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A CASE-STUDY VISION

Inclination measurement device for hospital beds' in ICU

Medidor de inclinación de camas hospitalarias en UCI

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ABSTRACT:

Ventilator-associated pneumonia is acquired by many patients connected to an artificial airway, causing their death of a great percentage to those who are affected. A close relationship has been found between ventilator-associated pneumonia and hospital beds tilting angle which the patients rest on. The correct position has been established between 30° and 45° to reduce the likelihood of ventilator-associated pneumonia; so a tilt sensor linked to the hospital beds is a good method for measuring. The present article describes an electronic device which was developed able to create a link between an IMU sensor connected to a microcontroller and a Wi-Fi module that allows to display, in a real time graphical interface, located in the control center, the current position of hospital's beds for being monitored by the nursing staff providing a record of the patients' status in intensive care and emergency units. Device's performance was checked by hysteresis and fixed position test along a previously defined time where errors in measurement of inclination remain within a suitable range.

RESUMEN

La neumonía asociada a la ventilación mecánica es una patología con una elevada tasa de mortalidad adquirida por pacientes conectados a una vía aérea artificial. Reportes bibliográficos indican una estrecha relación entre esta patología y el ángulo de inclinación de las camillas en las que reposan los pacientes –cuya posición adecuada se encuentra establecida entre 30° y 45°–; por lo que un sensor de inclinación adherido a las camillas es un adecuado método de medición. El presente artículo describe el desarrollo de un dispositivo que vincula un sensor IMU conectado a un microcontrolador con un módulo Wi-Fi, el cual provee un reporte hacia un computador del centro de control –vigilado por el personal de enfermería– a través de una interfaz gráfica que, en tiempo real, informa la posición de las camillas. Este dispositivo permite registrar la inclinación de camas en la unidad de cuidados intensivos y urgencias. El dispositivo fue sometido a pruebas de histéresis y de posición fija las cuales arrojan errores en la medición de los ángulos dentro de rangos seguros y no interfieren con el correcto funcionamiento del dispositivo.

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1. Introduction

Ventilator-associated pneumonia (VAP) occurs roughly 25% of those mechanically ventilated patients and is acquired after 48 hours following from endotracheal intubation. VAP represents one of the most common nosocomial infection in the intensive care units (ICU) and has the highest mortality rate [1], [3]. It has been proven that semi-recumbent position patients, between 30° and 45°, have a lower probability of coming down with VAP, therefore, the patient position becomes an important parameter to control inside an ICU [4].

Currently, the tilt control is done by healthcare staff by changing the hospital bed tilt intuitively. Despite of some beds have embedded technology that allows to rotate the bed easily, this is not accurate enough because the staff cannot get feedback to ensure the proper tilt [2], [4]. Some studies have been done to quantify the ability of the healthcare staff to tilt the hospital beds in an angle from 30° to 45° resulting into they did not have a good performance in this task [5], [6]. So, the best solution is to develop a system able to measure accurately tilt of each hospital bed and report the healthcare staff whether the position is right or wrong in accordance with [3] and [4].

At present, inertial measurement units (IMU) are used in measurements of human movement and healthcare applications. Reports from [7] and [8], have proved that IMUs have a great performance due to their electric and mechanic features, furthermore, their accuracy and low cost compared with other devices make them a great choice to perform tilt measurements.

Through this article, the development of a system is able to measure patients position in ICU is additionally described. The system is also composed by different subsystems. The first one is a device capable of accurately measure the tilt of several hospital beds at the same time, this subsystem consists of an IMU, a microcontroller and an electrical circuit for power supply using electrical means. These subsystems of tilt measurement are attached to those different beds for periodically monitoring the tilt state of each one. The second subsystem involves the connection between each single device and a central computer where the state of beds is displayed. Wi-Fi connection using Wi-Fi modules and a PC was implemented, this connection allowed tilt data transfer from any bed to the central PC; The final subsystem is the software for data visualization of tilt values of those beds connected to the central PC. The visualization includes a visual alarm system that is triggered when the tilt value is under 30°. These three subsystems offer a good control alternative for avoiding VAP inside ICUs by measuring and monitoring the tilt state of the beds in the unit.

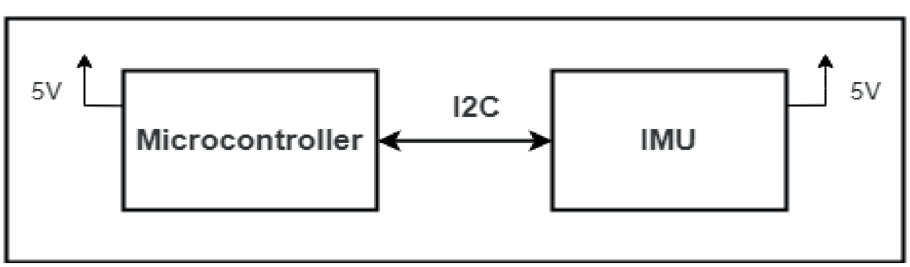
2. Materials and methods

2.1. Tilt Sensor Configuration

A connection between an Inertial Measurement Unit (IMU), MPU 60-50 [9], and a microcontroller, Arduino-UNO, was made; the goal was to record the tilt sensors raw data at any time and process them to get a reliable tilt measurement. This connection was made as shown in Figure 1 where can be seen the voltage requirements of each device and the communication protocol used between them.

MPU 60-50 has a gyroscope and an accelerometer. I2C (Inter-Integrated Circuit) protocol allows the data given from these two sensors can be

Figure 1. Connection schematic between MPU6050 and Arduino UNO.



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extracted. The gyroscope measures angular velocity and the accelerometer measures values of linear accelerations. Using mathematical equations, the tilt value can be found with these data. The gyroscope and the accelerometer have three axes for taking measurements, however, specifically for this application, only one output of the three axes was necessary to use. Since the hospital beds only rotate in one axis, therefore, the measure of the other axes is not necessary.

After getting the raw signal, a preprocessing data stage is followed. A complementary filter was used in order to get an accurate measurement that combines the data of the two sensors of the IMU and attenuate high frequencies from the accelerometer signal and low frequencies from gyroscope signal, the filter was applied using (1) [9].

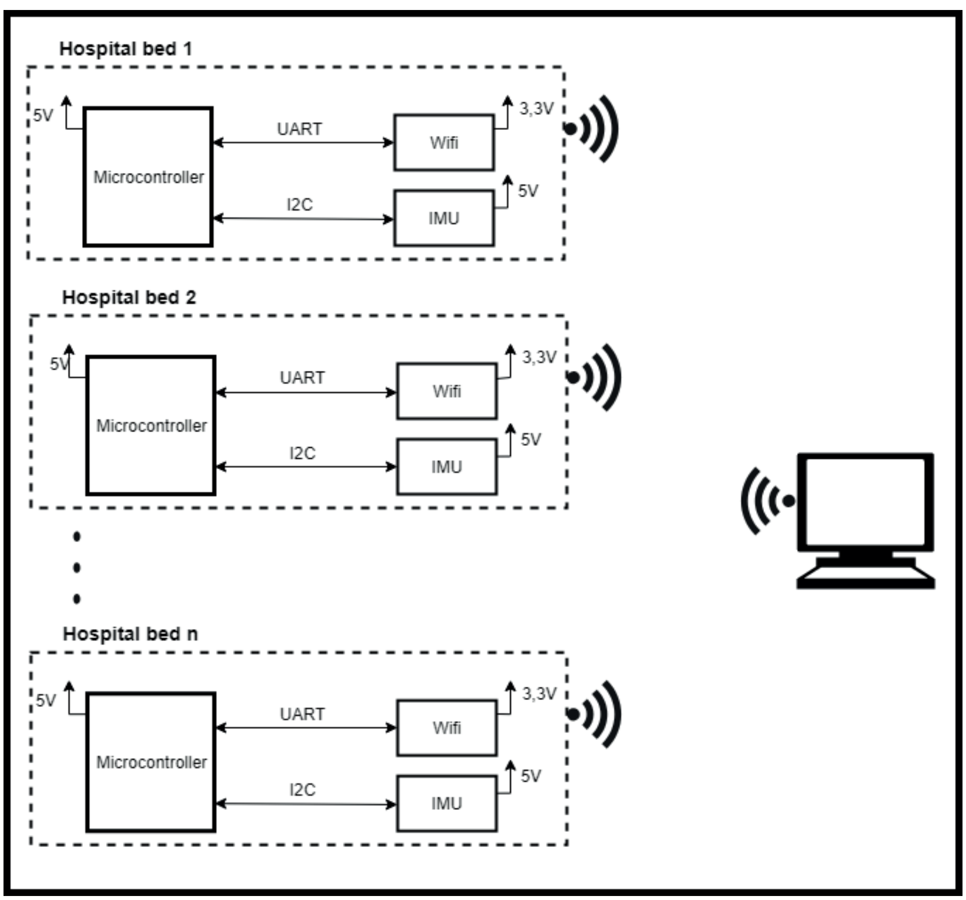
This filter uses previous tilt values to calculate the new ones; the tilt value got from the accelerometer($\theta accelerometer$) is calculated with trigonometric equations, and the angle from the gyroscope($\theta gyroscope$) is got from multiplied angular velocity with the sampling period, which is 10 ms. Finally, a weighted sum of data was made, where the parameters A and B are used to calibrate the sensors. In this application, a took the value of 0.98 and B of 0.020, the sum of these values always must be one, which is one of the features of a complementary filter.

2.2. Wireless Communication

A devices network was made using the Wi-Fi module ESP01 [10]. This network provided a constant check of the tilt of any hospital bed. As shown in Figure 2, information comes from several devices

$$\theta current = A * (\theta previous + \theta gyroscope) + B * (\theta accelerometer) \quad (1)$$

Figure 2. Wireless communication between the network of devices and the central for visualization.



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to the central server. First, the microcontroller sets I2C communication with the IMU getting and processing the data as explained in 2.1; then the microcontroller sends the data to the Wi-Fi module ESP01 through an UART (universal asynchronous receiver-transmitter) communication protocol and finally the tilt data are sent wirelessly through TCP (Transmission Control Protocol) communication between the server and the ESP01.

Communication settings between the microcontroller and the Wi-Fi module was made using AT commands given from manufacturer [11]. These commands indicate to ESP01 which server it should be connect to, as well as, the frequency the information must be sent. Figure 3 shows the protocol communication used. First, the microcontroller sends AT commands and the IP server address to the Wi-Fi modules in order to set connection with the server, then an acknowledgment response of right connection is sent to the microcontroller; next, a label value is sent that indicates from which hospital bed the data comes from, this value matches the number one to the bed one and the number n with the bed n of the unit. After that, the tilt data is sent and the PC receives it. Finally, a confirmation response is sent to the microcontroller to indicate that the data arrived to the server. The process of sending data happens every two seconds.

2.3.Power supply Design

Current requirements were assessed getting a value of 250 mA in total. Manufacturer's voltages specifications for ESP01 and Arduino UNO were used, 3.3 V and 5 V respectively. Those conditions were satisfied using the power source MB102 that has a maximum current of 700 mA and dual voltage outputs of 3.3 V and 5 V, ideal for the circuits used.

On the one hand, a block connections diagram it is shown in Figure 4, in which it can be seen that the energy comes from the electrical grid in an AC signal of 110 V, then it is converted to DC energy through an adapter of 12 V and finally that voltage is converted to 3.3 V and 5 V in the power source. The elements are connected as follows: Microcontroller and Wi-Fi module get energy from MB102 and the IMU get energy directly from microcontroller board with a pin of 5 V.

Figure 3. Communication protocol between microcontroller, Wi-Fi module and PC.

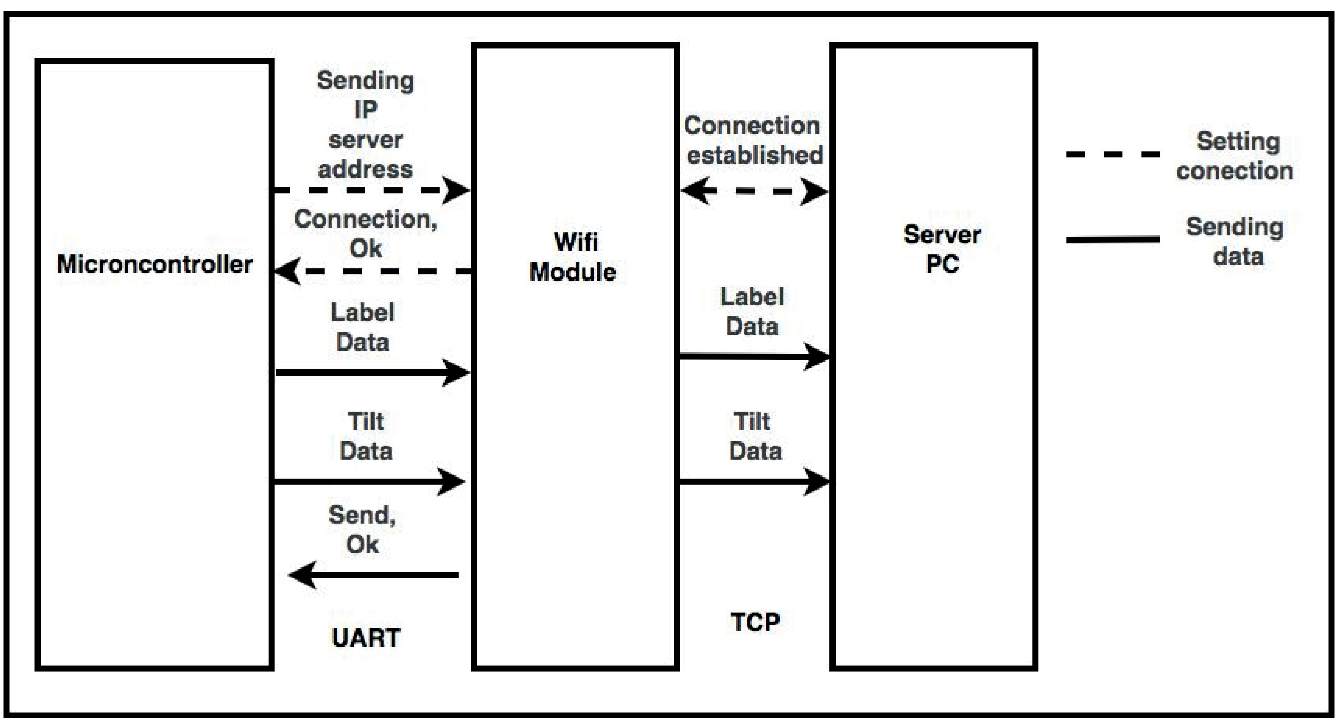

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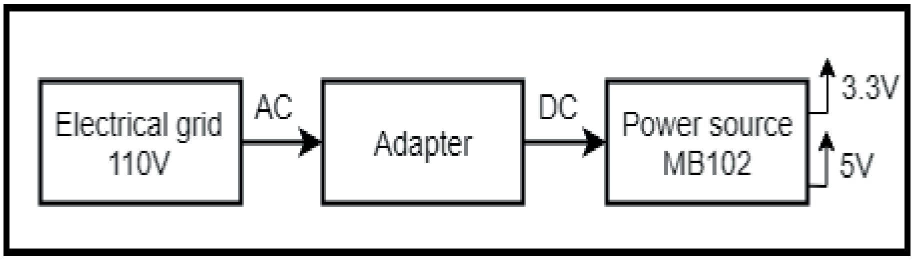
Figure 4. Connection schematic of the power supply.



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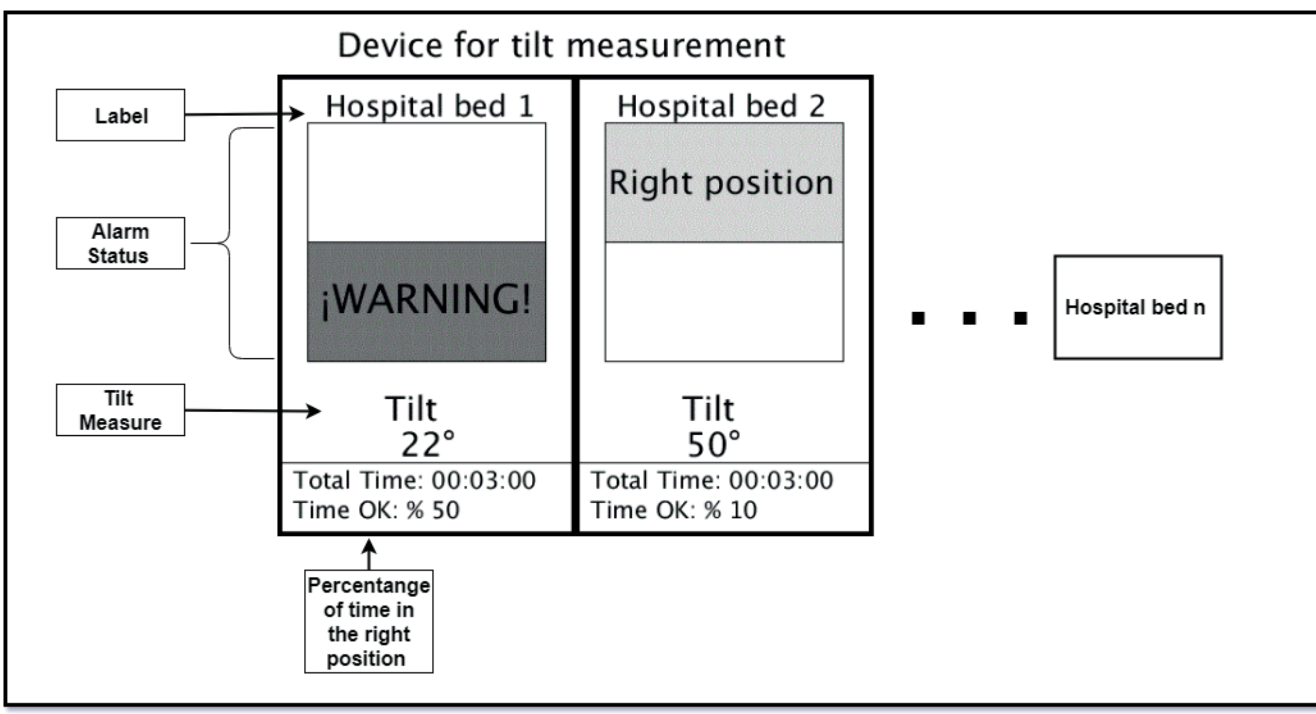
2.4.Data Visualization and Server Design

Reception of data in the PC required a web server. "Network, a "Processing" software library, was used for build a server and connect it with the Wi-Fi modules set as clients.

On the other hand, a graphic user interface software was designed using "Processing" for data visualization of the tilt information of each hospital bed, this software identifies the labels named in 2.2 and the further data received is saved into a vector that has a reserved position for each device. Next, the data stored is assessed in order to activate or deactivate a visual alarm that depending whether the tilt is greater or lower than 30°. When the alarm is activated, it is displayed the message: "WARNING", with a red background, and when it is deactivated it is displayed the message; "right position" with a green background. Also, the measurement time is registered and the percentage of time in which each bead remains in a good position is calculated too.

Figure 5. Graphic user Interface. Time format "hours: minutes: seconds".



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2.5. Practical Test

Two tests were done to observe the signals behavior given by the sensors, tests are described as follows:

2.5.1. Hysteresis Test:

The goal of this test was to identify data deviation in the measurement of the sensor when the tilt of the roll axis was increasing compared to the values when it was decreasing. Furthermore, it was compared the measurements obtained with the ones taken with a pattern (protractor).

Test started with the roll axis in 0°, then tilt was increased gradually 5° every time until getting 90°. Next, from 90° position the tilt was decreased also 5° every time until getting 0°. A protractor was used to have a reference measurement, those values were compared against the values of the sensors as shown in Figure 6, in which vertical axis depicts sensor tilt measure and horizontal pattern tilt measure, both in degrees.

2.5.2. Fixed Position Test:

As a matter of fact, the goal of this test was to determine the measure stability when the sensor is held in a fixed position for a certain time. One hundred measurements were taken, first measures started with roll axis in 0°; tilt was increased 10° every time until getting 90°.

The sensor was held 1 minute in each position and the sampling period was 6 seconds, getting 10 measures per angle. In this test a protractor was also used as reference in order to held the sensor in the right position. Finally, it was possible to plot the obtained data as shown in Figure 6 where vertical axis represents sensor tilt measurement in degrees and the horizontal axis show time in minutes.

Figure 6. Hysteresis Test.

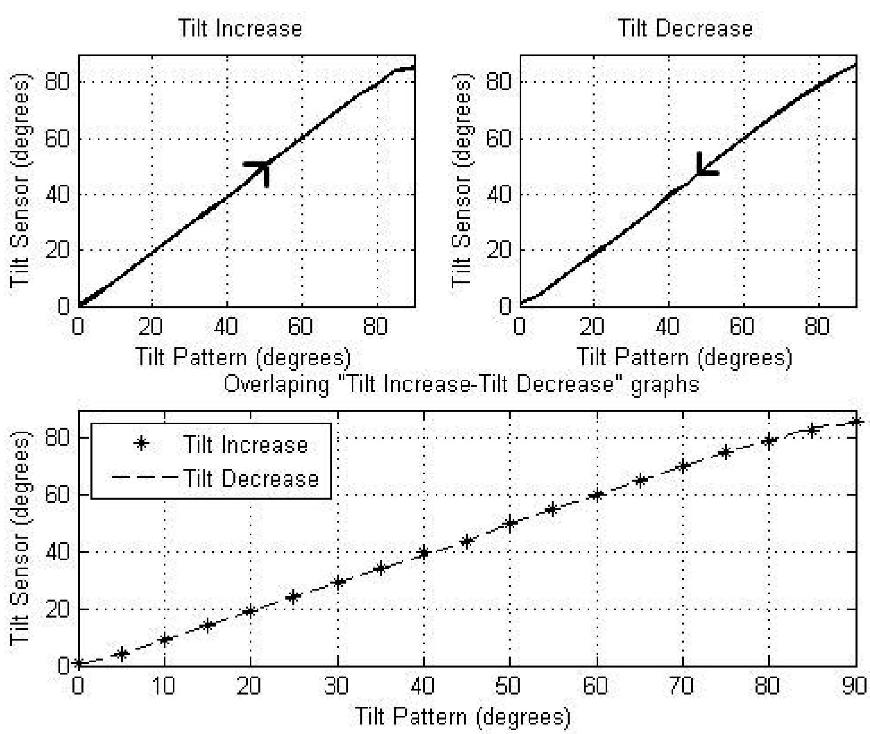

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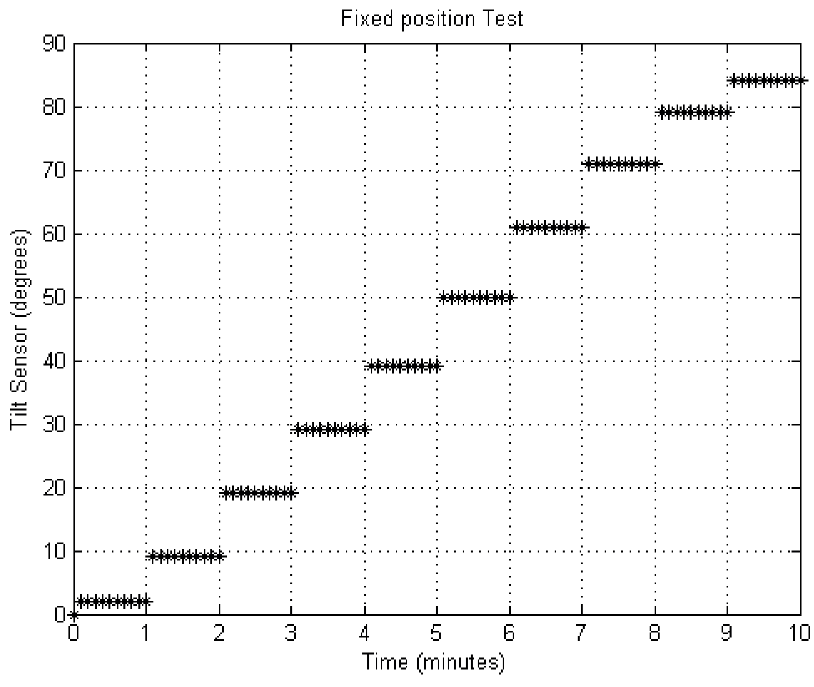
Figure 7. Fixed Position Test.



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3. Results

The hysteresis test was assessed through root mean squared error (*RMSE*), this error determines the differences between two signals and it is obtained by the mean of the square of the errors, in which errors are the differences between the values of the two signals, *RMSE* is calculated with (2).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=0}^{n}(X_i - Y_i)^2} \qquad (2)$$

In (2): n is the number of values of any of the two signals, which must to be equal in both signals, X_1 is ith value of the first signal and Y_1 is the value of the second signal. Three *RMSE* were obtained as shown in Table 1.

Table 1. Mean squared error calculated for different types of data.

Data	RMSE (degrees)
Tilt increase–Tilt pattern	1.25
Tilt decrease–Tilt pattern	1.37
Tilt increase–Tilt decrease	0.45

Source: own.

Additionally, the linearity of the curves shown in Figure 5 was assessed obtaining a linear regression coefficient with the data, the results are shown in Table 2.

Table 2. Mean squared error calculated for different types of data.

Graph	Regression coefficient
Tilt increase	0.9985
Tilt decrease	0.9987

Source: own.

However, fixed position test showed that standard deviation of the five samples in each position is zero, which means absolute stability in each of the 10 different position chosen. However, it is remarkable that at values close to 90°, there is an error of precision, not stability. Two *RMSE* was calculated in order to quantify this error, first one was calculated with the mean of the data “Tilt-increase-Tilt-increase” and the signal “Tilt-pattern”, within the range between 80° and 90°, getting 3.5° of error; second one was obtained with the same data within those values between 0° and 80° getting 0.7° of error.

4. Discussion

The static analysis made to the data of the practical test, shows that tilt measurement with the sensor is suitable for the application described. The hysteresis test confirms the two signals as fairly similar due to the fact that root mean squared error (*RMSE*) between data "Tilt increase–Tilt decrease" is near to zero, therefore, it can be inferred that sensor hysteresis is negligible and doesn't affect the measurements significantly. Then, a comparison of sensor's data with pattern data showed an error of 1.25° in one case and 1.37° on the other, which is acceptable according to [4], [5]; Linear regression determined the measure traceability, the coefficients calculated are very close to one (the ideal), 99.85% in one case and 99.87% in the other, so the sensor has a good traceability. On the other hand, fixed position test suggest that the measure stability is of 100%, which shows that the sensor has a good precision. Although there is an accuracy error at values close to 90° in this application is not important because of the fact that tilt of the hospital beds is rarely between 80° an 90°; Usual range of movement is beyond 80° and results shows the error is meant to be around 0.7°, which is pretty acceptable.

Device network and communications protocols provided a pretty easy and optimal hospital beds tilt control. They allowed to extract the data from each bed and send it to the main central, in where information clearly displayed to healthcare staff. This achievement means a radical change in the way that the problem is currently tackle and gives a reliable alternative to those health care institutions which have not the right tools to prevent VAP.

User interface was a key factor in the function of the system, since corrective action depends on the data visualization and the alarm system. When alarm system is triggered healthcare, staff change tilt of the beds and this action is life-saving. So, therefore the alarm is presented as a simple message that everyone could attend.

Finally, time percentage in the right position of each bed gives valuable information in future, by establishing the relationship between this value and the number of patients with VAP in ICU. Also, databases can be constructed in order to assess the performance of the devices.

5. Conclusions

The presented system is able to measure a reliable tilt in order to know the position of each hospital bed accurately, also, the electronic device registers the percentage of time in the right position, which can lead to establish important results in future researches. Wi-Fi communication protocol provided successful data sending, since it is possible to get an effective control between reception system and its several massive information sending systems.

In addition, the supply circuit implementation, the algorithm optimization and the graphic interface allowed an increased in the device's functionality and efficiency due to the possibility of making it independent from other elements by connecting it to the electrical grid.

Further researches involve incorporations of this device on several hospital beds, carrying out those suitable experiments for checking a good performance of the interconnected devices, as well as, printed board circuit design and its case for a better assembly in the hospital beds.

Acknowledgments

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