Microcontrolled air-mattress for ulcer by pressure prevention

Cristian F. Pasluosta, Juan M. Fontana, Diego A. Beltramone, Ricardo A. M. Taborda
Universidad Nacional de Córdoba. Córdoba, Argentina

dbeltramone@efn.uncor.edu

Abstract. An ulcer by pressure is produced when a constant pressure is exerted over the skin. This generates the collapse of the blood vessels and, therefore, a lack in the contribution of the necessary nutrients for the affected zone. As a consequence, the skin deteriorates, eventually causing an ulcer. In order to prevent it, a protocol must be applied to the patient, which is reflected on time and cost of treatment. There are some air mattresses available for this purpose, but whose performance does not fulfill all requirements. The prototype designed in our laboratory is based on the principle of the air mattress. Its objective is to improve on existing technologies and, due to an increased automation, reduce time dedication for personnel in charge of the patient. A clinical experience was made in the local Emergencies Hospital and also in an institution dedicated to aged patients care. In both cases, the results obtained and the comments from the personnel involved were favorable.

1. Introduction
The ulcers by pressure are an unquestionable reality in clinical practice, whose incidence varies, according to the institutions, between 20% and 60% of patients in geriatric centres. This fact is really alarming, because it is a problem whose prevention is, at least in theory, easily attainable. It is alarming from the point of view of the patients, who see a continuous deterioration while staying in the hospital which often continues even after leaving, during post-hospitalization. It is alarming from the point of view of the professionals, who feel a kind of frustration, which perhaps is interpreted as a testimony of negligence in treatment and care. Finally, it is also alarming from the institutional point of view, because an ulcer can be the cause of a longer hospital stay, which generates a considerable increase on costs.

By definition, ulcer by pressure is the loss of substance of the skin due to the continued pressure that is exerted on it [1], [2]. Its prevention demands from personnel, strict and intensive protocols of preventive cares. Among them, it is of paramount importance the rotation of the patient at regular intervals, in order to produce a change in the points of support of the body. If this is not strictly made according to times and positions established by protocol, certainly the probability of ulcer will increase.

Nowadays, there exists a trend to consider ulcers as a problem that appears by causes either normal or at random; therefore, unpredictable [3]. The physiopathology of the process of formation and resolution of the ulcers is well-known. This has conduced to the establishment of protocols that, in theory, should simply and easily prevent them. For that reason is incomprehensible its high incidence, its negligence, and its certainty and continuity in the hospitals. Nevertheless experience shows that
results are more than often not good, because existing protocols are too demanding on care personnel as well as on the family and the patient himself [4].

The objective of this project is to offer a possible aid to the treatment of the ulcers by pressure based on automating part of the prevention protocol, thus reducing the demand on patient care personnel. Besides that, the proposed system is flexible thru programming and allows for a register of events.

2. Design

The air mattress for ulcer by pressure prevention was divided in cells in order to permit alternative distribution of pressure applied to human body (figure 1). Ideally, each cell should coincide with protuberances in the body due to bones lying underneath. By successively inflating and deflating cells, contact pressure is varied and air circulation is improved, thus diminishing probability of ulcer formation.

![Figure 1. Air Mattress configuration](image)

The air mattress is inflated by an air pump installed on a separate unit. There exists also an option to use centralized compressed air available from the hospital installations.

The sequences for deflation and inflation are handled by electrical valves commanded by a microcontroller which receives information of the pressure in each cell from 3 differential pressure sensors (MPX2100 of Motorola Company). Signals from sensors are previously conditioned by a differential amplifier connected in instrumentation configuration. Then, they are filtered through a Sallen-Key low pass filter [5]. The microcontroller used is PIC16F877 of Microchip Company [6].

The cells are grouped in three sets, as shown in figure 1, each one handled by one valve. Two of them, named 1 and 2, constitute a main set, since they are located in bone elevations.

3. Development

The complete system (figure 2) consists on the air mattress, a main unit and a PC (optional). The main unit controls the inflation and deflation of the cells, as well as data communication with the PC. Its front panel has three connectors for the hoses that carry pressurized air into the cells of the mattress. It
is possible to select either an internal air source (air pump) or an external air source (compressed air source) thru a control in the back panel.

Figure 2. Left: main unit. Right: Air Mattress

The principle of operation of the system can be explained with the aid of the block diagram of figure 3. The Microcontroller provides control signals for the Air Control System block built with three valves and an air source. Assuming the mattress is fully deflated, the system will initially pump up group 1 until pressure reaches a programmed value. Then group 2 will start inflating and simultaneously group 1 deflates. As soon as #2 reaches its prefixed value, will start deflating and #1 inflating again, and the whole process will thus cycle itself indefinitely.

![Block diagram of the system](image)

Figure 3. General block diagram of the system

Each group of cells counts with a pressure sensor which provides a signal on the order of mV which must therefore be amplified and filtered in Signal Processing block. Then, the signal enters the microcontroller where it is processed in order to determine when the valves must be activated.

A separate valve commands Group 3 cells independently from the other two. This group is also important for the final contexture of the mattress.

It is important to mention that the equipment has a visual and sound alarm system, which will activate when one or more of the cell groups has not reached the preset pressure within a programmable time period. Like in most medical instrumentation, sound can be silenced during a programmed time interval with a button in the frontal panel. The visual alarm will remain active until the group of cells that triggered it reaches the preset pressure.

It is also possible to establish a bidirectional connection between the main unit and a personal computer (PC). The benefits are multiple: Firstly, the pressure of the three sensors can be recorded, accessed at any time and used to generate pressure-versus-time graphs. Second, the connection can be used to change and set parameters in order to adapt it to different patients. The link Main unit - PC is materialized thru a serial communication with standard RS-232.

The software handling the System-PC communication and PC-Human interface was developed on Labview [7]. The main menu consists of three main functions: "Current Data" (figure 4) is used to show pressure sensors data. In addition, distinctive data of the patient and the measurement can be entered manually. All information is saved into a file which can be accessed later at any time using the...
function “Registered Data”. Finally, the third function, named “Pressure Set”, is used to program the values of maximum pressure for each group of cells.

![Figure 4. "Current Data" function](image)

It is important to consider that the prototype will work regardless being connected to a PC or not, since, once the air circuit is connected, the equipment programmed and turned on will operate autonomously and indefinitely.

A 50 Hz interference with the microcontroller was traced to the air pump and was solved thru appropriate filtering at the Signal Processing block.

4. Experimentation
Initially, the equipment was tested by placing healthy volunteers on the mattress in order to verify the complete operation. All pressures were verified, particularly different values for programmed preset switching threshold pressures. The bidirectional communication between the computer and the microcontroller was also tested, in order to make sure that the pressures registered in each one of the cells were correct.

Once tests with healthy people were completed and minor adjustments made, new tests were performed with patients who presented some type of pathology that prevented them to move either the whole body or part of it. Tests were performed in two institutions: the Unit of Intensive Therapy of the Emergencies Hospital and an adult care center, both in the city of Cordoba, Argentina. In each place, the mattress was used on two patients, which could not move their body on their own.

5. Results
Figure 5 shows part of a several hours-long record of pressures obtained from one of the patients with skull traumatism and vascular brain accident. The section shown was obtained once the air mattress had already accomplished several cycles of inflation, and is thus representative of steady-state “in regime” operation.
The arrow remarks the moment when the system was pumping air to the second group of cells, a situation demonstrated by the ascending slope in the graph of the sensor 2. The dashed line demonstrates the mutually excluding operation between the group of cells nº 1 and nº 2, that is, once one of the groups (in this case Group 1) reaches the preset maximum pressure, it starts deflating and simultaneously inflating the other, in this case Group 2.

Figure 5 also shows that Group 3 cycling is independent from the other two, simply because its location does not agree directly with the main bony elevations. It begins inflating with a delay respect to the equipment start up and it will continue until its own prefixed pressure. Then, it stops and remains so for a programmable time interval until a new cycle starts.

The tests done in the geriatric institution indicate that the patients were feeling the seams between the cells, indicating that it is necessary to improve the material with the mattress was made.

On the other hand, the noise produced by the air pump, although is audible, passes totally inadverted when the equipment is operated in a hospital environment.

Due to its benefits, the personnel of the Hospital valued the prototype as a very useful development of direct application in the clinical practice environment.

6. Conclusions

According to statistical data, the great diversity of existing methods and devices for the prevention of ulcers by pressure, do not solve the problem totally. This can be originated by a bad interpretation of the methods, an incorrect use of the devices, or by faults in the design of them [8].

This prototype was designed with the objective to complement and to improve on existing alternatives by tackling the problem with a novel approach consisting on both a new design of air mattresses and improved control system with some degree of automation. The design of the air mattress emphasizes the surfaces of support in the areas where greater probability of an ulcer exists.

Considering that it is an experimental prototype, it is possible to state that most previously set goals were fulfilled.

On the other hand, the comments of both the medical and clinical engineering personnel of the Emergencies Hospital agreed on several advantages over existing air mattress models being used, which can be summarized as follows:

- Possibility of programming inflation pressures and timing
- Measurement of the pressures for early detection of changes in the conditions of the patient/air mattress.
- Continuous recording and visualization in digital and graphical form of the different pressures.
- Electronic and pneumatic system of control made with elements of easy acquisition and reasonable cost.
• Versatility and simple handling for the user.
• Possibility of using either internal pump or compressed air installation.
• Presence of alarms that alert on possible faults in the air mattress.

Certainly improvements on the device can be made and more testing with patients will be needed in order to obtain a greater amount of data to warrant correct operation. One of those improvements will be focused in the physical layout of tips and hoses that distribute the air within the mattress, since in the present form they ache it hard for the nurses to work around the patient for cleaning and the like.

It is also interesting to mention that, to obtain a greater versatility of the device, different sizes of air mattresses could be constructed. A solution could be the construction of, for example, three different and standard sizes in order to obtain an adaptation to three sizes of patients. (i.e.: children, small adult and big adult).

Nowadays studies are being conducted on different materials to use in manufacturing the air mattress, as well as on design improvements in order to optimize its benefits.

References
[1] European Pressure Ulcer Advisory Panel. http://www.epuap.org/index.html
[2] Informe medico: escaras. http://www.clinicalcla.com/notasescarass.htm
[3] Stryker R. P. 1974. Enfermería de rehabilitación. Iberoamericana.
[4] Lewis J. A. 1997. Procedimiento de cuidados críticos. Manual Moderno.
[5] Daryanani G. October 1976. Principles of active network synthesis and design. Wiley and Sons Inc.
[6] Microcontroller PIC 16F877 data sheet. Microchip.
[7] LabView 7.1 Manual. National Instruments.
[8] Ulcera por decúbito (escaras) http://www.intermedicina.com/Avances/Clinica/Fotos11.htm