Sensors & Transducers
Published by IFSA Publishing, S. L., 2018
http://www.sensorsportal.com

Monitoring the Microclimate in the Shoe-foot Interface

[1] José de Jesús SANDOVAL-PALOMARES,
[1] Javier YÁÑEZ-MENDIOLA, [2] Alfonso GÓMEZ-ESPINOSA
and [1] José Martin LÓPEZ-VELA
[1] CIATEC A. C, Omega 201, Industrial Delta, 37545 León, Gto., México
[2] Tecnologico de Monterrey, Campus Querétaro, Epigmenio González
#500, Fracc. San Pablo 76130, Querétaro, Qro., México
Tel.: + 52 4777100011
E-mail: jsando@ciatec.mx

Received: 31 July 2018 /Accepted: 28 September 2018 /Published: 28 February 2018

Abstract: A new continuous monitoring portable system device is presented here, it allows to reduce the complications that arise from diabetic foot ulcer, because of temperature and humidity disorders. This device monitors the microclimate of the shoe and consists of one array of 10 sensors to obtain the temperature and humidity data between the foot and the insole interface of the shoe. It has also a software interface for viewing and analyzing the data. Temperature monitoring of the participants showed an average range of 23.90 °C to 29.34 °C and 51.57 % to 69.78 % relative humidity.

Keywords: Temperature, Humidity, Microclimate, Ulcer, Diabetic foot.

1. Introduction

People with diabetes have a high risk of developing diabetic foot and with it, blood irrigation disorders, high risk of suffering dryness in the foot, which favours the appearance of ulcers and in serious cases the amputation of lower limbs. There are certainly techniques where temperature changes are analyzed like infrared thermography, which is a visual technique that uses thermal cameras. One study [1]. Found a close relationship between the temperature of the foot plant and the ulcers present in diabetics, so they defined a classified pattern of the thermal footprint. Another study [2] of the plantar area of the foot, found a relationship of temperature and sudomotor anomalies, since these affect the foot autonomous regulator system, which severely reduces of the sweating required and generate diabetic foot disorder located on the plantar surface of the foot showered in dry skin. Another study [3] recommend a regular monitoring of foot temperature. They used a commercially device known as TempTouch, which an infrared sensor point, to conduct a study looking for early warning signs of diabetic foot danger, finding that people who underwent traditional foot care control, were more prone to severe injury, 7 of whom had ulcers, while in a clinical care group using this monitoring device only 1 ulcer injury occurred. Is common that dry skin occurs over certain temperature and humidity conditions, adding disorders in diabetic foot [2, 4]. It is accepted in the literature that it is important to have a quantitative way to measure temperature and humidity conditions. The development of solutions for sensor applications is an important area in healthcare monitoring [5].

In this paper, we propose the measurement of the temperature and humidity magnitudes in a microclimate environment, associated with the foot and shoe interface that is a closed environment, where the foot is inside the shoe. It allows experimental tests to be carried out to obtain a model of microclimate behavior, as well as, to identify the increase or decrease in temperature, initially in a controlled environment, but potentially in real-life environments.

A continuous-monitoring portable-system device is presented here to help preventing the complications that arise from diabetic foot [6-7]. The device consists in one array of 10 sensors to obtain the temperature and humidity data of the microclimate between the foot and the insole of the shoe. A software interface was developed to show graphically data from the microclimate. In order to perform an analysis of the data's behavior, a 2D plot approximation of the data was created following an exponential curve [8-9].

2. System

The acquisition of temperature and humidity data is carried out in the microclimate between the plantar surface of the foot and the insole of the shoe, with a system consisting of three modules. The first one Data Acquisition Module (MAD), is a portable module that allows us to take direct data of temperature and humidity using 10 sensors. A second module, Interface Module (MIN) who interconnects MAD module and a personal computer (PC) and the third module Data Analysis Module (MAN) a software user interface, that allows acquisition of the data and displaying text and graphics of the temperature and humidity results.

Fig. 1 shows a block diagram how details their relevant elements and how these modules are integrated into the system, to acquire, process and analyze temperature and relative humidity data.

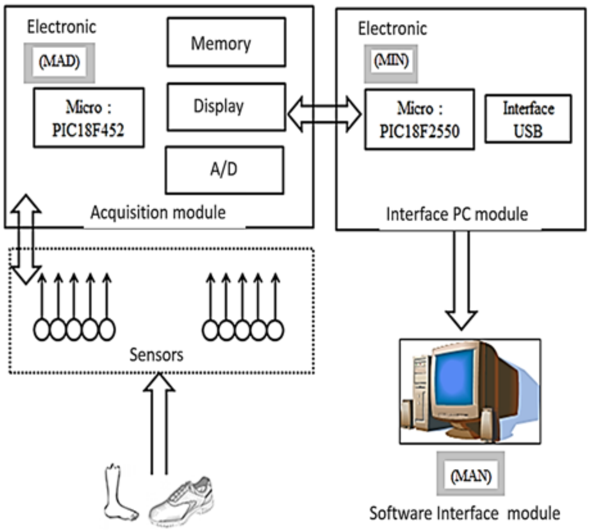

Fig. 1. Block diagram of the system for temperature and relative humidity measurement, showing the Data Acquisition Module (MAD), the Interface Module (MIN) and the Data Analysis Module (MAN).

2.1. Hardware Architecture

The MAD architecture consists of 10 SHT15 sensors (Sensirion, Switzerland) with reading ranges of 100 % RH ± 2 % for relative humidity and -40 to 123.8 ± 0.3 °C for temperature. For the connection and communication we used a microprocessor PIC18F452 (Microchip, USA), an AT24C256 memory (Atmel, USA), and a 9 V battery. The sensors were separated into two flexible segments with five sensors each one. They were connected to a screen for viewing the temperature and humidity data during capture.

2.2. Data Acquisition Module Architecture

Fig. 2 shows the sequence diagram of component activity for temperature and humidity data collection. At the top and separated in columns the components are shown, the sequence in time is represented by the horizontal lines of each row, which contain numbered circles (1 to 7), which defines which component is activated.

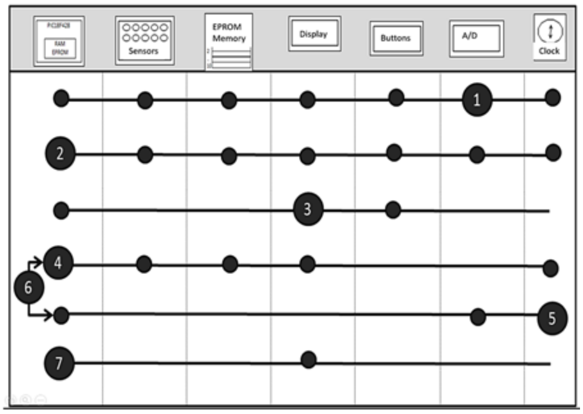

Fig. 2. Sequence diagram of component and activities for temperature and humidity data collection.

Next, the activity sequence diagram of Data Acquisition Module is explained:

1. Each of the components are energized; microcontroller, sensors, memory, screen, keyboard and clock, and are ready for to be recognized by the PIC18F428 micro.
2. Start routines are executed in PIC18F428, mainly recognizing each component (which depends on which pin has its connection), in addition to making readings to the memory to initialize some parameters and recognize the status of the previous readings.
3. The microprocessor shows the menu of options on the display and is waiting for instructions from the user who uses the buttons to navigate between the different menu options.

4. Once the data reading option has been selected, the microcontroller takes control and executes routines to be sending and receiving data to each one of the sensors, a data recording structure is generated in such is the way that the readings of the 10 sensors in a register, which is stored in the EPROM memory, the reading counter is incremented and the operation is displayed on the display.
5. The time by the user between readings is programmed using the buttons, and defines how the clock sends the instruction so the microprocessor for the next reading by sensors of temperature and humidity.
6. It is the cycle that presents the intervals of readings that will be executed until the programmed time ends and it is when the microcontroller stops making requests to take readings.
7. The user is informed by the display of the number of readings executed.

2.3. Interface Module Architecture

Fig. 3 shows the sequence diagram of component activity for send the temperature and humidity data collection to the personal computer (PC).

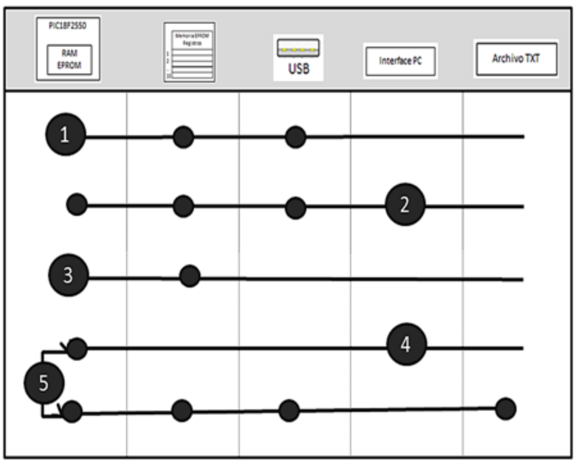

Fig. 3. Sequence diagram of component activities for sending data to the txt file in the PC.

Next, the activity sequence diagram of Interface Module is explained:

1. The MAD and MIN module is connected through its external interfaces using a flexible cable, the MIN connects to the PC via USB and, the PIC18F255 microcontroller starts the component recognition routines and if there is no problem a green light LED is illuminated in the MIN module, indicating that it is ready for data transfer.
2. The user executes the computer program interface for the data readings and through the USB interface, requests the data registers from the microcontroller.
3. The microcontroller initializes the data readings, taking from the EPROM each of the readings registers and sending them one by one to the computation interface.
4. The program interface creates a data file and writes the one data record,
5. Defines a cycle that reads the remaining records and requests their writing in the created file in point 4.

2.4. User Interface

In MAN module, the obtained temperature and humidity data is stored in a database in MySQL, then the user interface can be used to select readings and plot data in a graphical form in both 2D and 3D. It allows comparison of data between different sensors and readings intervals and some basic statistics calculus can be developed.

The MAN is composed of 3 main Subinterfaces, Fig. 4 shows a block diagram of how the components are integrated in their logical sequence, an identification of components was made under a simple nomenclature (MAN-01 to MAN-04).

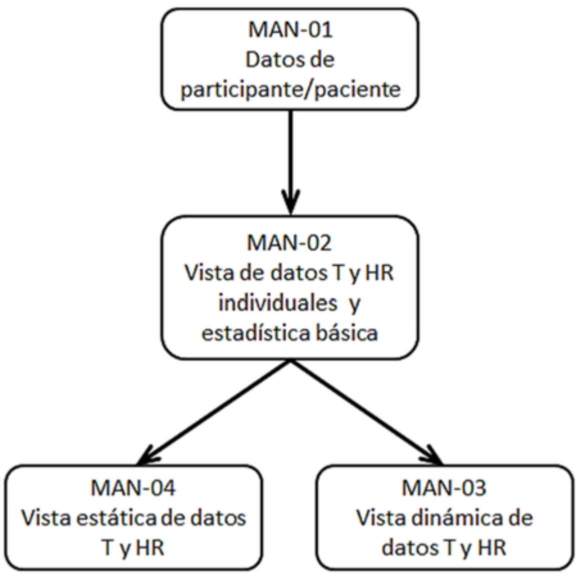

Fig. 4. Diagram of blocks of computational interfaces of the data analysis module (MAN).

2.5. Data Readings

The sole of the foot was divided according to the way in which plantar length is considered, this division is proposed [10], where the foot is divided into 3 areas known as forefoot, midfoot and hindfoot, this division it is shown in Fig. 5.

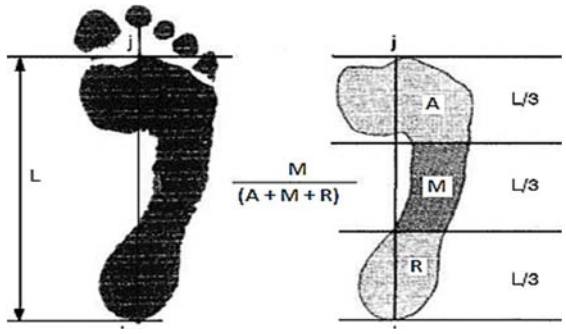

Fig. 5. Division of the footprint: forefoot (A), midfoot (M) and hindfoot (R).

In a 1 cm insole was made five circular holes considering the division shows in Fig. 5: forefoot (A), midfoot (M) and hindfoot (R), followed by the placement of a sensor in each hole; the holes create an air channel of the microclimate zone between the plantar-insole surface and the sensor Fig. 6, this allowed the sensor to read the temperature and humidity data without problems, Fig. 7 shows the insole with the placement of the sensors. The five sensors were placed on the insoles of both the left and right footwear. In a controlled area with 23 °C and 50 % relative humidity, the insoles are placed inside the diabetic footwear for acclimatization phase, Fig. 8. The MAD module is switched on and programmed with reading intervals of 1 min and a time of 60 min for data collection. In our scenario, we took data from adult male participants and who declared to be without diseases or pathologies on their feet, Fig. 9. For the first 5 minutes, the data was obtained from the footwear and configurations insole, followed by the remaining 55 minutes where the participants had their feet in the footwear. After 60 min, the reading cycle is complete and the system is switched off. This test cycle was repeated five times for each individual. After each cycle, the data was downloaded by connecting the MAD-MIN-PC and using the software interface.

In Fig. 9 the placement of the reading module, the footwear with the insole placed in one of the participants is observed and the portability and independence of the system for data collection is shown.

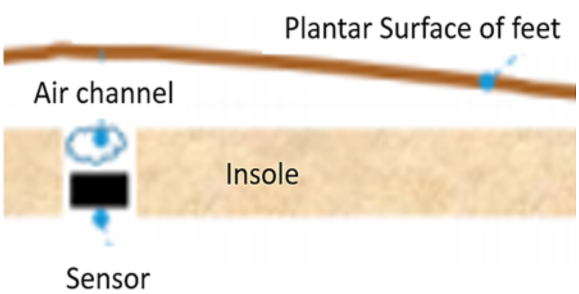

Fig. 6. Microclimate between the feet plantar-footwear insole surface and the sensor.

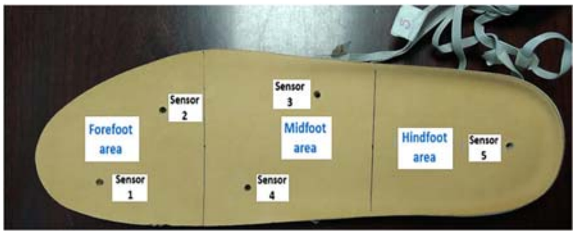

Fig. 7. Image of placement of sensors in the footwear insole used, considering the division of the foot, forefoot, midfoot and hindfoot.

Fig. 8. Diabetic footwear used in reading tests.

Fig. 9. The placement of the reading module in one of the participants.

3. Results

3.1. Monitoring Portable-system

Fig. 10 shows the continuous-monitoring portable-system, MAD module, with the interface connected to the 10 sensors placed on the insole, the display to show temperature and humidity data, the MIN module with the interface to MAD and UBS to PC.

Fig. 11 shows the menu where the user can interact with the MAD, in order to perform various tasks, such as the start and end of readings, interval programming, it also shows a series of messages giving information on parameters of temperature and humidity readings.

To shows the corresponding experimental readings temperature graphs and the time behavior exponential graph, the Fig. 12 present the user software interface of the module MAN, with the temperature and humidity 2D graphs of 10 sensors, and modules for selection of sensor to show, the number of reading, time range and statistical results.

Fig. 10. Prototype of portable system for monitoring the microclimate in the interface of foot, shoes and insole with sensors.

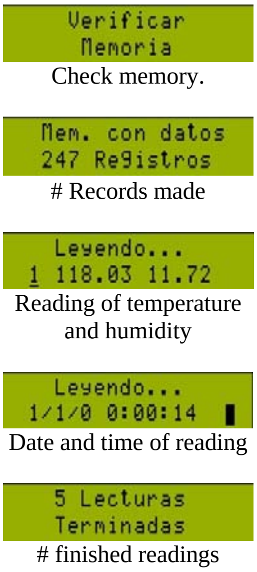

Fig. 11. Display that shows a series of messages giving information on parameters of temperature and humidity readings.

The Fig. 13, show some graphs of experimental measurements of temperature, and curve behavior of an exponential polynomial.

Other interfaces of the MAN module allow to visualize in numerical format all the readings made or range of these in basic statistics such as the average, minimum and maximum reading of the humidity and temperature data of the selected results. Fig. 14, also has the interface to store general information of the participants; name, age, gender, weight, height, measurement of the foot, some particular character of his feet Fig. 15.

3.2. Test

Temperature monitoring of the participants showed an average range of 23.90°C to 29.34°C, in relation to relative humidity the results were 51.57 to 69.78 RH. There were no technical problems during the 3000 temperature and humidity data readings.

4. Conclusions

We provided a portable and autonomous microclimate monitoring system for temperature and humidity readings placed into the shoes. Up to eight continuous hours of readings at one minute intervals, technically without problem.

Our results have indicated that the system for monitoring microclimates in the shoe-foot interface is a useful tool for medical applications, which may help to decrease or prevent the onset of diabetic ulcers and other diabetic foot complications.

For the future work, we are planning to perform studies using several types of footwear, as well as working with specific population groups that require specialized footwear, such as factory workers and patients with diabetes.

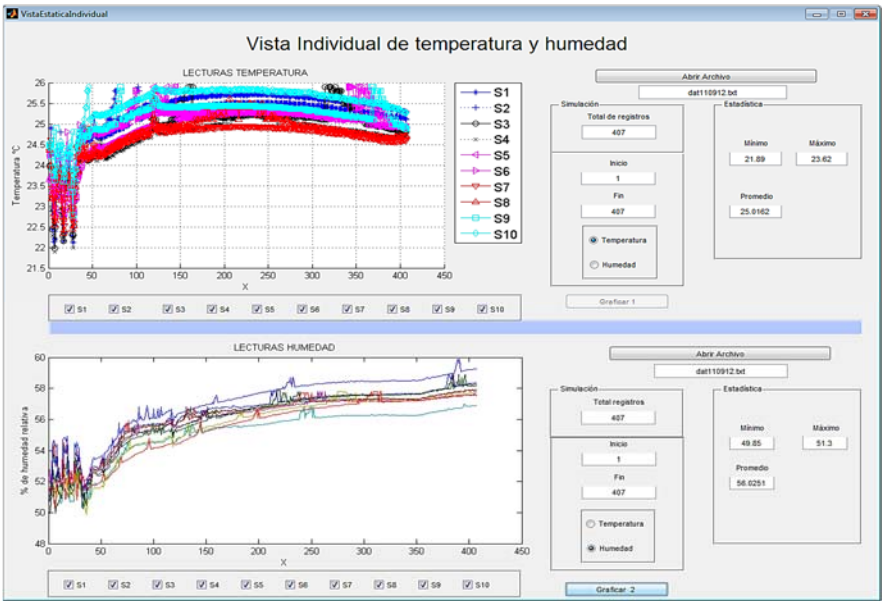

Fig. 12. Software interface to select the data range of each sensor and show its 2D graph.

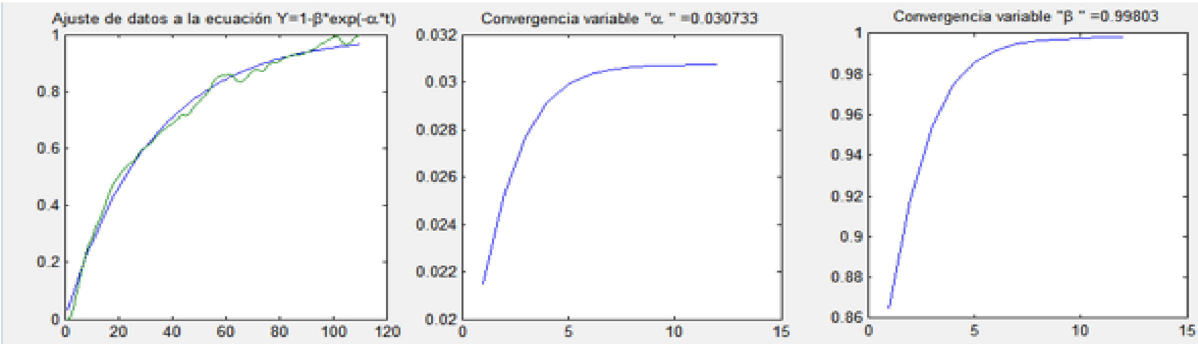

Fig. 13. Graph of experimental measurements of temperature, and curve behavior of an exponential polynomial.

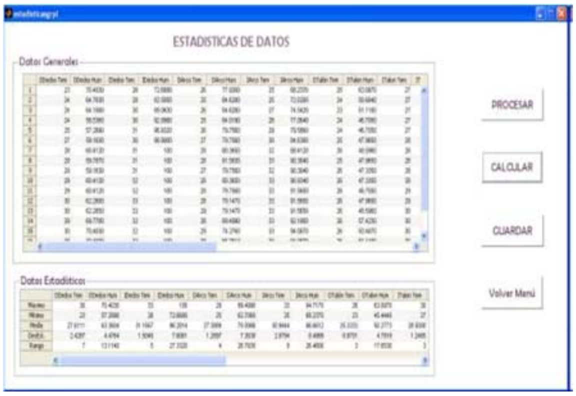

Fig. 14. Interface that show readings made or range of these in basic statistics such as the average, minimum and maximum reading of the humidity and temperature data of the selected results.

Fig. 15. Software interface general information of the participants; name, age, gender, weight, height, measurement of the foot, some particular character of his feet.

References

[1]. Takashi Nagase, Hiromi Sanada, Kimie Takehara, Makoto Oeb, Shinji Iizaka, Yumiko Ohashi, Miho Oba, Takashi Kadowaki, Gojiro Nakagami, Variations of plantar thermographic patterns in normal controls and non-ulcer diabetic patients: Novel classification using angiosome concept, *Journal of Plastic, Reconstructive & Aesthetic Surgery*, Vol. 64, Issue 7, 2010, pp. 860-866.

[2]. Pi-Chang Sun, Hong-Da Lin, Shyh-Hua Eric Jao, Yan-Chiou Ku, Rai-Chi Chan, Cheng-Kung Cheng, Relationship of skin temperature to sympathetic dysfunction in diabetic at-risk feet, Diabetes Research and Clinical Practice, Vol. 73, Issue 1, 2006, pp. 41–46.

[3]. Lawrence A. Lavery, Kevin R. Higgins, Dan R. Lanctot, George P. Constantinides, Ruben G. Amorano, David G. Armstrong, Kyriacos A. Athanasiou, C. Mauli Agrawal, Home Monitoring of Foot Skin Temperatures to Prevent Ulceration, *Diabetes Care*, Vol. 27, Issue 11, 2004, pp. 2642-2647.

[4]. Aye M., Masson E. A., Dermatological Care of the Diabetic Foot, *American J. Clinic. Derma*, Vol. 3, Issue 7, 2002, pp. 463-474.

[5]. Razak A. H. A., Zayegh A., Begg R. K., Wahab Y., Foot Plantar Pressure Measurement System: A Review, *Sensors*, Vol. 12, Issue 7, 2012, pp. 9884-9912.

[6]. Sandoval-Palomares J. J., Yáñez-Mendiola J., Gómez-Espinosa A., López-Vela J. M., Portable System for Monitoring the Microclimate in the Footwear-Foot Interface, *Sensors*, Vol. 16, Issue 7, 2016, 1059.

[7]. Sandoval-Palomares J. J., Yáñez-Mendiola J., Gómez-Espinosa A., López-Vela J. M., Portable System for Monitoring the Microclimate in the Footwear-Foot Interface, in *Proceedings of the 1st International Conference on Microelectronic Devices and Technologies (MicDAT'18)*, 2018.

[8]. Foresee F. D., Hagan M. T., Gauss-Newton approximation to Bayesian learning, in *Proceedings of the IEEE International Conference on Neural Networks*, Vol. 1-4, 1997, pp. 1930-1935.

[9]. Nocedal J., Wright S. J., Numerical Optimization, 2nd Edition, *Springer*, Berlin, 2006, pp. 259-262.

[10]. Cavanagh P. R., Morag E., Boulton A. J. M., Young M. J., Deffner K. T., Pammer Se, The relation of static foot structure to dynamic foot function, *J Biomech*, Vol. 30, Issue 3, 1997, pp. 243-250.