools and languages for the digital image processing. Some examples are OpenCV and MatLAB. [15]

On the other hand, MatLab's use has become increasingly popular to the extent that it is the most important for programing and a fast development for scientific application, including image processing.

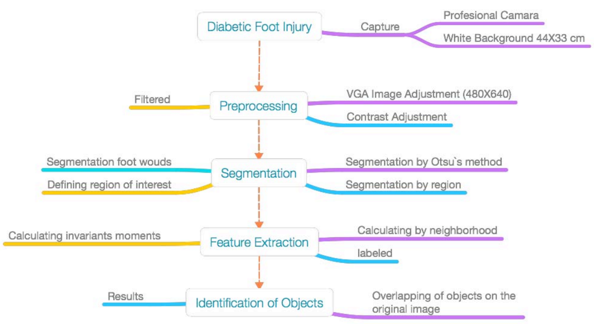

Fig. 1. Diabetic foot injury algorithm

B. Image Capture Protocol

The images used for this paper were taken at the Centro Integral en Diabetes, located at the city centre of Zacatecas.

For the trials and the algorithm design, fifteen photographs were taken to a patient's foot from 6 different. For some angles, the photographs were taken more than once using the camera's flash and without it. [16]

Photograph background: as shown in figure 1, a white acrylic o polycarbonate plate was used, 48 x 37 cm measures, with a 2 cm distance from each corner. In addition to, there is a removable part of the plate that permits the central location of the foot when the sole is to be photographed

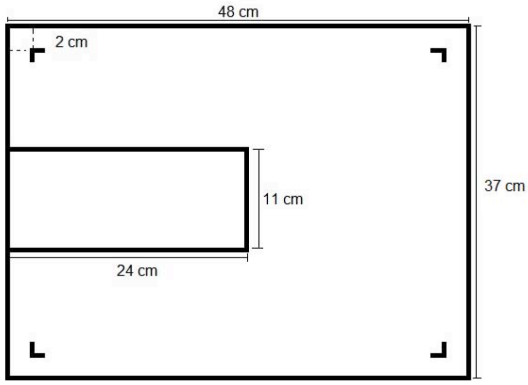

Fig. 2. Background structure

Camera: a professional 16 megapixels digital Canon was used. However, it is enough to use a medium or superior range camera. Ambience lighting: the photographs were taken indoors using artificial light produced by common 2 fluorescent lamps. This lamps provide a wide lighted surface which creates a homogenous lighting with little object reflection.

Foot placement: the patient's foot is located on the plate in a position that maintains the interest area within the drawn marks. To take the sole's photograph, the removable part is taken out then it is superimposed to fill in the empty space.

Camera's positioning: the camera is horizontally placed within a distance that allows de lens to locate the 4 corner marks but it most not exceed the perimeter limits. It is recommended to use a tripod to prevent movement whilst taking the photograph. [17]

Image capture: before shooting, the image format is changed to a 4:3 to 4:3 and the flash is deactivated because its light may cause unwanted lighting. Having done that, a picture from 6 different zones is taken: front, back, left side, right side, superior, and sole. It is convenient to take the photograph from these 6 zones even though there is no damage, this is if and electronic file should be made.

C. Pre-processing

This first stage is divided into three main processes: re-dimension, space color conversion, filter, and region of interest delimitation. Before any manipulation is made it is important to remember that: the capture protocol does not standardize the camera resolution so the images dimensions might vary. The conversion of space color and filter processes might take longer depending on the photograph's size. First, considering the previous information, the image is resized to 640 x 480 pixels (figure 2a). This is the right size because it maintains the necessary information to obtain the desired characteristics.[17]

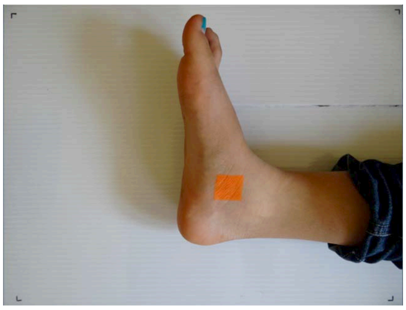

Fig. 3. Simulate lesion to determinated correspondences pixel-cm^2

The second step of the process corresponds to the RGB - HSV space conversion. Out of this transformation there are three components left H, S, and V, out of which the S (saturation) component is taken, as explained in the previous chapter, that corresponds to the color purity (figure 2b). Because of this characteristic it is possible to perform a segmentation of the wounds that, as a consequence of the blood and air in the tissue, are pure red.

From the previous step a gray scale image is obtained, and it shows from the least saturated zones to the most ones. However, it is more useful an image that shows more saturated areas because that shows the wounds, that justifies investing in the image as shown in figure 2c. [15] [17]

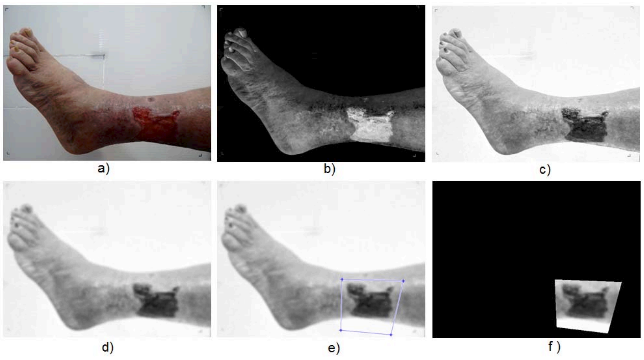

Fig. 4. a) Original image resized, b) S components (Saturation in the HSV model), c) investment b), d) smoothing filter on c), e) polygon selection of regions of interest f) interest areas defined on a black background.

It is important to filter the image to reduce drastic intensity changes in the wounds. Therefore, a softening filter is applied in a series of consecutive occasions (figure 2d). It was determined that the most convenient number of repetitions is 13.

The resulting image in this part of the process shows that the darker areas on the purest color zones are not only red but green, blue, magenta, cyan, and yellow. Although most of the colors do not appear on the original captions, yellow might appear in certain foot zones, even more if the skin color is lighter. A possible solution to this problem is the manual delimitation of the areas of interest using a selection polygon.

As a result, the image obtained is a photograph were the lesions are seen as dark spots surrounded by lighter areas that are enclosed by a completely black background. The image is ready to be segmented. [18]

D. Segmentation

As a result, the image obtained is photographs were the lesions are seen as dark spots surrounded by lighter areas that are enclosed by a completely black background. The image is ready to be segmented. [19] [22]

Fig. 5. Result of the detection and evaluation of lesions after adjusting the sensitivity of the algorithm. a) Original image, b) result of the detection and evaluation of lesions using default parameters c) result of the detection and evaluation of lesions after adjusting the sensitivity of the algorithm

E. Post-Processing and Character extraction

Using both the internal and external markers found, the gradient image from the first step is modified through minimal exposure so that there are only regional minimum where the interest objects are located. (figure 2d). Finally, the Watershed transform is calculated (figure 2e) and it is superimposed on the image where the regions of interest were delimitated (figure 2f).

Afterwards the image is binarize with a 254 threshold, so that the corresponding wound's pixels are kept white whilst the remaining pixels are black. (figure 3)

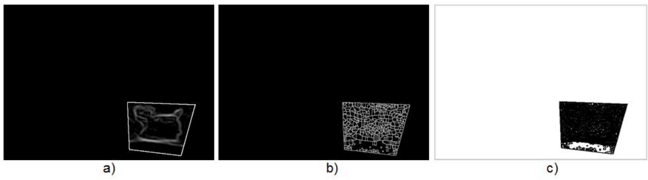

Fig. 6. a) Image of gradient, b) Result of applying the regional minimum Watershed transformation on a), and c) a)

At this point and in some cases, there might appear some unwanted objects in the form of isolated pixels or spots due to a poor delimitation of the interest regions (figure 4b). Consequently a contraction operation is applied to reduce unwanted objects to dots without affecting the wound's contour. Then, a cleaning process is used to eliminate the image's isolated white pixels. The result is shown in figure 4c. The last step of this stage is to fill in the found wounds. This process allows to observe the segmented wounds as white objects over a black background which will facilitate the characteristics extraction stage (figure 4d). [20] [21]

At this stage the object labeling and property calculus is performed.
The labeling allows differentiating the objects amongst each other. Having done this, it is possible to easily obtain a wide array of properties related to each one of them, for example: perimeter, area, eccentricity, solidity, and orientation, amongst many others. For this paper, they are particularly important three characteristics: contour, area, and centroid.
While the object's contour and centroid are graphically shown, the area is obtained from the pixel's number that comprises it. However, the pixels number as such is not a representative measure for the physician. For this reason, it is performed a conversion from pixels units to square centimeters. This is obtained by multiplyingthe pixels number by 0.0047. The result is obtained by calculating the relation between the pixels number from the image (640 x 480 = 307200 pixeles) and the background area (44 x 33=1452 cm^2). [22] [23]

III. RESULTS AND DISCUTIONS

Besides its functionality, the system has to be as neat and esthetic as possible. Within this context, and by taking advantage of the MatLAB's GUI environment, the graphic interface is developed to improve the user's experience, and to present the results in a neat and elegant format.

The interface originally shows just one button to load the image to be processed. After loading it, and on the bottom part a text box will appear for the numbers of regions of interests to be typed in. An image will be temporarily displayed where the regions will be delimitated with the mouse pointer. In the end, the figure will automatically close and the algorithm will continue until the results are shown. [22]

The results will be presented in an image similar to the original but with the centroids and the contours drawn in it (figure 5). The image will be shown in a new figure to verify and check the process or save it.

In the event that the wounds' detection was not correct the side bar will display to allow the algorithm's sensitivity adjustment (figure5). It is important to clarify that the sensitivity actually corresponds to the height threshold used for the segmentation stage.

From the algorithm applied to the trial images it is observed that, in all the cases, the detection of lesions was successful with acceptable quality because of the adjustment parameter that allows the sensitivity variation until the desired result is obtained. In some of the cases the detected contour might differ from the lesions' limits as a consequence of the softening performed on the filtering stage. Figure 6 shows the results for a trial image.

The lesions area depends on the lesions' detection, meaning that the higher the detection quality is the lower the error. Besides, it has to be mentioned that an error in the image is present since the background is further away from the camera than the wounds are, and the reference measures belong to that background. However, it is possible to disregard this error given the fact that all the images present it.

IV. CONCLUSIONS

The lesions automatic detection is not an easy task. There is still not a single method able to recognize the lesions with the same efficiency that the human vision does. This paper aims, within its limits, to achieve the detection in the best way possible. To accomplish the research it was necessary the use of several advanced techniques for digital image processing, including a wide bibliographical research of the used techniques. [22][23]

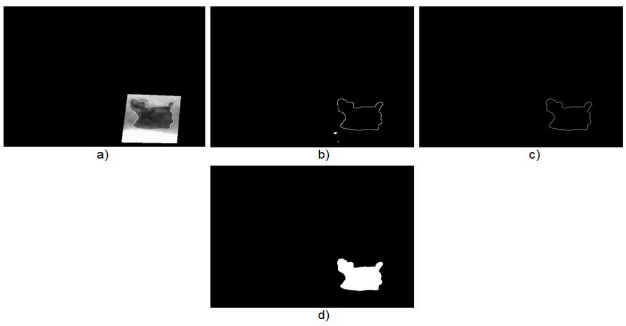

Fig. 7. a) Growth of the bottom, b) binarizing a) with a threshold of 254, c) removal of unwanted objects, d) filling the desired objects.

This papers contribution is an evaluation system of the diabetic's foot that can be a useful tool for the physician with the following advantages: it allows the automatic detection of ulcers and wounds on the patient's foot. It is capable of calculating the area and location (according to the centroid) of the ulcers and wounds as well as other geometrical characteristics if that is required. The variables are no longer depending on the evaluation's results. It is a non-invasive method and it allows an easy handling of the obtained results.

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