Simulation and Development of a System for the Analysis of Pressure Ulcers

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Abstract— **The following article presents preliminary research concepts on the analysis and prevention of pressure ulcers at different stages using a sensor-based system with the purpose of reducing the occurrence of this illness. The general objective is to reduce incidences on bedded patients by improving the detection in areas at risk of developing pressure ulcers or detecting infected wounds once the ulcers have developed. The aim is to build an electronic system with an adequate sensor capable of analyzing the biomarkers released during infection so as to provide a wide analysis of the state of the pressure ulcer. The device takes a picture of an area in a patient without mobility and runs an optimal analysis of potential and present pressure ulcers along with its symptoms. The method used includes Sensors (Adafruit MiCS-5524 MQ2 and MQ3), Techniques of programming with Arduino and Integration of materials (microcontroller). The results will be displayed in a Matlab GUI which the final user may interact with. The MQ2 sensor specifies that the sensor works 75% with alcohol in an environment of 1000 ppm. The technologies combined will be part of a larger project that will include software and hardware development for the device. We conducted a usability test of the interface among potential users and received an average score of 87.75/100.**

Keywords—prevention ;pressure ulcers;electronic system ;sensor

I. INTRODUCTION

Even though 95% of pressure ulcers are said to be avoidable, however, in 2013 they caused 29,000 deaths all over the world [1]. According to a study carried out by BMJ [1] Pressure ulcer incidences had a wide range of incidents. "Pressure ulcer incidence in general acute care ranged from 2.8% to 9.0%. In long-term care, the incidence rates ranged from 3.6% to higher than 50%, and in home care from 4.5% to 6.3%". The annual mean prevalence rate of pressure ulcers decreased from 7.8% in 2005 to 1.4% in 2011 and has kept relatively unchanged up through 2014 [2].

A recent study in the United States presented further up to date incidence and prevalence rates of pressure ulcers in different settings [3]: table1.

	Incidence	**Prevalence**	**Immunosuppressed**
Acute care	0.4-38%	10-18%	8-40%
Long-term	2.2-23.9%	2.3-18%	
Domestic	0-17%	0-29%	

TABLE 1. Prevalence and incidence of Pressure Ulcers in 2013 in the US [3]

Ulcers are described as an injury of ischemic origin located in the skin and underlying tissues, with loss of cutaneous substance due to the prolonged pressure or friction between two hard planes [4]. Depending on its involvement with the skin, pressure ulcers are classified in the following way:

<u>Grade 1:</u> Pink or reddened skin does not go away after the pressure disappears within 30 seconds of relieving it. It affects the epidermis.

<u>Grade 2:</u> Skin with loss of solution of continuity, vesicles and flictenas. It affects the epidermis and superficial dermis.

<u>Grade 3:</u> Loss of tissue that extends deep through the skin, even reaching the deep dermis and hypodermis. It is in the form of a deep crater unless it is covered by necrotic tissue.

<u>Grade 4:</u> Total loss of skin thickness with frequent destruction, tissue necrosis or injury to muscle, bones or supporting structures (e.g. sinus capsule tendon). It presents injuries with caves or sinuous routes. Depending on the stage there may be a need to remove the infected tissue in order to avoid septicemia from developing and contaminating other areas of the body [5].

A. *Aspects to consider in the valuation of the Ulcers:*

Guides used by nurses have specific instructions to evaluate the state of the ulcer. Presented below are those aspects from the guide that will be used for the purposes of this article; Description and location of the lesion; Extension and size; Depth; Color of tissue and study of the skin and surrounding tissues; Color: pigmented, pale, cyanosis, rosy; Texture: Temperature: cold, hot. Normal; Humidity: dry, wet, and normal; Edema: degree and location. The most important signs and symptoms of an infected wound are the following:

- Fever
- An inflamed, hot, red or sore wound.
- Blood or pus originating out of a wound
- Bad smell originating from the wound (here we propose the implementation of the electronic nose)
- Dizziness or fast heartbeat [6,7].

II. Method

The project is developed in several reasonably isolated parts.

A. Knowledge of the current market's devices (E-Nose)

The devices we found in the current market that were particularly interesting for this project were different types of E-noses that could be potentially modified for our project requirements. However, the previously problem with these devices remains: A need to focus on the development of a specific sensor. Moreover, the computer systems of the existing E-Noses are not complex enough to provide specific diagnosis or the ability to send data to a server [8].

B. Sensors

The Arduino will be the device that unifies the different sensors that we will use therefore it is necessary to know how to program it and transform it into a common point between the sensors and the devices iOS. The information provided by the sensors must be sufficient to be able to classify the ulcer and give the user a detailed report on the scar's state [9,10].

C. Integration of materials

The assembly of materials refers to the knowledge and ability to solder the material (with the proper machinery and materials) and how to position the different components on the microcontroller, which in this case would be the Arduino plaque [11].

III. Proposed System

The following diagram, which will be explained later, represents the architecture of the entire device and how the orders, data and signals travel as a whole.

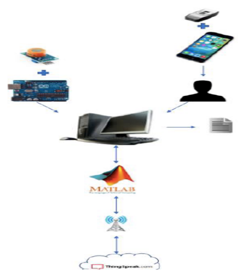


Image 1. Diagram of the overall process (source: self made)

The diagram presented above describes the general architecture of the project. On the one hand the MQ3 sensor with the aid of the Arduino UNO (the Arduino plaque chosen for the project) will analyze the alcohol content in the environment. The user must make sure to place the device at a distance of 5-cm from the wound and ensure that the wound has not been recently cleaned with a solution that contains alcohol in order to avoid errors. Luckily, nowadays the use of alcohol to clean wounds has been widely substituted by iodine solutions that do not affect the sensors [12]. In any case, the ideal solutions would be that the wound has been unaltered by any type of solution). The data would then be transferred by the USB of the Arduino to the computers port and then read by the Matlab program [13].

On the other hand, the user (medical/home care staff) should retrieve thermal data with the help of the Flir One thermo graphic camera and a mobile device (either an iOS or Android, depending on the model of the camera purchased). This data will later be manually introduced by the user.

These two inputs are then Analyzed by the Matlab program, which can give an immediate diagnosis. For this function to be possible there must be an internet connection. If the patient has a channel and previous data, the program is able to give historical information on the evolution of the wound in terms of gas and thermal results. Finally, and provided the analyzed patient has a channel (and so, in the general case, previous records), the program gives the user the option to save an image report for easier and more visual storage.

A. Home tag

The Home tag is the one that the user sees when he opens the interface and has the following appearance:

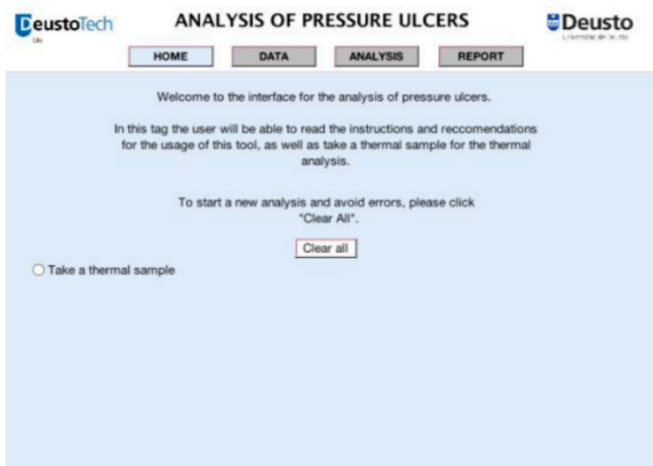


Image 2: Home tag (source: self-made)

The buttons are "Home" (the current, in light blue color), "Data", "Analysis" and "Report"; buttons will take the user to the corresponding tags.

The display panel will be designed so the user can manually introduce the data from the Flir One thermal camera and app (See Image 3)

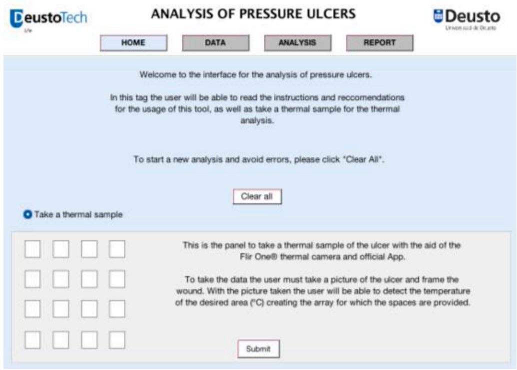


Image 3. Home tag with thermal sample display (source: self-made)

The matrix of blank spaces emulates how the thermal sample is displayed in the App. Since this sample will be used in the thermal analysis, it must be checked that it is correct (i.e. numerical) before it is submitted. If the data is not corrected, the spaces are cleared and a warning message will appear.

B. *Data tag*

The Data tag has the following appearance and will follow the same color code and style as the home tag. At the start a message box will be displayed to remember the user to classify the patient by clicking in either "Unknown Patient" or "Existing Patient". This message will also appear in the following tags until the user has classified the patient.

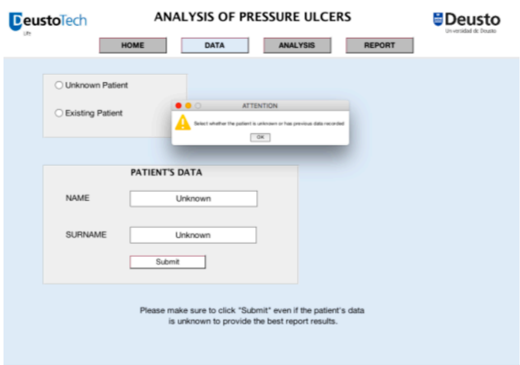


Image 4. Data tag (source: self-made)

Firstly, the user must classify the patient as "Unknown" (no historical data is desired) or "Existing" (has historical data). Then, after inserting the name and surname, several operations will take place after clicking on the "Submit" button.

C. *Analysis tag*

The analysis tag is where the main functions will take place. This tag only has 2 radio buttons corresponding to different options: either thermal or gas test. The user should know that the thermal test is to confirm the diagnosis of infection in the pressure ulcer since an increase in temperature is one of the main symptoms of inflammation, which is a previous state before infection.
In summary, if the gas analysis is positive then the thermal analysis should also be positive unless the patient has a severely compromised immune system so as to not have a thermal reaction to the potential infection.

D. *Thermal gas panel*

The thermal gas panel is shown so the user can introduce the patients regular temperate such that afterwards a radio button "See Data" (with the String values ("See values") will appear [14]. This radio button when clicked, will display a panel with maximum values of the thermal data and gas analysis, and it is only visible once the user as selected at least one of the analyses. When none of the analyses has been selected, the radio button disappears.

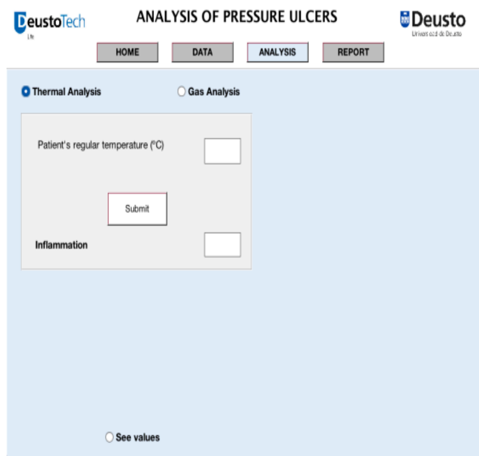
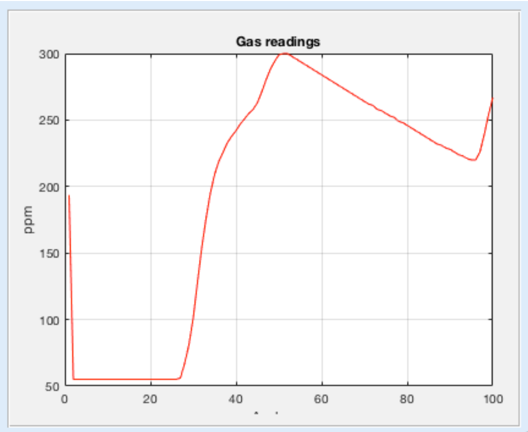


Image 5. Thermal analysis (source: self-made)

Just after the end of the gas analysis, a new panel with a graph showing the Arduino reading is automatically displayed [15]. It does not matter whether the gas analysis is positive or negative. The graph shows the parts per million detected in each analysis. The X-axis shows that one hundred readings were taken, a number that was established in the code with the variable "NumValues".



Graph 1. Displayed gas readings (source: selfmade)

The values that will be saved in the ThingSpeak channel are the maximum value of the analysis and the same for the thermal data. Finally, the user can see both maximum values detected by pressing the "See Value" radio button that will display the following panel.

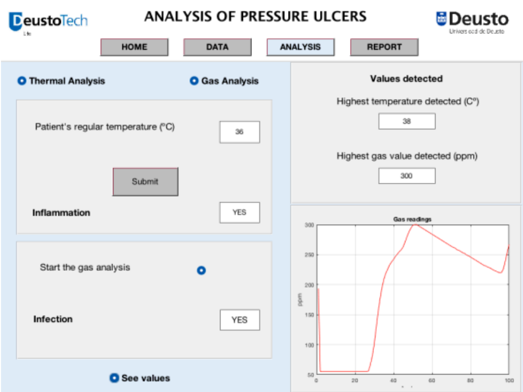


Image 6. Complete Analysis tag (source: self-made)

E. Report tag

Once the user clicks on "display summary" radio button, a panel with a complete summary of the data will be displayed.

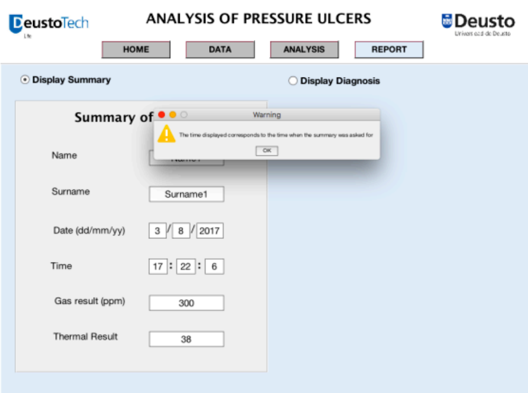


Image 7: Report tag with warning message (source: self-made)

A warning message is displayed right after the summary is displayed explaining that the time of the summary is the time of when it was requested (there would be a dilemma if the time displayed was that of the analysis since two different analyses can be made. For this summary to appear, the code must display several elements saved in the workspace, and calculate the time and date.

Finally, once the diagnostics has taken place, a new button must appear. The "General Report" button will display a new panel where the Summary of the test is still visible with the title "Summary of the Recent Test" and there will be 2 graphs displayed with the thermal and gas evolution of the analyses.

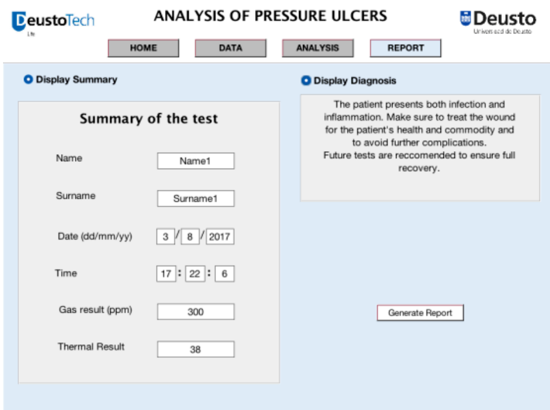


Image 8. Report tag with diagnosis (source: self-made)

If at any time only one test has been taken (e.g. thermal test but no gas test) it will be represented in the graph as a space. This way, the graphs represent a more accurate depiction of the medical history by showing the results in a parallel fashion. Image 10 shows what the user generated report will look like.

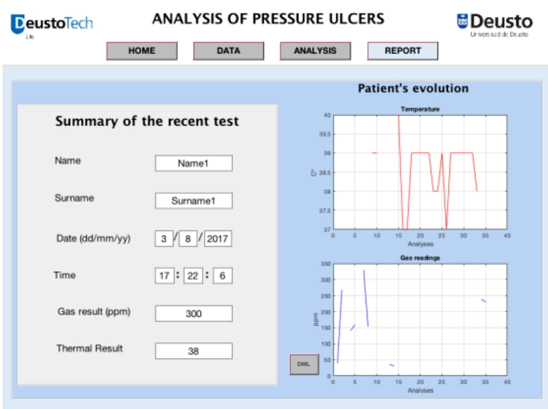


Image 9. Generated report with downloading button (source: self-made)

IV. RESULTS

The tests for sensor selection were done using the programmed electronic nose and subjecting this sensor to the similar conditions. The following target factors were evaluated; sensibility, accuracy and recovery time. We note that the selection of the definitive sensor was done after a thorough theoretical research such that either of the chosen sensors is considered to have a good response and recovery time. However, the final choice was made due to two main factors: the variety of gases that the sensor responded to and the recovery time.

The MQ family of sensors showed a more stable signal in the analyses. The MQ3 sensor provided similar results to those of the MQ2 in clean air conditions and with the presence of alcohol. However, the MQ2 sensor reacted to more gases that could make the results questionable. According to the datasheet of the MQ2 sensor, it works better at 1000ppm in alcohol environments (75%), while the MQ3 responds better within a lower alcohol environment (approximately 100ppm), which would simulate the environment of an infected wound of a patient.

We realized a usability test on our interface. The interface received an overall punctuation of 87.75 which is considered a pass since it is above the average score of 68 for the System of Usability Scale. A more specific overview of the score is provided:

System of Usability	**Score**
80.3 or higher	A
68	C
51 or lower	F (need of major fixes)

The interface obtained a very good mark. The test was completed by 10 participants with ages ranging from 19 to 34, consisting of 6 females and 4 males. The interface has proved to be easy to use and intuitive. Constructive criticism suggested a more automatized response would improve the interface.

V. CONCLUSION

In conclusion, combining sensors with an interface facilitates the monitoring of pressure ulcers, and not only because they are avoidable but because of the physical and psychological damage that is inflicted on patients. The following research covers two needs: sensors that can detect ulcers and a flexible interface for users.

Both sensors MQ2 and MQ3 had similar results in the presence of alcohol, however, with no stimuli; the MQ3 provided more stable results due to the diminished sensitivity to gases. The main drawback towards using a sensor was the recovery time. Although gas sensors do not provide accurate results when performing an analysis for a short period of time, we did find significant differences between the MQ and Adafruit sensors.

We conclude that the interface is fairly simple to use and has sufficient features. However, according to the usability results it would be best to avoid the necessity to click as many buttons and automatize results and functions.

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