Smart Chair for Mitigation of Skin Pressure Ulcers

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Abstract—Pressure Ulcers are still a great health problem, even in developed countries, that usually appear in impaired individuals as result of long periods of immobilization. It is estimated that the European prevalence rates range from 8.3 % to 22.9 % in hospitalized patients and is estimated that this kind of wounds represent 2 % of the European budget for primary health care. To mitigate this problem, a working device was built in order to assess the microclimate created between a sited individual and where he is sited on. To that end, the device was composed by pressure, temperature and humidity sensors, controlled by a microprocessor that made all the data management, sending it wirelessly to a platform on the Internet that stores all the information acquired, having also a user interface that shows up the data.

Keywords-Pressure; Ulcer; Sensors; Ischial; Smart Seat.

I. INTRODUCTION

Pressure Ulcers (PU) are injuries located at the top layer of the skin, and/or at its underlying tissues, as consequence of an ischemic process and tissue necrosis. They are normally chronic wounds frequently related to long periods on hospitals where most of their time patients happen to be on a laying position, compressing the soft tissues between a bony prominence and the external surface of the body.

The pressure ulcers can be classified according to the National Pressure Ulcer Advisory Panel (NUPAP) [1] and the European Pressure Ulcer Advisory Panel (EPUAP) [2] grades, where 4 stages can be defined and each stage can provide a different standard for treatment and prevention for pressure ulcers:

Stage 1 – Non-blanchable erythema at skin: In this stage, the skin is intact only with the presence of a located erythema (usually associated to a bony prominence) [1].

Stage 2 - Partial loss of skin thickness: Dermis partial loss of thickness [1].

Stage 3 - Full loss of skin thickness: At this third stage, the tissues lose their total thickness. The ears, occipital region, nose cane and malleoli does not present subcutaneous tissue, so the PU are more superficial at these zones [1].

Stage 4 – Full loss of tissue thickness: At this stage, the full loss of tissue thickness can lead to an exposed bone, tendon or muscle, yet, the depth, depends on the wound's anatomical location[1].

A. Risk factors on Pressure Ulcer creation

The pathologic conditions that lead to PU are multifactorial and integrate several pathogenic ways; moreover, the individual's weakness (generally on elder individuals) can be one catalyser of this whole process.

The risk factors can be divided into intrinsic and extrinsic factors: Extrinsic factors create skin damage through external conditions, while intrinsic factors are related physiological and body function factors [3], [4].

1) Extrinsic factors:

Between all the extrinsic factors, excessive pressure forces, friction, shear forces, and excessive humidity are considered the most important and more likely to lead to skin wounds and PU development [5].

a) Pressure: A long duration pressure at soft tissues between two surfaces (usually between a bony surface and rigid surface), generates a pressure higher than that of the surface capillary vessels, creating occlusion on these vessels and consequently tissue hypoxia, and ischemia, which can lead to an ulceration process [6]. The human organism response to this situation of excessive compression is the frequent change of position, relieving this way the compressed zone, re-establishing the blood flow [6].

b) Shear forces: Shear forces happen when two surfaces slide over each other. Relating to PU, shearing forces are created by the gravity felt upon the body, pulling it down, and at the same time there is a force, parallel to the body, creating a resistance to the gravity force, and these two forces combined create a friction and shear forces at the individual's skin [4]. This kind of forces are usually related to incorrect body transfers and mobilization on impaired individuals [5].

c) Humidity: is the chemical change on skin's pH, alternating the epidermis's resistance, making it more likely to develop wounds created by other factors [6][10].

2) *Intrinsic factors:*

These kinds of factors are directly related to body structure and its function; more precisely the immobilization, sensibility malfunctions, gender, age, nutritional state, incontinence and a bad tissue perfusion rate can trigger the PU development [7].

Some systems for mapping the pressures felt under a seated individual's body can be found on the market, and those systems usually provide a visual perception for the pressure felt under the bony prominences relatively to other body segments with greater amount of soft tissues. Those systems have great utility when choosing an efficient wheelchair cushion, or even to find the best position to the seated individual (in terms of anterior/posterior and side leaning) so an effective pressure relief can be achieved. Although those mentioned systems have great utility, their lack of interaction with the wheelchair user and attendant makes those systems less useful, as they are not designed for a whole day of utilization. Our concept is a system that not only monitors the pressure under the individual's body all day long, recording the values, but also monitors the microclimate generated under the seated individual, warning the attendant if any risk values are being reached, and with all this information, measures can be taken in order to prevent wounds to appear.

This work is divided in five sections, such as section I, where an introduction to the studied problematic have been made; section II explains the architecture of the study, and the approach to the study, and the materials used in the study are present in section III. Section IV and Section V present the discussion of the problematic and the solutions found on this study, and the conclusion respectively.

II. ARCHITECTURE

Our approach to solve this positional issue consists of a smart electronic seat; a chair that monitors the environment that is created between the seated individual and the base of the chair, in order to quantify the values of pressure, temperature and humidity that may represent a risk to skin integrity, and also a response for the necessity to mobilize an impaired individual that lacks that capacity.

This smart seat collects data that is processed and stored in a server, and warns the attendants identifying which of their patients has a risky environment underneath, and needs to be mobilized in order to shift weight to another body part (most of the times the pressure is transferred to the back if the chair/wheelchair has a tilt in space option). The system architecture can be seen bellow on Figure 1.

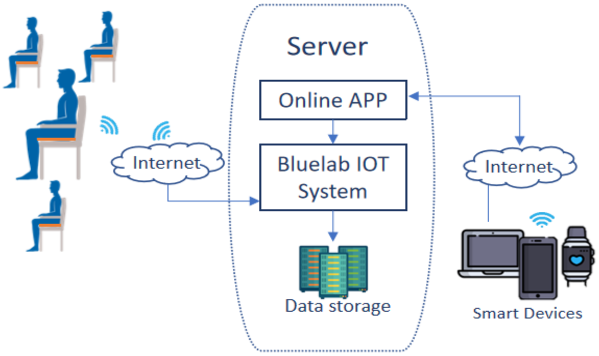

Figure 1. System configuration with the chair system being in contact with the server by wireless and can be accessed by smart devices through internet connection.

The architecture of this work, seen on Figure 1, uses the chair explained above as the centre piece of the whole data acquisition and processing system. After the data acquired by the sensors embedded in the seat, a microprocessor manages the data processing by reducing its noise with a low pass filter, and sends that data by Wi-Fi through an internet connection to the BlueLab IoT system where it is stored [8]. The stored data can then be retrieved and displayed graphically for user comprehension. The system is scalable as the replication of the smart chairs on the same location can be achieved by the same internet connection and different chair ids. Each chair is identified within the BlueLab IoT system as a different station. If needed, geographically different locations can be monitored by the same access to the BlueLab IoT system. Furthermore, each chair can send an alarm (SMS) to the attendant that will aid the sitting person in finding a new position. The system would be suitable for users from every ethnicity, gender weight and age, as the sensors provide absolute values for temperature humidity and pressure, and those values will be compared with the surrounding environment.

III. MATERIAL AND METHODS

The hardware used on each seat is composed by a microcontroller, Analogue to Digital Converters (ADC), batteries, and several sensors for temperature, pressure, and relative humidity. The sensors are set on a mat and it is called the shieldboard.

Microcontroller: is a NodeMCU lolin V3, designed by Espressif Systems, with a processor Tensilica L106 32-bit, speed at 80~160 MHz, flash memory of 16 Mb. It has also ESP8266 communication built in for internet connectivity with 802.11 b/g/n protocol. The whole microprocessor itself has a current consumption between 10 uA and 170 mA with a 3.3 V voltage supply. This microcontroller was programmed with Arduino IDE V1.8.9, and the program stored within the microcontroller's flash memory. Executed whenever the microcontroller starts up, sampling the sensors every 3 to 30 seconds; the sampling rate will be defined in future by the results. The sampled data is sent over the Wi-Fi connection.

The program can also emit an alarm that will result on the sending of a SMS by the BlueLab IoT system.

Sensors and Shieldboard: for monitoring the micro-environment created between the individual's body and the surface where he is sited; two kinds of sensors are used: Resistive Pressure Sensor, and Digital Temperature and Humidity Sensor. For pressure quantification, three FSR 406 (Force Sensing Resistor), from Interlink sensors with size 43.69 x 43.69 mm, and a sensitivity range from 0.1N to 100 N [9]. The sensors surface area is wide enough to cover all the skin area that lies under the ischial bony prominence. The location of the three sensors is designed to be adaptable to the "wearer ", as the sensors can be easily repositioned to be right under the bone tip. In the main configuration, two sensors are placed under each ischial bone, and the remaining sensor is placed further front to the first ones, this way, this third sensor records the pressure under the thigh, as a reference for the values of the first two sensors. The temperature and humidity sensors were placed in way that one of the sensors stays under the person to monitor the environment created at the zone that is expected higher values of temperature and humidity, and the second sensor were placed outside the shiedboard, in order to monitor the values of temperature and humidity of the surrounding environment for the person. This way we can have both quantified results for the microclimate under the person and also relative results, depending on the surrounding environment. This configuration is schematized on Figure 2.

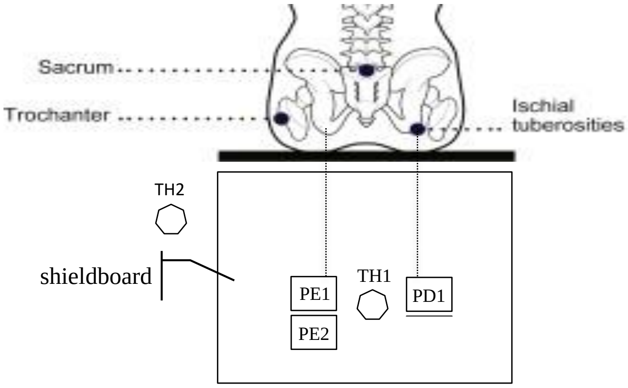

Figure 2. Seat sensors: PE1, PE2, and PD13 are pressure sensors, while TH1 and TH2 are temperature and relative humidity sensors.

Regarding temperature and humidity sensors, two sensors were used: model DHT11 from Vellemam manufacture [10] with temperature range from 0 to 50 degrees (+/- 0.2 degrees error), and a relative humidity range from 20% to 90% (+/- 5 RH error). These two digital sensors provide the temperature and relative humidity of the environment created bellow the individual's body, and their disposition on the shieldboard above the chair's seat can be seen on Figure 2. The main objective with the integration of these two sensors is to quantify the values of temperature and relative humidity, in order to understand the influence that the body heat and moisture has on the ulcer development that makes the tissues more vulnerable and susceptible to become damaged.

The DHT11 has one digital pin for both input and output 1-wire communication. It is connected directly to one of the GPIO (General Purpose Input Output) pins.

The number of sensors can be increased, and with that in aim the I^2C communication protocol is used for the ADC. Module ADS 1115 with 16-bit resolution is used in a module from Adafruit [11] directly connected to the appropriate GPIO pins. The module has 4 ADCs one for each pressure sensor.

To power the smart chair device, two 2600 mAh @ 3.37 V batteries each with a 5V converter, connected in parallel, are able to supply up to 5000 mAh @ 5V. As the system itself consumes around 170 mA, the batteries should maintain the system active for around 29 hours, which is enough for a whole day use, as they should be charged every day.

As a proof of concept, an experiment was performed with the following phases:

A – 3 min of no pressure applied to the shieldboard,
B – 5 min of person sitting still,
C – 40 min of sitting person relaxed,
D – Sitting person repositioning; pressure pattern change,
E – 40 min of sitting person relaxed,
F – 3 min of no pressure applied to the shieldboard.

IV. RESULTS AND DISCUSSION

An experiment was performed to evaluate the use of the shieldboard and to identify the different circumstances of the sitting subject by analysing the data logged through the BlueLab IoT system. The collected data is presented as a graph on Figure 3.

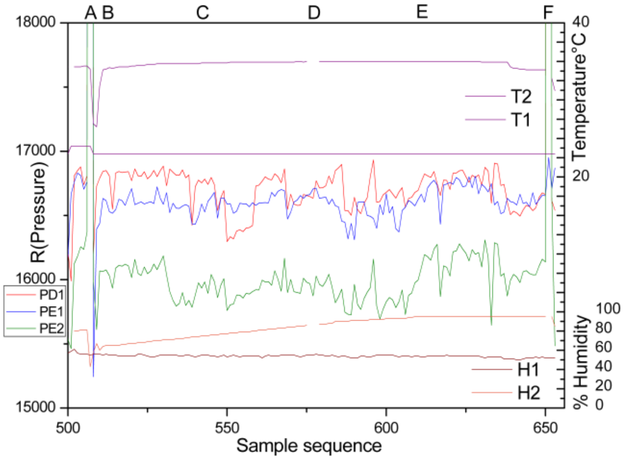

Figure 3. Pressure, temperature and relative humidity values from the experiment.

The graphical representation of the data presented in Figure 3 has on its X axis the sample sequence of the data frames; consecutive samples are 30 s apart. The Y axis has three different scales: on the left the resistance value, R, which is proportional to the pressure exerted on the sensors (PD1, PE1 and PE2), on the top right temperature between 20 and 40 ºC for sensors (T1 and T2), and on the bottom right the relative humidity 0 to 100% for the humidity sensors (H1 and H2). At the top of the graph letters A to F represent the different phases of the experiment.

Sensors T1 and H1 are ambient sensors and their values are almost constant as they represent the condition of the room. Sensors T2, H2, PE1, PE2, PD1 are positioned on the shieldboard under the sited person.

Results show a rapid increase in temperature of the seat and a gradual increase of the humidity under the seated person, reaching values that may result in a microclimate dangerous to the top layers of the skin, if this condition remains through time. Pressure signals show that the sensors are sufficiently sensitive to capture unnoticed movements of a person sitting still. Some of those variations in pressure, for example around sample 550, may indicate a change of position of the individual; an unintentional repositioning as the conscious repositioning occurred in D. In D missing values of T2 and H2 are NaN (not a number) probably due to fault contact of the sensors during the repositioning. The fact that temperature and humidity present high values, indicate a dangerous microclimate to the skin that can lead to ulceration, and the recorded values at the time of mobilization 34.8 degrees and 77% humidity, and those values endanger skin integrity. Temperature and humidity kept increasing with time reaching the max values of 35 degrees Celsius and 95% humidity, values that can be highly dangerous to skin and can lead to ulceration, if there is no mobilisation. The pressure felt under the ischial tuberosity is expected to be greater that the felt on the thigh [12], and the results have also corroborated that fact.

Although the system proved to be functional, there is still room for improvement, as the sensors used may be more accurate in order to improve the data acquisition on the bony tip of the ischial tuberosity, and also the environment. The possibility to link the system to a module on a power wheelchair could be an important improvement for user to change its own position in situations where no attendants would be around.

V. CONCLUSION

The device proved to be functional as it is able to record the microclimate generated under a seated individual, indicating values of pressure, temperature and humidity as direct data. It is also possible to indirectly know if for example the person has fallen as it can be identified by absence of pressure on the sensors, and such event can be immediately sent to the attendant (by SMS for example). Storing data online enables the use of several stations where each can be associated to a smart chair, and the acquired data can be linked to the person who is using the chair. This is helpful in a scenario where multiple patients are being treated at the same time as in hospitals and nursing homes, once the attendant will be warned to change the patient's position, and therefore, distribute the pressure location felt on the body, creating a relief and preventing the appearing of pressure ulcers.

Also, other events can be monitored, like the sudden absence of pressure, that can indicate that the patient have left the chair without permission or has fallen off the chair.

For future studies, the creation of a predictive algorithm could be an important improvement for the prevention of PU, and the whole system could be that way much more intuitive and effective. Force Sensors should also be increased in quantity in order to cover more body surface and relate the pressure felt at some location to the forces applied to the forces registered to the other sensors, having that way a relative pressure from one location regarding the surrounding areas.

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