Electronic System of an Intelligent Machine: the Case of an Assistive Bed Device

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Abstract This work presents the electronic design of an intelligent device that includes a monitor system for automatic movements of a robotic hospital bed based on posture classification and identification. This feature was carried out in response to the necessities defined by the application of a diagnostic identification methodology. This method was successfully applied to a public Mexican hospital and the issue identified was the mobility of elderly people and physically challenged individuals. The movement of these patients can be performed routinely or sporadically during their stay in a hospital. For patients who require a particular routine application of this action, the system includes an intelligent monitor system. This intelligent system allows medical experts to program the movements of the robotic bed considering the posture of the patients and the time in bed. This paper shows the hardware and software design of the electronic system and the physicals results.

Keywords: Assistive bed, robotic bed, posture classifciation

1 Introduction

In recent years, the Artificial Intelligent Systems (AIS) have been used in several applications such as industrial control, robot control, traffic surveillance, remote sensing, and speech recognition to mention a few. In particular, the insertion of AIS to medical environments has been a challenging task due to the high-risk decisions in the diagnosis, monitoring, and care of patients. However, in the rehabilitation of patients with limited or restricted mobility, as is the case of geriatric patients, AIS have been used to control the positioning of robotic hospital beds. This approach prevents the appearance of ulcers because of the bed pressure on the tissue. The system also takes into account the activity monitoring and bed-rails control [9,4,12].

Most of the commercial systems for automatic control of hospital bed positions are based on the detection of patient posture. This information is obtained using presence sensors, digital cameras, thermal cameras and mattress pressure sensors [5]. On the other hand, modern hospital beds can adopt twelve positions ranging from the home position to the sit to stand position but do not have a mechanism to prevent accidents when the change of configurations takes place. Some of the most frequent accidents, when the bed is moving, are the downfall of patients, bad posture when the bed is moving, and injuries caused by improper use of motion controls. In this research, we show the electronic design of an AIS, proposed to reduce the risks of operating a hospital bed with multiple positions. The primary objective of our AIS is to prevent accidents when the bed is moving; this is done by detecting the posture of patients using a mattress pressure sensor. We identify the position of patients by performing an analysis and classification of the pressure distributions using an initial training set of correct postures for all bed posts.

Electronic design is essential to acquire, manage and transport the control and power signals to all the system. The implementation of a module to process inputs and outputs has been widely developed [2,13,14]. As an example, the work of Bustamante Malla [1], designed and implemented a control card and data acquisition with a resolution of 12 bits and it is managed by a computer (PC). Ordoñez [10] implements a device to obtain the voltage-current measurements from a solar system, and it is based on a micro-controller connected via RS-232 to a computer for processing the information. This development has also been implemented to solve the bigger requirements of particular systems, where it is needed to read and manage the information of an array of sensors. In [6] the data acquisition of 96 high-resolution underwater sensors was carried out. Another goal is to achieve the velocity requirements of some systems, for example, image processing in [8]. This field is still developing and growing up since the requirements of new systems are increasing.

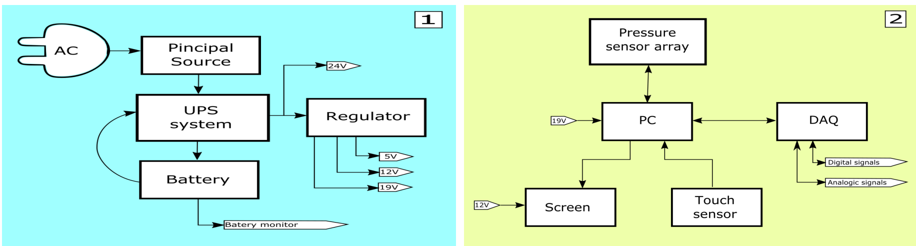
2 System Requirements

Electronic requirements to achieve are: source from 110 VCA at 60 Hz which is part of the facilities in all Mexican hospitals, autonomy of at least 5 hours, ability to handle electrical breakouts and the energy supply for the actuators to move the system. The system to be designed must also be capable of getting the different type of data from all the sensors on the physical system. The electronic design also has to handle the information to be sent back to control the behavior of the machine. It must read all the devices at the same rate and maintain the information in the buffer until the manager program asks for the data. This is proposed to avoid data loss when the CPU is performing another action, for example transferring data online or attending interaction with the user. The complete system must be able to deal with 65 digital input/output signals, 28 analog inputs, two analog outputs and 3 USB ports. Digital pins will be used to manage the data acquisition and communication from a 20 buttons keypad array, read with nine digital lines and distributed into distinct areas to deliver comfort to the final user. It will use 16 motors with the capability of changing its direction at any time or PWM control. It also uses various limit switches to determine the bound of some movements, two presence detectors, and a teach pendant with eight buttons, driven with four lines. Finally, the system includes some extra lines for future improvements.

Analog inputs contemplate the management of 17 feedback signals from motors, 2 inclinometers, the battery monitoring pin, 4 load cells to know the pressure at the support points of the system, two thermometers wires and 3 extra lines to allow future changes. Finally, analog outputs will be used to manage the RGB LED's and provide quickly visible information about the status of the entire system. Moreover, finally the USB ports to acquire the information from 2 arrays of pressure sensors and the last one will be used to read the information from the touchscreen of the graphical user interface.

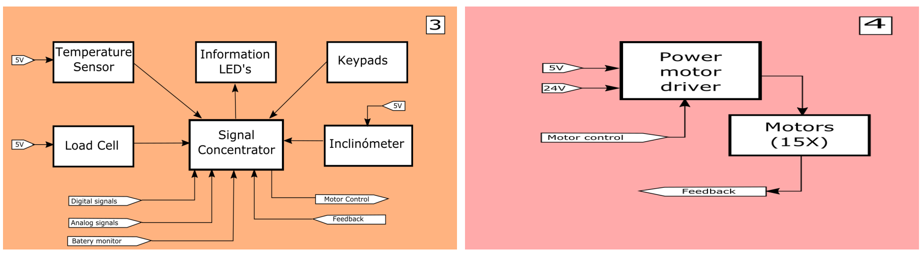
3 Electronic Design

The architecture of the system is shown in Figure 1 and 2. In these pictures can be seen the functional division of each element that compose the system. This division also helps to design carefully and individually the logic sections of the robot. Another positive feature of this conceptual and physical disposal is the advantage of providing straightforward repair and technical support for the modular design give the opportunity to change the malfunctioning card only.



(a) (b)

Fig. 1. System architecture



(a) (b)

Fig. 2. System architecture

3.1 Power Sources

The system will be connected to a 110 AC voltage network, and the elements inside must fulfill the supply requirements of each internal component. Therefore, it was implemented some linear and switching voltage regulators to provide the proper value. If the AC voltage supply fails the system must remain working, and this device handles this case by implementing a UPS system. In Figure 1(a) can be seen the block diagram of this module.

3.2 CPU and User Interface

Module two contains some commercial products that were previously selected to work together, and they are shown in Figure 1(b). The CPU was selected by comparing the ARM and Microcontroller architectures. Finally, a PC was chosen, considering the advantages of increased capacity and processing speed; it allows programming a graphical interface with a high-level language and easy programming of complex algorithms. In this work the BOXDC521HYE Intel NUC was implemented using a Linux distribution like the operating system, since this approach has shown important advantages among others [14]. The pressure sensor array has its data acquisition, but the processing of the information must be carried out on the PC, and then all the data must be moved via two USB ports. On the other hand, the touch sensor located on the screen to interact with the user also has to be connected via a USB port. These connections are handled directly by the PC. The last element in this module is a commercial NI USB-6212 to move data to its final stop, the PC. This element manages the digital and analog signals to be sent in one direction or another.

3.3 Signal Concentrator

This module can be seen in Figure 2(a) and handle all the digital or analog information used in the robot from all the sensors. Given that the characteristics of the DAQ-6212 are lower than the requirements of the system, this module aims to manage the signals by multiplexing the digital pins. Additional functions of this module are the organization of all the wired connections and isolation to provide a safer configuration. In some cases, this module also accomplishes the signal conditioning to provide the necessary characteristics to be read or written to its target device.

3.4 Power Drivers for Actuators

The design of this module contains the electronic required to interact the 24 volts power supply of the motor by changing the state of the TTL connections from the signal concentrator module. This card also contains an electronic configuration to avoid undesired activation of the motors as well as to prevent configurations that can damage the card. This module is displayed in Figure 2(b).

4 Supervisory Control

The system acquisition is governed by a program dedicated to administrating all the information read from the physical system. This program is running on the CPU selected. Figure 3 shows the flow diagram of this specific program to interact with the DAQ.

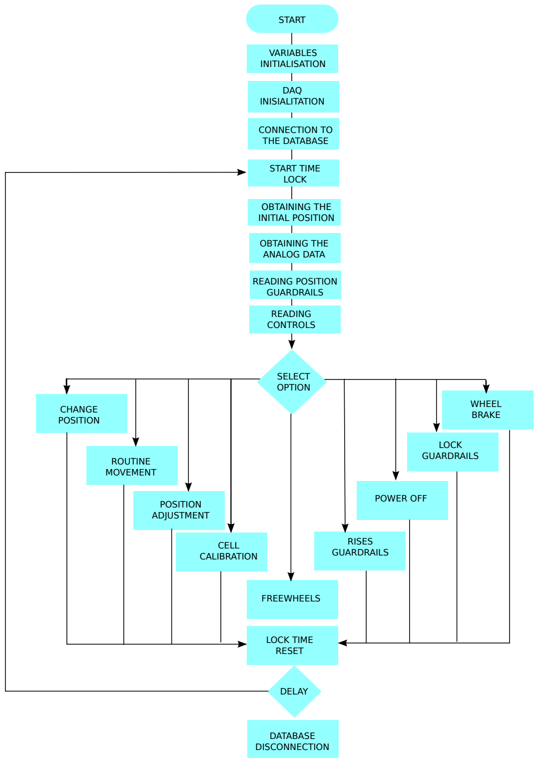


Fig. 3. Software behavior

Thus, the database of features (see Fig. 4) is constructed such as it contains three set of equal size of the three basic positions and an appropriate number of its variants. The database of features is then used to construct the model of the classifier to make predictions of pressure distributions that do not belong to the database.

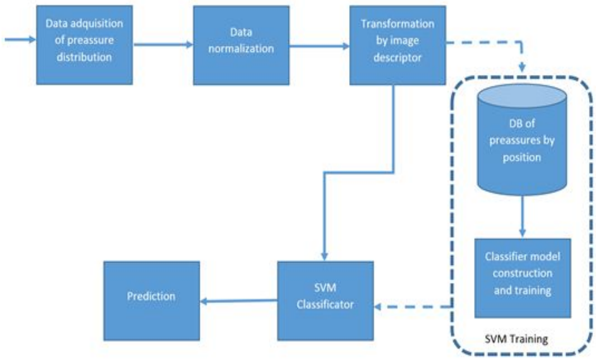


Fig. 4. Main blocks of the IS for posture recognition.

5 Experimental Implementation

This section shows the experimental implementation of the described system. In Figure 5 can be seen a diagram that contains the four modules explained before and all the electrical connections corresponding to the complete system. It also plots an idea of the number of elements to be read with the data acquisition system developed in this work.

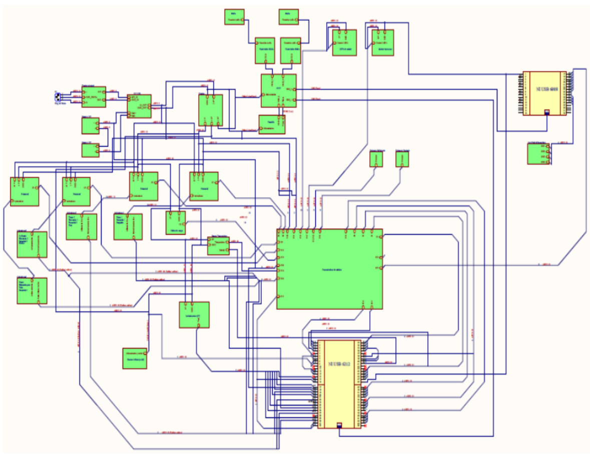
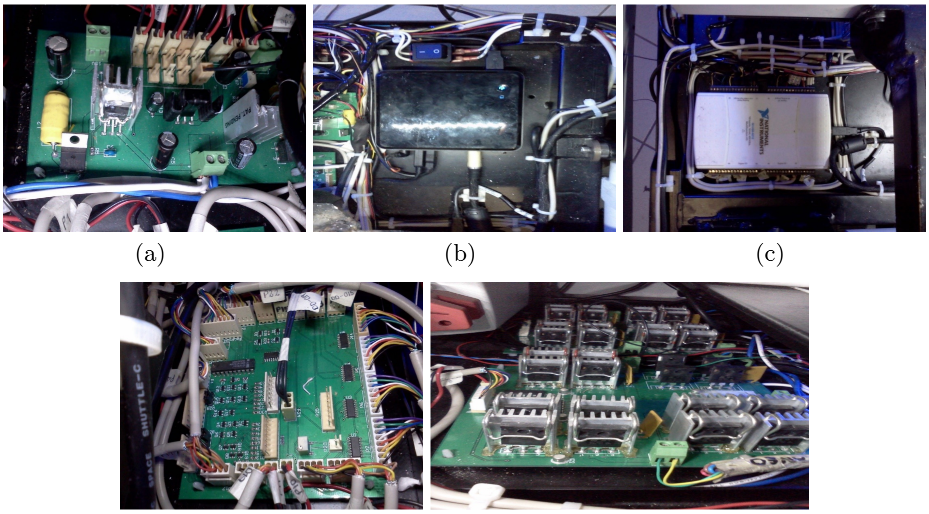


Fig. 5. Electrical diagram of the system

Figure 6 shows some pictures of the implemented system. In Figure 6(a) can be seen the physical card that corresponds to the module 1, this PCB will provide the correct voltage to each of the devices in the robot. Figures 6(b) and 6(c) display two of the components of the second module, these are the PC (NUC) and the USB-6212 respectively. The signal concentrator card can be seen in Figure 6(d) and correspond to the module 3 explained before. Finally, the power driver card is shown in Figure 6(e).

It is important to mention that this development accomplishes the requirements of the environment where this robot will be working. To achieve this goal some previous prototypes were implemented to check functionality and in the end the final design was carried out.



(a) (b) (c)

(d) (e)

Fig. 6. Experimental implementation of the system

6 Intelligent System for Automatic Control of Bed Positions

A robotic hospital bed can adopt several positions depending on the needs of a particular patient, also can be programmed to perform a series of movements over a period. The figure 7 shows the transition diagram of our robotic hospital bed of the most used positions by medical specialists. The initial position is the *home position* to which all other positions can reach, except the sit-to-stand position. The transitions of the robotic bed are performed using mechanical actuators, and the time it takes to go from one position to another depends on the weight of the patient and the current position. When a transition is performed may happen that the patient falls or can be hurt by being in a bad posture, even when a specialist is operating the robotic bed.

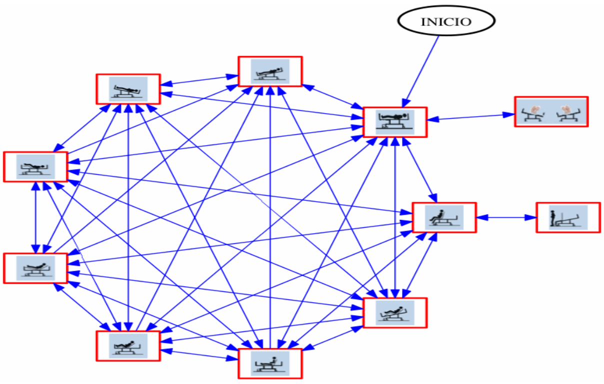


Fig. 7. Pression levels obtained of one person.

The AIS will be able to detect if the patient is in a correct position to perform the requested transition, and will send a visible alert to prevent possible downfalls. Figure 3 shows the main stages of the AIS for the posture recognition. In the initial phase, the pressure distributions are obtained from the pressure sensor array. The second and third stages present an analysis and pre-processing is performed. Also, a feature extraction using Histogram of Oriented Gradients (HOG) [3] and Scale Invariant Feature Transform (SIFT) [7] descriptors are applied over the pressure distributions that are considered as grayscale images. In the fourth stage, a database of features is constructed and in the last two phases we build a model for feature classification and prediction. We compare the results of three classifiers such as Support Vector Machines (SVM), Decision Trees (DT), and Bayes-Naives Networks (BNN).

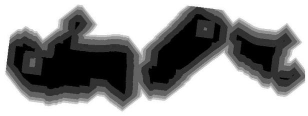
To simplify the posture recognition we consider these basic postures: the *right lateral decubitus*, *supine* and the *left lateral decubitus* positions (see Table 1), and since that the *prone* position is almost the same as the supine position, its detection is achieved by an analysis of the pressure distribution. The Table 1 shows the three basic correct positions displayed as grayscale images, obtained from simulated data of the pressure sensor array.

Thus, the database of features (see figure 4) is constructed such as it contains three set of equal size of the three basic positions and an appropriate number of its variants. The database of features is then used to construct the model of the classifier to make predictions of pressure distributions that do not belong to the database.

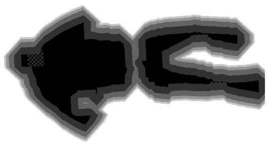
Finally, the AIS for posture recognition can be used to control the actuators of the robotic hospital bed in a semi or automatic way, and can prevent accidents when the bed is moving slowly. Thus, when a bad posture is detected, then the AIS send a signal to the actuators either to stop the transition movement or to return to the previous position. This intelligent device allows the hospital medical team to improve attending in caring for people with motor disabilities.

Table 1. Simulated basic posture positions.

a) Left lateral decubitus LLD (**class 1**)



b) Right lateral decubitus RLD (**class 2**)



c) Supine (**class 3**)

d) Prone (**class 4**)

7 Methodology for Posture Recognition

The proposed methodology takes the raw data of sensors and transforms it into HOG image. This representation as HOG image will be used as input in one SVM classificator, the final output is the classificator prediction about the position. Our system receives, as input, one array of 448 elements, with pression levels (0-4096 units of pression). Each of wich represents one sensor on the surface where a person is lying down; these sensors are distributed in 32 rows and 14 columns.

Figure 4 shows the main blocks of the proposed methodology for posture recognition. In the initial stage, the pressure distribution is obtained from the pressure sensor array. The data obtained from the sensors is in the range of 0 to 4096 levels of pression, where 0 is the maximum pression possible, and 4096 is null pression. Then, in the second block we transform raw data taking three considerations. The first considers the pression applied by the human body (considering weight between 40 to 150 Kg) which is between 2500 to 4096 in the scale of pressures (see Figure 8). Then we can cut the range only to human body requirements and gain definition. Second consideration is an array scalation from 2500-4096 scale to 0-255 scale for process the array as gray scale image in the next block. The final consideration of the second block is applying a scale algorithm for images to obtain interpolated image of raw pressure data.

In third stages, we use a feature extraction using HOG descriptor and applying it to the pressure distributions that are considered as gray scale images. In the stage delimited with a broken line, we make the SVM model, the first three stages are repeated several times with one human body in different positions. We consider the positions described in Table I and we make a data base with this. Then we use this data base for make a SVM model to know the position.

When SVM model is ready, we can use it to monitor person movements. The fourth stage implies to take this SVM model and to use it as input the first three stages output; then the fifth stages have an accurate prediction.

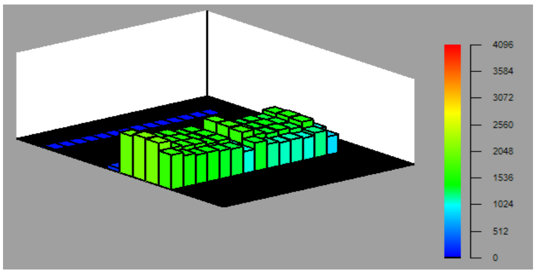


Fig. 8. Pression levels obtained of one person.

8 Interface

Our development also implies a design and manufacturing respectively to graphical interfaces that display the positions of the patient (Figure 10). As well as an exclusive work for the aesthetic look of the device that allows safe, comfortable, reliable and clean. These details are very important in the context of usability to give confidence to the user.

In constant operation of the bed, measured position is presented in the graphical interface, and it must display the real position of the physical system. Therefore, the user must have real information to observe and handle the variables in the machine.

Additionally, this development takes into account the implementation of a function call [11], to isolate the design and constructibility of the Graphical User Interface (GUI). Therefore, this work is done considering the flexibility of the entire system.

In Figure 9, the primary screen of the graphical user interface is shown, which displays patient data found in the bed. The system takes data from the position in which the patient as well as the pressure and temperature continuously to have a better management system is.

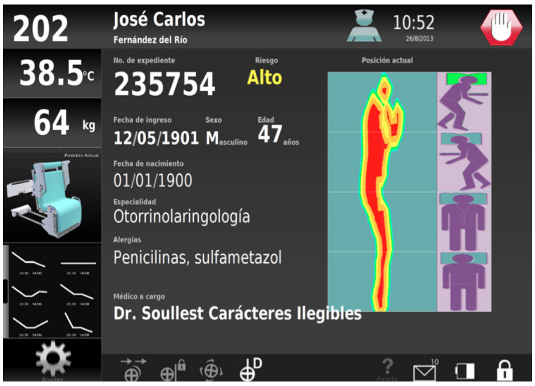


Fig. 9. Interface.

In one of the screens, the twelve possible configurations that can take the bed as well as a short description of the position are shown. Within the interface is the option to set the position or series of positions that will receive the patient at a given time. This is done to continue with routines that the patient has already predefined or update routines depending on the patient's improvement. In the section go to position a preview of the desired configuration is done to take into account which is the position to which anger the system if the desired position the start button is pressed to go to the settings or begin programmed sequence before. The interface has blockages or stops to the bed which depend on the position in which the current system is and who is to come, this depends mainly on the position where the patient is.

Fig. 10. Positions in the interface.

The Figure 11 contains an interactive way to manage the positions of the system with easy handle method. The use of the touch screen enable the user to perform its task using specific areas in the screen. On this screen limits movement with every part of your system.

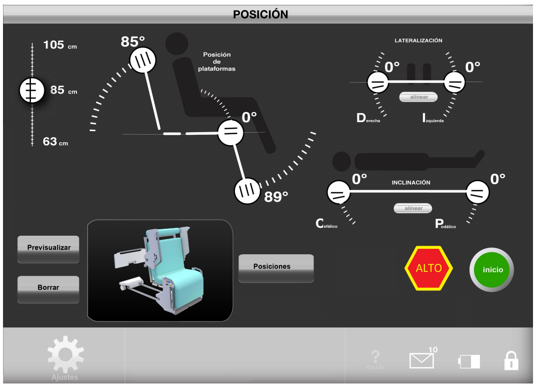


Fig. 11. Movements in the interface.

9 Conclusion

In this work a successful implementation of a data acquisition system was carried out, and the resultant system was applied to manage the behavior of an assistive robot. The design an implementation of an Artificial Inteligent System was carried out. This approach was based on an NI-DAQ-6212 device and all the required electronics to achieve the desired objective using a system with lower capabilities. The design and implementation of a GUI taking into account the actual requirements for applications as well as a cognitive approach to making the product more efficient when the user is interacting with it. This GUI was also applied to command the behavior of a mechanical machine, therefore making a Mechatronic system. The whole system was built and tested with successful results at a prototype level.

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