STANDUP database of plantar foot thermal and RGB images

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Abstract

In this paper, we provide details of a research database consisting of 415 multispectral images (a thermal image and an RGB image) of plantar foot images for healthy (125 images) and diabetic subjects (290 images). Healthy persons with no diabetes are members of two research laboratories (IRF-SIC in Morocco and Prisme in France). The second group is composed of type II diabetic patients who participated in an acquisition campaign at the Hospital Nacional Dos de Mayo in Lima, Peru. The objective of this paper is to describe the dataset for external researchers who might be interested in using it. We describe the recruitment and acquisition protocols as well as the equipment used to help other units to create similar databases. Our database has been created in the context of the STANDUP Horizon 2020 #777661 project, in which eight scientific research entities and European high-tech companies are partners.

Keywords
Diabetic foot, thermal imaging, medical database, research data, mobile health.

Introduction

Diabetes is one of the most common diseases in the world, which is correlated with a high mortality index. Uncontrolled diabetes can affect several organs, namely: feet, eyes, heart, kidneys, nervous system, and blood vessels [1][2]. In the Horizon 2020 STANDUP Project, our studies are dedicated to the problem of diabetic foot (DF), which could be infection, ulceration, or destruction of deep tissues of the foot [3]. The severity of DF can lead to hospitalization and even to lower limb amputation, which generates substantial costs and loss of life quality. In the majority of cases, a proper risk assessment of diabetic patients associated with diabetic foot care can significantly prevent the development of diabetic foot disorders. Currently, risk assessment for DF is based solely on neuropathy and vascular analysis. However, according to diabetes experts, further improvements are needed.

In the literature, several studies have proven that the use of temperature could be of great relevance in the early diagnosis of DF problems [4] [5]. Foot temperature varies from patient to patient and is dependent on surrounding temperature and activity level. Usually, the temperature difference between contralateral areas of the left and right feet does not exceed 1°C. A temperature difference greater than 2.2 °C is considered abnormal and is called hyperthermia [6]. Due to neuropathic sensory loss, diabetic patients rarely feel pain and injury in the feet, especially in the early stages of the disease. Therefore, temperature elevation can be a very useful indicator of foot ulceration risk. It has been demonstrated that a strategy including information on hyperthermia reduces foot ulceration by 70% [5][7].

For a healthy person, according to [8] the temperature distribution in a thermogram of a foot sole is a bilateral butterfly pattern. Whereas in diabetic patients, this temperature varies and there is no typical pattern as in normal people. The cold stress test [9] is another effective method for estimating thermoregulatory problems. The temperature difference before and after a cold stress is important in the early detection of diabetic neuropathy problems [10].

In the European horizon 2020 framework, the main objective of the STANDUP #777661 project is to propose promising solutions and technologies that could help doctors and specialists to improve the DF diagnosis, to detect hyperthermia at an early stage, and to develop better DF ulcer treatments using thermal information. STANDUP is a collaboration between clinicians, researchers, and industry partners. The first task in STANDUP was to create a database of thermal and color images of the foot sole for healthy people and diabetic patients. Thermal and color images are taken using the STANDUP protocol, that is freehandedly with a smartphone connected to a dedicated thermal camera that can take a thermal and RGB images at the same time. To our knowledge, this database is the first multispectral database containing thermal and color images of diabetic patients' plantar feet.

Materials and methods

Choice of the thermal camera

Camera resolution: The largest foot that we consider is 30 cm long. So, the vertical field of view we chose is 40 cm: 30 cm to include the foot sole plus a 5 cm margin at the top and bottom of the foot. In the other direction, 40 cm is enough to contain both feet in their width (about 10 cm), including the same 10 cm margin for each foot. The field of view is then 40×40 cm² (see figure 1).

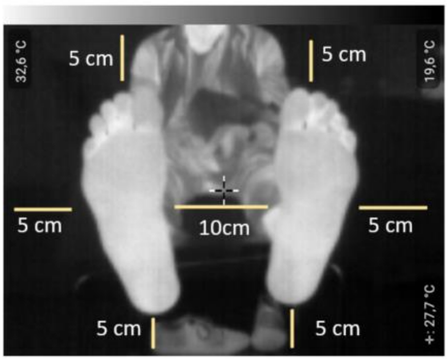

Figure 1: margins to be respected during the acquisition of thermal images of plantar foot

Hyperthermia occurs one week before the ulcer. The smallest hyperthermia area is approximately a circle of one cm in diameter. According to Shannon's first theorem and the values used in image processing, two pixels are required to see the smallest risk area. This means that every camera larger than 80×80 pixels can be chosen.

Camera sensitivity: Hyperthermia corresponds to a temperature variation higher than 2.2°C. The differential accuracy must therefore be better than 0.2°C (about 10% of the value to be evaluated).

Spectral range: For a healthy person, the mean skin temperature under normal conditions is about 32°C. Wien's law shows that the infrared radiation wavelength is around 9.5 µm. Therefore, the spectral range of the chosen camera must contain this wavelength.

For this study, we chose the FLIR ONE Pro camera (figure 2). It is composed of two sensors. A thermal sensor that measures heat through infrared emission, characterized by a thermal image resolution of 160x120 pixels. The spectral range of the thermal sensor is 8-14 µm. FLIR ONE Pro can detect temperature differences of 0.1°C. The other camera is a conventional 1440x1080 pixels RGB camera, designed to work in parallel with the thermal core. FLIR ONE Pro is designed to be plugged into a smartphone (figure 2.b).

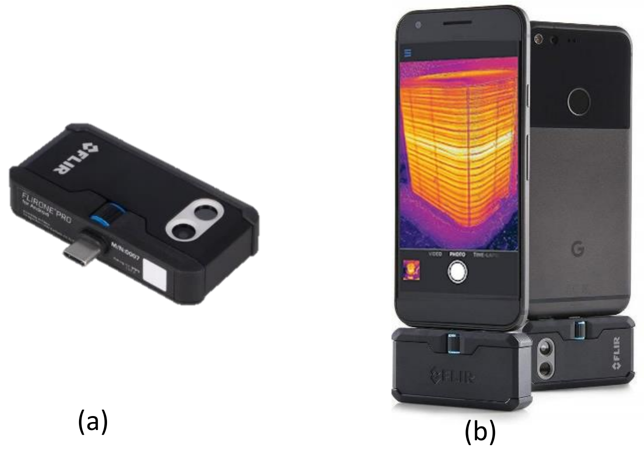

Figure 2: acquisition system: (a) FLIR ONE Pro camera (b) FLIR ONE Pro camera plugged into a smartphone

The FLIR ONE Pro camera software includes an alignment control technology called Multi-Spectral Dynamic Imaging (MSX) [11], allowing it to provide spatially registered RGB and thermal images. MSX increases the clarity of acquired images by integrating edge and contour detail of visible light into thermal readings in real-time. This technology does not dilute the thermal image or reduce its transparency. A thermal image and RGB image of the plantar foot surface are captured simultaneously and at the same location as shown in Figure 3.

(a) *(b)*

Figure 3: An acquisition example: (a) the thermal image and (b) the corresponding RGB image

Recruitment and acquisition protocols

1- Healthy subjects

The first acquisition campaign was conducted at the PRISME laboratory of the University of Orleans in January 2017. The participants were students of Polytech Orléans in internship at PRISME, Ph.D. students, and PRISME staff. A total of 22 people participated in this first acquisition campaign. This group was composed of 10 women and 12 men with an average age of 25 years. It corresponds to a total of 22 multispectral images.

From December 2018 to March 2019, we organized a second acquisition campaign at the Ibn Zohr University in Agadir, Morocco. 17 students and members of the IRF-SIC laboratory participated. In addition, a cold stress test acquisition campaign detailed in section 2 (figure 6) was carried out for 43 people at two different times. This gives a total of 60 people, of which 25 were women and 35 were men with an average age of 30 years. It corresponds to a total of 103 multispectral images.

The total number of healthy multispectral images (thermal and RGB) is of 125.

Recruitment Protocol of healthy subjects

The criteria for recruitment were as follow: any non-diabetic and volunteer adult without diabetes and without foot problems.

Acquisition Protocol of healthy subjects

To ensure a high image quality, the room conditions must be adapted to thermal image acquisition. We conducted the acquisition campaigns in rooms large enough to place the equipment and provide freedom of movement for the technician and volunteers. The lighting was controlled during the acquisitions. Windows were partially covered or shielded to prevent outside infrared radiation from entering the room. The temperature was controlled at 20° ± 1°C. The protocol is as follows:

- Remove shoes and socks and the acquisition will take place ten minutes later.
- The person read and sign the consent agreement form.
- Complete the data sheet with the person's information.
- The person lies down on a medical bed or sits in a chair, feet at the end, vertical, and 10 cm apart.

- Make an acquisition at a sufficient distance from both feet to meet the margins shown in Figure 1.

Typical multispectral images (thermal + RGB) are shown in figure 4 at PRISME, and figure 5 at IRF-SIC.

Figure 4: example acquired in PRISME

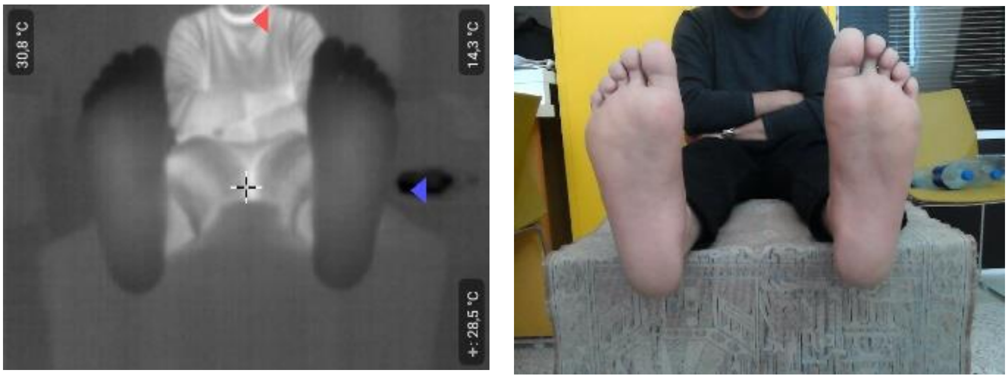

Figure 5: example acquired in IRF-SIC

2-Diabetic subjects

Diabetic subject's database was acquired at the Hospital Nacional Dos de Mayo (HNDM) of Lima in Peru from January 14, 2019, to March 9, 2019. The approval of this study by the ethics committee of the HNDM occurred on January 10, 2019. 145 diabetic patients participated in this acquisition campaign. The campaign is performed under the supervision of nurses and medical doctors. The thermal stress test was applied. Each subjects had a pair of multispectral images (thermal + RGB). It corresponds to a total of 290 pair images for diabetic subjects. 91 women and 54 men with an average age of 63 years.

Recruitment Protocol of diabetic subjects

The subjects in HNDM, are diabetic patients who have a regular examination in the diabetic department. We have excluded from this campaign patient with ulcers, partial or total amputations.

Acquisition Protocol of diabetic subjects

The objective of the campaign in Peru was to perform, in addition to a thermal study, a cold stress test. This test consists in immersing the patient's feet in cold water at 15°C for 1 minute [9] [12]. The campaign was performed in a north-oriented room with small windows and controlled luminosity. The average temperature in the room was 20°c with a variation of less than 1°C. The acquisition protocol is as follows:

- Remove shoes and socks and the first acquisition will take place ten minutes later.
- The person read and sign the consent agreement form (figure 6.a).
- Complete the data sheet with the person's information.
- The person lies down on a medical bed and places his or her feet on the end of the medical bed, in an upright position and 10 cm apart. The distance between the camera and the feet is chosen so that the feet are completely visible in the image, as in Figure 1. The first acquisition (thermal image and color image) at time T0 is performed (figure 6.b).
- The patient is asked to sit on a chair. Each foot is inserted into a plastic bag. The feet are then immersed in cold water at 15°C for 1 minute (figure 6.c).
- The patient lifts his feet, the plastic bags are removed and a waiting time of 10 min is observed before a second thermal and color acquisition corresponding to the time T10 is made (figure 6.d).

(a) Sign the consent agreement form (the two persons on the left side)

(b) First acquisition at time T0

(c) Immerse both feet one minute in water at 15°C

(d) Second acquisition T10 10 min latter

Figure 6: Cold Stress test protocol

Images at time T0 and T10 are shown in figure 7.

(a) Time T0

(b) Time T10

Figure 7: Example of a diabetic patient without ulcer or amputation (Dos De Mayo Hospital) (thermal and RGB) acquisition at T0 (a) and second (thermal and RGB) acquisition at T10 (b). We can see that feet are colder at time T10 than time T0

Data availability

Due to the sensitive nature of this data, images are currently only available internally to some partners of the STANDUP #777661 project. It's also worth mentioning that the database will be publicly available on https://www.standupproject.eu/home/fr once the research project is completed in June 30, 2023.

Ethics approval can be obtained through a formal request to the STANDUP horizon 2020 #777661 project coordinator for a specific research project. The project website (https://www.standupproject.eu/home/fr) contains the coordinator's contact; however, interested parties are advised to contact the corresponding author (doha.bouallal@uiz.ac.ma) for further information.

Informed consent and patient details

The authors declare that this article does not contain any personal information that could lead to the identification of the patient(s). The authors declare that they obtained a written informed consent from the patients and volunteers included in the article. The authors also confirm that the personal details of the patients and volunteers have been removed.

Author contributions

D.Bouallal, A. Bougrine, R.Harba, L.Vilcahuaman and R.Canals jointly acquired the images. Dr. Hugo Harbanil and his medical team handled the clinical analysis and controls carried out for patients before image acquisition. D. Bouallal, A. Bougrine, R. Harba, R.Canals H. Douzi, and L. Vilcahuaman provided extensive knowledge of the data collection procedures and systems. D.Bouallal and A. Bougrine designed the research dataset and supervised its preservation. All authors contributed to the writing of the manuscript and approved the final version.

Conflict of interest

No potential conflict of interest was reported by the authors.

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Scientific papers that used this database

- "A joint snake and atlas-based segmentation of plantar foot thermal images" **DOI:** 10.1109/IPTA.2017.8310081
- "A comparison of active contour prior shape segmentation methods: application to diabetic plantar foot thermal images " https://csitcp.net/abstract/9/94csit04
- "On the segmentation of plantar foot thermal images with Deep Learning " **DOI:** 10.23919/EUSIPCO.2019.8902691
- "Segmentation of plantar foot thermal images: application to diabetic foot diagnosis" **DOI:** 10.1109/IWSSIP48289.2020.9145167

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