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Remote Diagnosis of the Footprint Using a Portable-Podoscope System

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Abstract: In the literatures, some podoscope systems have been introduced to analyze the plantar footprint. However, there is an absence of a low complexity portable system with control capacity and trace ability of users and their results through a web application. Therefore, the objective of this study is to develop of a portable system that allows the automation of the process; reducing the errors of human character and the times of accomplishment. The development methodology of the research is a cascade type that begins as an initial phase in analyzing of the requirements and restrictions of the system. Then the physical and circuit design of the platform are carried out. Once the first two stages of the methodology are complete, the algorithms of the portable system based on Android studio and the web application are developed under the Laravel framework. Finally, the performance of the proposed system and the analysis of the results will be presented. In this study, the footprint of 35 users and a total of 70 samples will be analyzed. The results show 74% accuracy compared to the manual method.

INTRODUCTION

In humans, all body weight support is made up of several bones, along with joints, ligaments and muscles [1]. The three main points of the foot, known as the tripod of the foot which are support this weight: the anterior transverse arch, the lateral longitudinal arch and the medial longitudinal arch.

In this structure, medial longitudinal arch supports more weight. While the longitudinal are has a duty to m aintain balance. Morphological changes occur in the medial longitudinal arch due to muscle weakness or excessive ligament stretching. The high arches cause damage to the foot bone and ankle injuries[2].

In the literature, many podoscope systems have been introduced to quantify the plantar foot[1-6]. In Cucek *et al*. [7], the methods of assessing the footprint are presented in four categories. These four categories are environmental footprints, social footprints, economic footprints and economic footprint. Currently, the environmental footprints are the main tools for assessing the footprint. However, among the tools used to evaluate footprints, the photo-podoscope is one of the simplest tools to facilitate visualization of footprints.

The photo-podoscope is a system that evaluates the footprint using a computer[8]. In Moreno and Gvitierrez an inexpensive remote podoscope system is presented. In this system, result data sent by internet to have a remote diagnosis from an expert. In Laowattanatham *et al*.[9], a digital podoscope is presented. The scanned foot image is color-mapped by a software to calculate the foot index. In[8], an automatic podoscope system to calculate the footprint arc index is presented. This system uses a camera with the help of a mirror to obtain the image of the plantar footprint. In this experiment, the average accuracy for the index values of automatic computation arc in the footprint image is 93.99% and the precision for the classification of the type of footprint arc is 84.40% compared to the manual calculation of the footprint expert. The structure of this podoscope is reported by Crisan *et al*.[10]. This type of podoscope is a low-cost computer-assisted optical system with synchronized dual illumination that reduces the environmental effects and improves scanning resolution, in addition to providing a greater number of viewing options. In Laowattanatham *et al*.[9], almost a similar system is proposed. This podoscope has a construction based on the modification of an optical scanner. In[11-14] to improve an accuracy of foot classification use neural network process. In this process, it is using a combination of multiple indicators. The process part of this to enhance the accuracy of images, the proper lighting of the screen is an important issue in the photo-podoscope. There are different techniques in this case. For example, in Buchelly *et al*.[15] by applying a lighting system, the quality of the footprint morphology has been improved. After capturing the image, there are image-processing steps including the use of filters, segmentation, contrast adjustment, edge detection and more. The final image will vary depending on the system designer and the image quality. Most of these processes are based on statistical techniques such as using Poisson distribution to perform an image segmentation[15, 16]. Using these techniques improves the accuracy of the results analysis.

On the other hand, the Hernandez-Corvo Index is one of the most used methods to evaluate the footprint. In Nirenberg *et al*.[17] the researchers makes the estimation using three methods and compares the results. These technicians are: a manual technique that uses a ruler (direct technique) an Adobe Photoshop technique and a GIMP (GNU image manipulation program) technique. This estimate is made using a group of 50 young people. In this study, the estimation error for the Hernandez Corvo index is 0.997 compared to the manual evaluation. The analysis of the pressure of the contact area of the foot and the morphological characteristics using the Medilogic method are presented by Lidstone *et al*.[11]. The adaptation thresholds of 0.1% of the Maximum Sum of Digital Values (MSDV) produced average errors of 7.31±17.44%. While in Buchelly *et al*.[15] the percentage of the average error of the Hernandez-Corvo index is 9.43%. Due to the proper performance of this method, this study will evaluate the footprint by the estimation of Hernandez-Corvo index.

In addition, some studies have added plantar pressure measurement to this system. This pressure can be estimated or measured using various methods including force-sensing resistors[18], microcapsules[19], optical podoscopes[20], hydro cells, critical light deflection[10], capacitive transducers[21] and image processing based method[15].

Typically, this examination is made in person and the results need to be reviewed by a specialist. In some cases where the presence of a computer or a specialist is not possible, a system with the ability to send data through the network or to the data center is required. On the other hand, test results may vary because of physical activity, shoe type, or history of illness. Therefore, it is important to record the patient's footprint history in order to study it at the time of examination. Digital podoscopes are a great tool to facilitate the process of footprint analysis. Since the process of capturing images in this system is paperless, the patient's foot history can be stored for many years.

This podoscope must have a robust and portable structure with independent power source according to the working conditions. When reviewing the literature, the absence of such systems is observed. Therefore, this study provides a podoscope utilizing a new web and Android system to save footprint plantar history where the image processing method is used through a data transfer and storage system to evaluate and identify alterations.

MATERIALS AND METHODS

Footprint assessment: In this study, the evaluation of the footprint is performed using the Hernandez Corvo arc index method. This method requires parameters that are estimated from measurements based on the footprint images. The footprint is divided to three areas: the rear foot part, the midfoot part and the forefoot part[10].

To calculate this indicator, points A and C are considered the outermost part of the footprint (as shown in Fig. 1). Then a line is drawn between these points. In addition, two points are specified, the upper and lower H

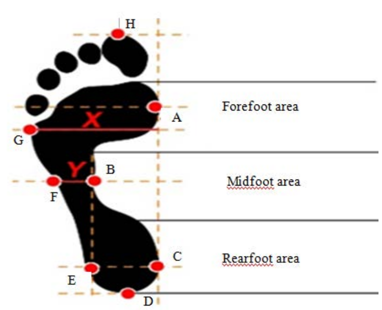

Fig. 1: The footprint is divided into three areas: the rear part, the midfoot part and the forefoot part

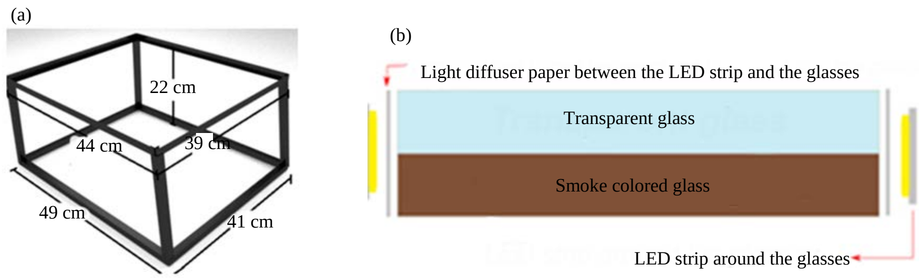

Fig. 2(a-b): a) The dimensions of the podoscope and b) The structure of the glasses of the podoscope

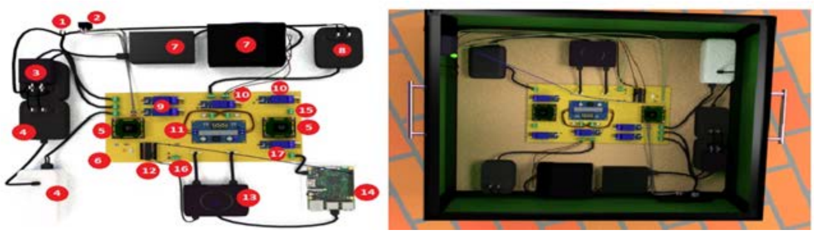

Fig. 3: Arrangement of the different modules of the system

and D. Similarly, points B, E and F. are obtained. The outermost point in the plantar footprint is G and the distance between this point and the AC line, it is the distance X. The distance Y is between points B and F. Then, the Hernandez-Corvo index can be estimated as Eq. 1:

$$IC(\%) = \frac{X-Y}{X}$$

Measurement equipment: In this study, a portable podoscope connected to a mobile application will be presented. The mobile application allows the acquisition of the footprint image and the estimation of the Hernández Corvo index through image processing techniques. As shown in Fig. 2a, the podoscope have dimensions of 22 cm high, 39 cm wide and 44 cm long. The capture surface of the podoscope platform must have the capacity to support a maximum weight of approximately 100 kg. For this reason, tempered glasses should be chosen.

The layout of the glass consists of two layers. The transparent glass allows the light of the LED strips to be distributed throughout its surface to determine the surface of the footprint. As a second level, there is a dark glass, which enables filtering of external lighting sources. The dark glass can be determined in different transmission percentages depending on the amount of external light desired to be restricted. In this study, it is used a grey glass with a transmission percent of 14%.

For lighting purposes it is necessary to adapt white LED lights around the glass since locating the light source at another point does not provide an optimal image for processing. As shown in Fig. 2b, the top surface of the podoscope is composed of a transparent colored glass and a dark glass, the dark-colored glass allows the filtering of external lighting sources and the transparent glass allows the light of some strips LEDs are distributed over the entire surface and there is a reflection in the areas pressed by the plantar footprint. The low cost substrate is used to analyze the plantar footprint with a lighting module similar to that described by Maestre-Rendon *et al*.[22]. In this lighting module, it is used a 12 V_{DC}, 6400 k, 50 cm, 75 LED with 14-16 lumens/LED illumination system. According to Fig. 3, the following modules are used in the Podoscope system:

- AC connection
- Switch connection
- 5 V to 3A adapter
- 5 V battery with 5 V to 3 A adapter
- Artificial vision cameras
- Printed circuit
- 6 V battery with 8 V to 9 A adapter
- 12 V to 3 A adapter
- Internal battery change relay to adapters
- Relays on lights and boost activation
- Boost elevator 6-12 V
- Atmega 328 and its proper polarization
- HUB USB
- Banana Pi
- LED strip connector
- Power switch connector
- Magnetization relay of Banana Pi

Image processing and index estimation: After completing the requirements analysis and system design stages, the different modules will be integrated and the system will be implemented in general. As can be seen in

Fig. 3, the different integrations of each module within the system are detailed together with their respective processes. The image appropriation and analyzing are developed using OpenCV[23]. The user interface and storage of patient data and records are provided using the Android studio, HTML5, PHP and MySQL Softwares. Using the procedure presented in Fig. 4, the plantar footprint index of each patient are estimated.

The podoscope uses a camera that is characterized by a resolution of 5 MP. The picture size captures by this camera is 600×800 pixels. It has a Banana P_i M3 processing module which is characterized by having an ARM Cortex-A7, Octa-core and 1.8 GHz CPU, Mali400 MP2 GPU and 5V-2A power. The Banana P_i M3 aims to capture the images of the plantar footprint, create a Wi-Fi network to send the image through a client-server socket to the mobile application and control the lighting module. In addition, in the offline cases, the platform power demand is provided by using a 5 V, 10000 mAh internal battery. Due to the use of the Aptina MI5100 CMOS camera, a distance of 22 cm is selected to maintain The image processing stages are described in the following steps.

Segmentation of plantar footprint: One of the most important disadvantages of the OTSU algorithm is that their performance is poor when lighting is not uniform. To solve this problem, two images are taken simultaneously with the platform lighting off and on. Subtracting these images an elimination of the external lighting sources obtains as shown in Fig. 5a-c.

When the original image turns to gray scale, the Otsu segmentation algorithm[24] is used to have a clear image of the plantar footprint. Figure 5 d shows the result after applying the Otsu function. In this study, the image is converted to a binary image using a threshold action. As shown in this figure, there are some noises in this image that can affect the results. For this purpose, a process of contour detection and shape selection similar to Medina *et al*.[25] is used. This process is done using the openCV software, so the output is an array of contours that display each of the shapes in Fig. 5d. In the following, shapes with area >2000 pixels^2 are selected. Eventually, this figure shows the plantar shape. In addition, any shape with an area of >200 pixels^2 placed in the upper part of the plantar shape can be considered as candidates for the rest of the toes.

The result of this filtering and segmentation method is shown in Fig. 5e. The process of the elimination of external lighting sources is carried out within the platform. This platform executes on Banana Pi-M3 running OpenCv 3.4.2 under Java language. Once the

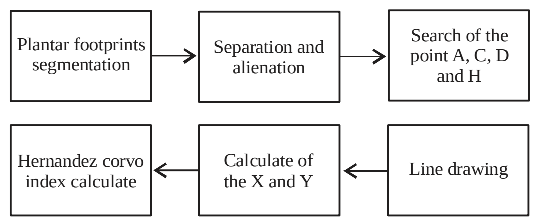

Fig. 4: General flow chart of image processing

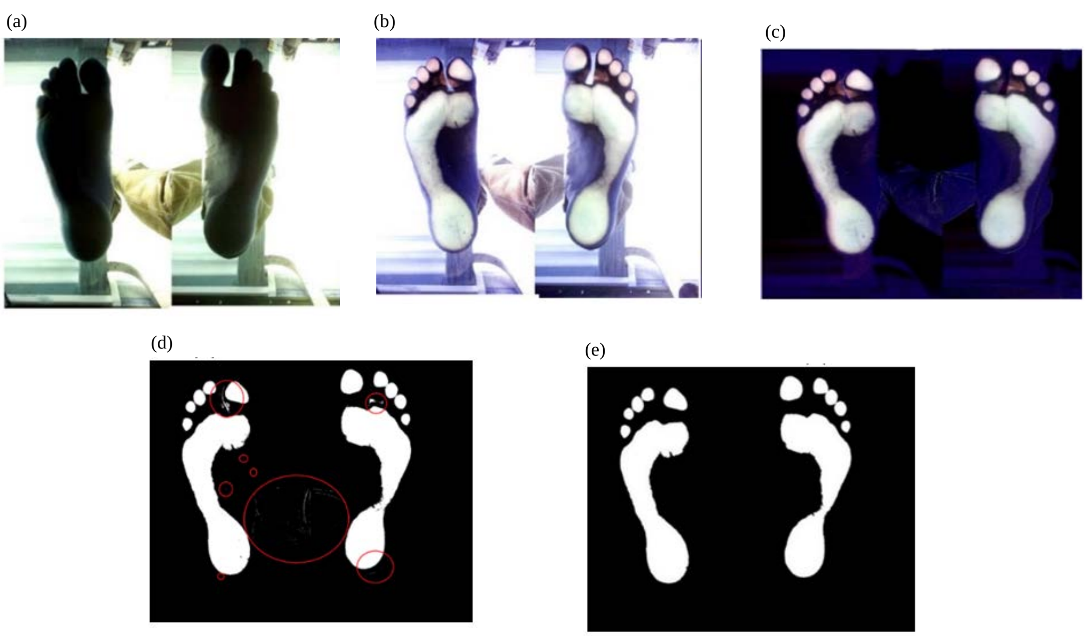

Fig. 5(a-e): Elimination of external lighting; a) Picture with the platform lighting off; b) Picture with the platform lighting on; c) Subtract of the images; d) Image with using Otsu and e) The final result of the filtering and segmentation

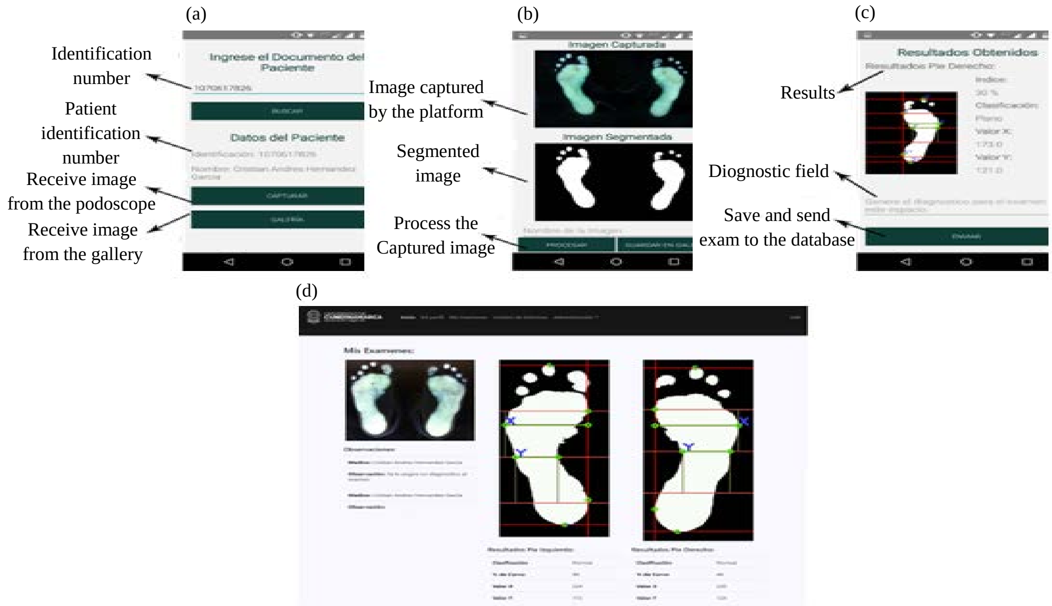

Fig. 6(a-d): Graphic interface of the mobile application; a) Receiving data; b) Exam display screen; c) Display screen of the results and d) Exam and results page in the web page

previous process has been carried out, the image is sent to the mobile device by means of Wi-Fi communication and TCP-IP protocol through a client-server communication.

Hernandez-Corvo index estimation: Once the segmentation processes are completed, the separation and alignment of the plantar tracks in matrices of different pixels are proceeded. To achieve this objective, the frame is divided into two parts, taking the average number of the total number of columns. For alignment of the plantar footprints, points A and C described in the Hernandez Corvo method are considered. Once the process of alignment of the plantar footprint is completed, the upper and lower points of the plantar footprint points are located. To find each point, the pixel matrix is rechecked and the pixels of each position are compared. By connecting the obtained points, the x and y intervals are obtained. Finally, using Eq. 1, the Fernandez Corvo index is obtained.

Graphic interface and management of patient record Mobile application: The graphical interface is coded and designed in Android studio software. This application can record and display data in online and offline modes. The software receives plantar footprint images by connecting the mobile device to the podoscope using Bluetooth, Internet network or via. images on the mobile device. Moreover as shown in Fig. 6a, the application can display patient information using the search field.

After performing the patient search and receiving the footprint image, the image is processed and its corresponding segmentation will be displayed as shown in Fig. 6b. Finally, once the image analysis and analyzing process has been executed, the results corresponding to each plantar footprint are displayed on the results screen as shown in Fig. 6c.

Web application: The web application is composed of four types of users who have different access to the information. The system is developed to allow traceability of the captured exams of each patient. For the development of this application, the Laravel framework tool and a MySQL database developed in MySQL Workbench are used.

For the design of the front-end of the application, the Bootstrap tool is used which is an open source tool for the design of websites with different types of templates for the creation of buttons, forms, navigation menus, etc., based on HTML and CSS. This application consists of register page user administration screen, statistical report page, diagnostics generation page and historical exams page as shown in Fig. 6d.

RESULTS AND DISCUSSION

The podoscope system presented in this study is shown in Fig. 7. The structure has a weight of about the dimensions of 22 cm high, 39 cm wide and 44 cm long. It has a transparent colored and a dark glass with a

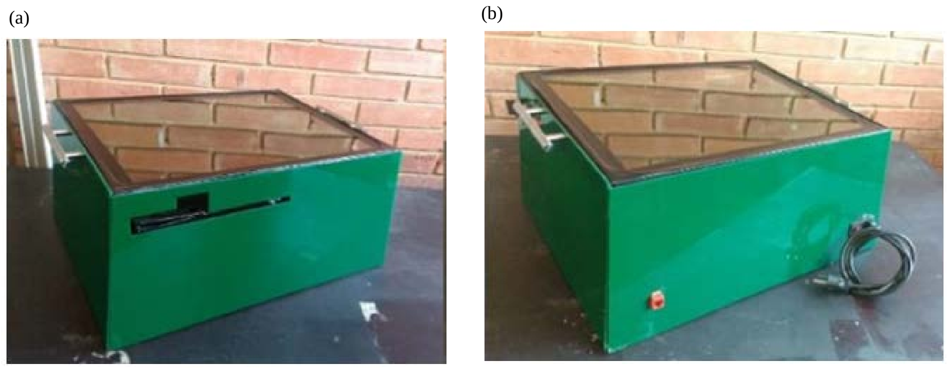

Fig. 7: The proposed podoscope system

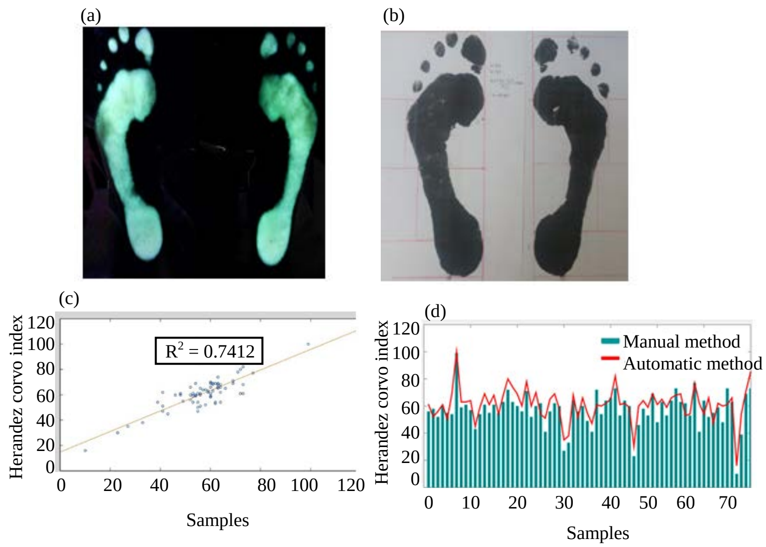

Fig. 8(a-d): Results; a) The image obtained with the podoscope; b) The image using the manual method; c) Dispersion diagram and d) Hernandez Corvo index for the manual and automatic methods

transmission percent of 14% in the top surface which can support the weight of approximately 100 kg. The person should stand on the platform with both legs. The patient should not move during the test. There are two cameras for grabbing the images. The top glass surface is illuminated in all of its sides using a LED strip. A typical image obtained with the podoscope is shown in Fig. 8a. On the other hand, a similar sample is taken by the manual method with applying vinyl paint in the area composed of the plantar footprint as shown in Fig. 8b.

For the validation of the device implemented together with the developed software, samples were taken with a total of 35 individuals and 70 fingerprints mainly belonging to students of the electronic engineering program of the University of Cundinamarca.

To see the accuracy of the proposed device, dispersion diagram is created as shown in Fig. 8c. The dispersion diagram has a coefficient of determination “R^2” of 0.7412. This coefficient is defined as the proportion of the total variance of the variable by the regression and shows the accuracy of the results obtained from the proposed podoscope with respect to the results obtained manually. Figure 8d shows the Hernandez Corvo index for the manual and automatic methods. It can be seen from the that the results obtained from the proposed podoscope are close to those obtained from manual method.

The limitation of the Hernandez Corvo method is that the segmentation technique used in this method is based on the estimation of thresholds. Therefore, this technique does not provide good accuracy. On the other hand, this estimation method can fail in people who are in the class strong-cavus and extreme-cavus of footprints. In this condition, the footprint will consist of two separated parts of the hint-foot area and forefoot area and it is not possible to detect the distance Y in the mid-foot region. In

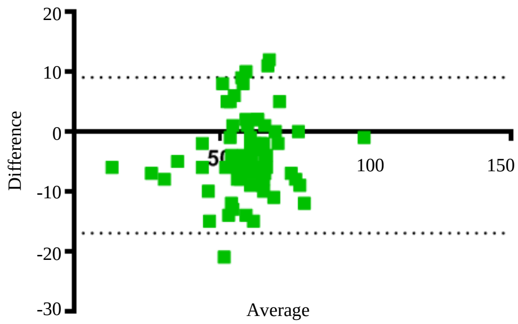

Fig. 9: Validation results using the Blant altman test

order to solve this problem, a kind of robust segmentation with applying deformable contours according to level-sets[26] being embedded into the software platform.

The Bland-Altman test[13] identifies any systematic differences between two measurement methods. The results of this test are shown in Fig. 9 for measurement of the Hernandez Corvo index using the proposed podoscope and manual method. As shown in this figure, 95% of the results are within the confidence interval (-16.96-9.079) indicating that the results obtained from the proposed podoscope are closed to the results obtained from the manual method. The obtained results of the Hernandez-Corvo index estimation can be compared with respect to accuracy. In[17], it is presented an optical podoscope and the Hernandez-Corvo index had obtained by using X and Y distances. This study considered 11 persons (smaller than the group reported in this study) and the minimum error achieved is 9.43%. This error is higher than the error obtained by this study. In Medina *et al*.[26], it is mentioned that the obtained error is lower than 10% showing the utility of the instrument for footprint classification. In[11, 12, 14, 15, 25], the patient results are not stored. Therefore, availability of specialist physician is mandatory. In some applications, it is important to record the patient's footprint history in order to evaluate of results. The proposed podoscope system is a great tool to facilitate the footprint analysis process.

In Medina *et al*.[25] in order to suppressing the external illumination it is used a black fabric for covering the platform that increases the time spent and humans. However, in this system by using a dark glass the external illumination is removed. This method reduces human errors and facilitates the process. These results show that the system works very well to identify the type of foot, perform the required scientific analysis automatically, transfer information to the Android or web system and store and display the evolution of physical therapy.

CONCLUSION

In this study, a portable podoscope system was presented. Moreover, in order to make this device portable, a proposed system was developed to save or send data using the Internet network. In this regard in the proposed system using android software, it was possible to analyze and evaluate the footprint using image processing methods. This feature was available on the web system to enhance system performance as well. The proposed podoscope allowed the estimate of the Hernandez-Corvo index under any light conditions. The results of the experiments showed that the results of the proposed podoscope had acceptable accuracy and it reduced the time needed to capture a plantar footprint, analyze the results and archive data.

The proposed system enables the instrument for evaluation of a large group of people, especially, in places where physicians cannot attend. In the treatment of athletes or young people it is important to record the patient's footprint history in order to study it at the time of examination where the proposed system can be useful. In practice, it was observed that with the proposed system a trained person could perform plantar footprint image acquisition and in another place, a physician studies patient data by the proposed software platform.

Among the alternatives to improve the proposed system, reducing the size and weight of the podoscope system by changing the type of camera and power supply. However, the solution proposed is economical, easy to transport and implement. Other options to improve process efficiency include reducing the size of the scanner to make it easier to move through a web or lighting system.

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