In-Bed Patients Behaviour Monitoring System

P. Bustamante[1,2], N. Guarretxena[1], G. Solas[1], U. Bilbao[1]
[1]CEIT y [2]Tecnun (University of Navarra)
pbustamante@ceit.es, nguarretxena@ceit.es, gsolas@ceit.es , ubilbao@ceit.es

***Abstract*- Falls on elderly people represent a significant health problem where having a permanent care personnel attention is the unique effective method to avoid them. As more is investigated on causes originating falls, more is known about pre fall conducts. This project studies in-bed patient behaviour with the purpose of detecting a fall before it happens, sending an alarm to the complete system. The work presented in this article is still being developed within the framework of INTEK projects founded by the Basque Government, in cooperation with *Atica Innovation Company*.**

I. INTRODUCTION

In the last years, the European Union has experimented a significant aging of the population, originating an increase in the number of elderly people as well as a decrease in the number of people who can assume their care [1].

This fact is causing an increase on research and later development of geriatric healthcare systems.

Patients' falls constitute a relatively frequent event; they bring individual injuries as well as institutional level consequences, being one of the indicators used for measuring the quality of the healthcare on Hospitals and Nursing Homes [2].

It is estimated that more than 50% of the hospitalized patients or geriatric residents undergo at least one fall a year, and most of these falls occur on the bedroom, when the patient tries to get out from the bed [3].

Bed falls derive in physical complications such as injuries, hip fractures, muscular weakness, etc., increasing patients hospital-stay-time.

The objective of the presented system is the monitoring of in-bed patients' behaviour, in order to be able to detect anomalous situations and distinguish them from habitual positions of in-bed people.

A. State of the Art

Several fall prevention related articles, patents and products have been studied with the purpose of analyzing the behaviour of patients in bed, in addition to know the fall prevention systems existing on market.

- *Behaviour*

Analyzing the behaviour of Hospital or Nursing Home in bed people [4][5], two main types of behaviour previous to a bed fall can be distinguished.

The first type of conduct includes the cases in which the patient is anxious, becomes violent and jumps or leaves the bed with abrupt movements. Occurs in disoriented people who want to get out of bed and, feeling caught either by the bars or by their own body, want to jump the obstacle. This type of patient does not escape secretly. Fig.1 shows the bed where all tests has been done.

Fig. 1. Equipment the project has been made with.

On the other hand patients with certain independence in mobility can be distinguished, classified like oriented, which although they are indicated that by different reasons they can't leave the bed without aid, they try it anyway. A patient of this group tries to leave secretly; he moves slowly towards the ends of the bed or raises the body over the side rail, resulting in a fall in some cases.

The complication resides in establishing a behaviour pattern that indicates a risk of fall, or contrarily, it indicates that the position of the patient is normal.

- *Prevention measures*

The installation of side rails on beds is one of the most frequently used prevention method in order to protect patients from possible falls, but is not the only existing solution.

A brief analysis of the products designed to avoid bed falls is detailed below.

Bedrails

Nowadays side rails are installed to avoid the patients attempting to get out from the lateral ends of the bed, but the experience has demonstrated not only that it is insufficient, but also that the use of side rails often implies the person

falling from a greater height when trying to climb them to get out of bed [6].

The data from several studies [7], along with the growing number of articles on bedrail related accidents and deaths [8][9][10][11], take us to look into and test alternative interventions to prevent the bed related falls.

Presence detectors

Presence detectors are a flat pad placed under the patient, which indicates whether the patient is laid in bed or not [12][13].

The presence detectors that can be found on the market are similar in terms of utility and operation but are made using different fabrication technologies. The most frequently used techniques are based on pressure sensors [14], conductive strips [15], deformable material [16] and metallic plates [17].

As a disadvantage, although exceptions can be found, most of the pads have a limited life time that ranges from 2 days up to 3 years.

Clips

Another fall prevention system used currently consist of an adjustable cord clipped to the patients clothes. As the resident attempts to leave the bed, the cord is pulled and removes a surface mounted magnet from the alarm unit [18][19].

Infrared sensors

It dwells in install infrared sensors in a fixed point such as the bedroom's wall or ends of the bed. The infrared sensor sends a beam of invisible light towards the receiver delimiting the bed's security area, so that when the patient tries to get up or leave the bed, cuts that beam, and the receiver identifies it as an alarm situation [20][21].

B. *Aims of the system*

The objective of this project consists of designing a system capable of monitoring in-bed people. It is about studying the behaviour of the hospitalized patients or residents in nursing homes while being in bed.

All the movements of a in-bed patient were tried to be registered, in order to study this behaviour: firstly, habitual movements, like the entrance and exit of bed, lying down, leaving the bed etc., to end with more unusual actions like the movements preceding a fall, or the fall itself.

Once known this behaviour pattern it will be possible to design a system capable of recognizing the different situations, movements or positions that usually take place, and detect when the in-bed person is in a situation implying fall risk.

The fall detection system must anticipate the falling moment, that is, to determine whether a person is in danger of falling or not and emit an alarm signal on time so that the fall can be avoided. Similarly the sensor is requested to determine the presence or not of the person in bed.

It must be considered that the system must be patient adaptable, it is to say, it must have several operation modes with the aim of choosing the most suitable one in each case, depending on the patients autonomy.

Finally, it is necessary to emphasize that system's error probability must be minimum, since it could be derived into a no avoided fall or in a false alarm, which implies the care personnel going uselessly to the patient's room, wasting their time and diminishing the reliability of the system on later alarms.

II. ANALYSIS

According to what studied in the State of Art about the behaviour of hospitalized patients or Nursing Home residents, in-bed people to whom this system would settle to, can be arranged in three groups: those patients who lack of mobility, those that can move but can not leave the bed by themselves, and finally those that, although with some difficulty, can leave the bed by themselves.

For that reason, it is interesting for the final system being based on different algorithms that activate according to the mode of operation indicated in each case:

- An algorithm that detects that the person is moving (for patients that can not move absolutely).
- An algorithm that detects an excessive agitation (for patients that can move something or feel very anxious) which implies a possible fall.
- An algorithm that detects the presence of a patient in bed (for all patients and those of the third group in particular)

Within these algorithms it is contemplated the option of detecting that a patient sits up.

The procedure followed in order to obtain the previous behaviour pattern groups has consisted, in the first place, on equipping the bed with several types of sensors.

After that, a simple test stage has been made with the purpose of eliminating those sensors that are not functional. Finally, a test of in-bed patient's behaviour has been made, taking data of 25 people of different height and weight.

A. *Sensors Selection*

The sensors have been placed in different points of the bed[1] according to the purpose they are destined to. What it is tried to monitor is the use of the superior bed rails, the movement of the patient and the position he is:

Bedrails

- Shock sensor.
- Acceleration suffered by the rails in X and Y directions.
- Extensometric gauge for measuring the bedrails' torsion.

Patient position

- Punctual pressure sensors.
- Height scales under the bed legs.
- Infrared sensor.

Patient movement

[1] The bed used in this project is model *Evolution 156* of Hill-Rom [22].

- Horizontal vibration detector.
- Video camera with motion detection configuration.

The camera has two possible use options: on the one hand, serves like a sensor, since it detects movement in certain zone of the image that visualizes, and in the other hand, presents the option to use it like a verification system: when the rest of the sensors announce a fall alarm, the camera allows to visualize the patient to verify if really exists a risk of falling or it is a false alarm.

B. Simple Test Stage

In one first stage some simple tests have been made with object of selecting the most suitable way of sensorizing the bed and discarding those sensors that are not useful or offer redundant information.

As a conclusion of this first stage, not to use scales to determine the position of the patient was decided, due to the complexity of the installation process and to its high cost. In the same way, the infrared sensor was discarded because expected results were not obtained.

C. Behaviour Test

Once this first analysis made, it is come to make the "behaviour test" with the purpose of determining how each sensor responds to certain movements of a in-bed person, and in this way, define the design of the final system.

12 sensors in the bed have settled in order to make the test of in-bed conduct (see the Fig.2):

- Shock sensor.
- Accelerometers on X and Y axes.
- Extensometric gauge.
- 8 plain pressure sensors.
- Camera with motion detection option configured.

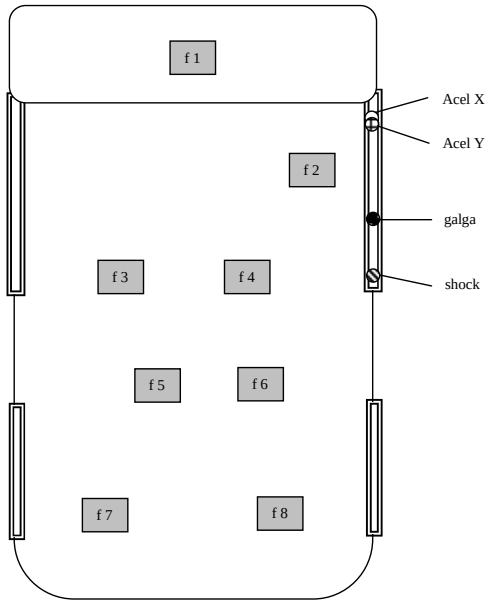

Fig. 2. Scheme of the bed's sensorization

Each voluntary patient, twenty-five in total, has made four tests, three related to each one of the operation modes of the final system and a free movement test.

The tests consist of repeating some common movements such as seating, lying down on a side, leaving the bed, etc., as well as others not so common that led them to locate themselves in extreme positions of the bed, as for example, to move effusively or to try to leave the bed from the end of the sidebars.

Each group of movements corresponds with one of the 4 tests made by each patient and these, as well, with an operation mode of the final fall detection system. Three operation modes are explained in the next paragraphs:

1. *Mode 1: lain down (patient position)*
   It emits an alarm when the patient moves towards some of the lateral side rails or moves away of the head section. It is adequate when it is desired to be alerted of the movements of the patient, mainly with patients who can not get up nor leave the bed by themselves.

2. *Mode 2: seated (bed exit)*
   It emits an alarm when the patient moves from the center of the bed towards an exiting point. It is indicated for the cases in which it is desired to be alerted of a possible attempt of leaving the bed. It is adequate for patients who can sit up, or move within the bed, but can't leave it.

3. *Mode 3: exit (out of bed)*
   It emits an alarm when the patient leaves the bed, and counts the time spent since the exit. It is indicated for the cases where the patient can move freely within the bed, and is desired to receive an alert in the case he leaves it.

Sensors output signals have been visualized in real time using *LabView* graphs [23], and all the data has been registered in addition.

The Fig.3 shows the typical screens in LabView, where all the data of the sensors are displayed and recorded, in real time, for the following analysis.

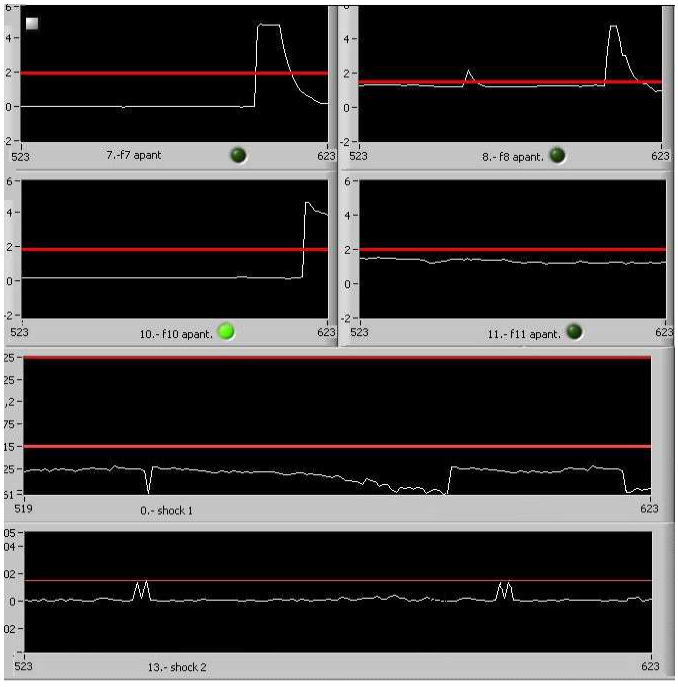

Fig. 3. Real-Time Data Acquisition.

Behaviour test data analysis

The next step has been the study of data collected in the test. Different graphics have been made, using the data collected from the sensors, in each test of each patient, and they have been grouped into operation modes.

Fig.4 shows the response of the sensors installed in the bed during the test in mode1 made by the patient nº 22. The first graph represents the periods in which the patient has leant the head on the central part of the pillow.

The sensor output maximum value (4,5V) corresponds to the moment in which the patient has totally leant his head on, and when the output value is zero, means that the patient does not have the head leaned on that point of the pillow. All the intermediate values are transitions from one position to the other.

Analyzing in the same way the rest of the graphs of the figure and studying the graphs of the 25 patients, the following conclusions about fall risk detection system are obtained:

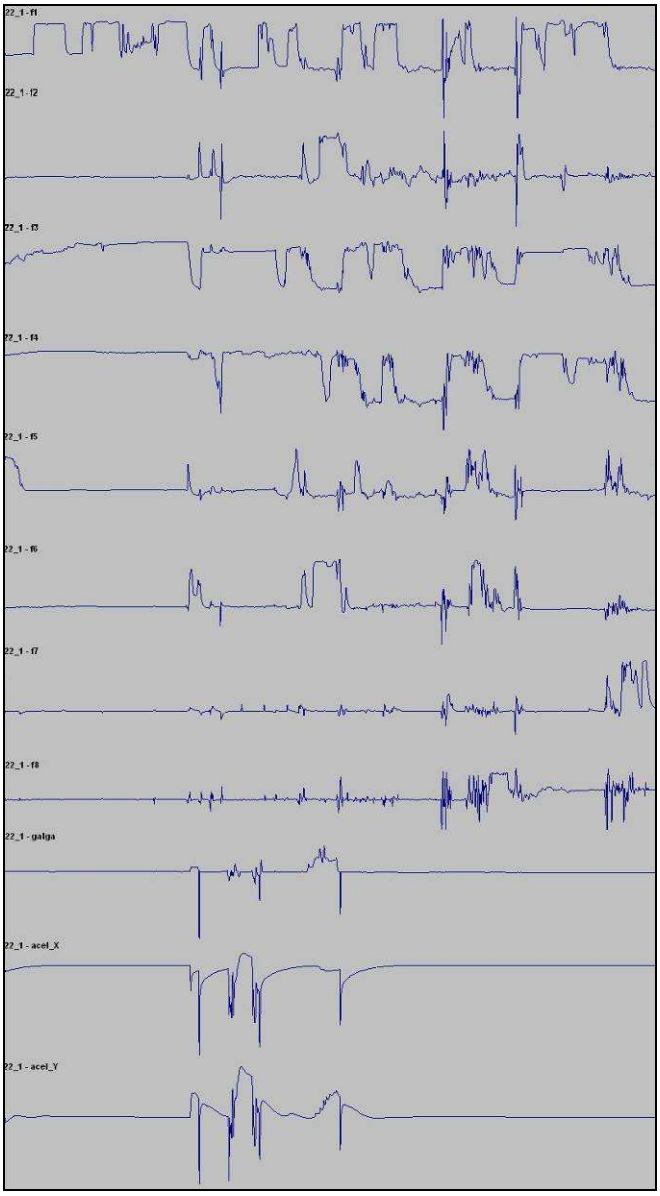

Fig. 4. Sensorial answers of the system when a patient makes the behaviour test on model.

Behaviour test conclusions

Equipping the system with the sensors used in the behaviour test, and establishing a threshold to each sensor, it is possible to design algorithms and implement them in *LabView* so that they detect the following positions of the patient:

- Is or not in bed.
- Is positioned in the right side of the bed.
- Is positioned in the left side of the bed.
- Is positioned in the very bottom side of the bed.
- Is lain down.
- Is seated.

III. DESCRIPTION

The patient monitoring and fall risk detection system is made of 12 pressure sensors, 2 shock sensors, a *datalogger* or data acquisition card, and a PC with the *LabView* program. In the Fig. 5 the scheme of the complete system can be seen.

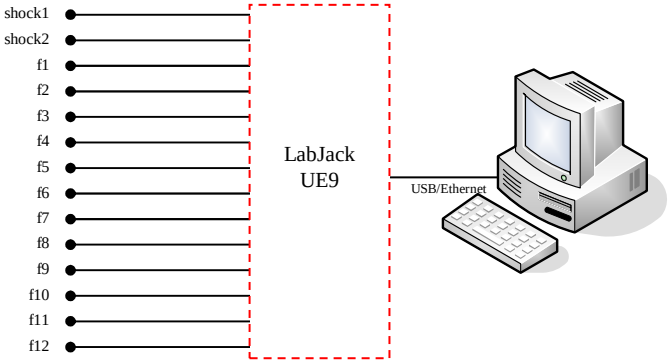

Fig. 5. Monitoring system connections scheme.

A. *Sensorization*

The sensorization has been made installing 14 sensors in different points of the bed. 12 pressure sensors under the mattress have been placed, distributed all over the surface of the structure of the bed. This type of sensor outputs a voltage which is proportional to the pressure.

Fig. 6. Shock sensor installed in one of the bedrails.

On the other hand, a shock sensor has been located in each of the side rails (It can be see in the Fig.6). These sensors produce a tension difference which is proportional to the acceleration of the impact or vibration to witch it is subjected. Its fabrication technology is based on piezoelectric ceramics,

and turns the impact's energy into its proportional electrical energy, that's why they do not need to be fed externally.

B. Data Acquisition

Data acquisition uses a combination of hardware and software measurement based on PC. In this project, a UE9 card from *LabJack* [24] has been used to collect the data originated by the sensors (see the Fig.7). It is a data acquisition and control portable device that can be connected by both USB and Ethernet ports. The network port makes possible to place the control PC further from the sensors (the bed) that in the case of using USB, what is a really useful option in case of making a test pilot in a real hospital or nursing home.

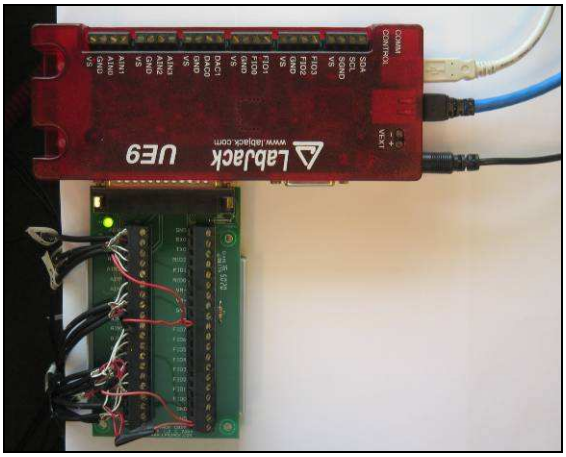

Fig. 7. Sensor outputs connected to the datalogger UE9.

LabView has been used as data acquisition card interacting SW component. The implemented program allows the acquisition, visualization and control of the UE9 card and makes a real time data analysis. This analysis concludes the position in which the *patient is* and decides whether he or she is *in risk of falling* or not.

Fig.8 and Fig.9 respectively show the schematic view and the frontal panel of the monitoring system in *LabView*.

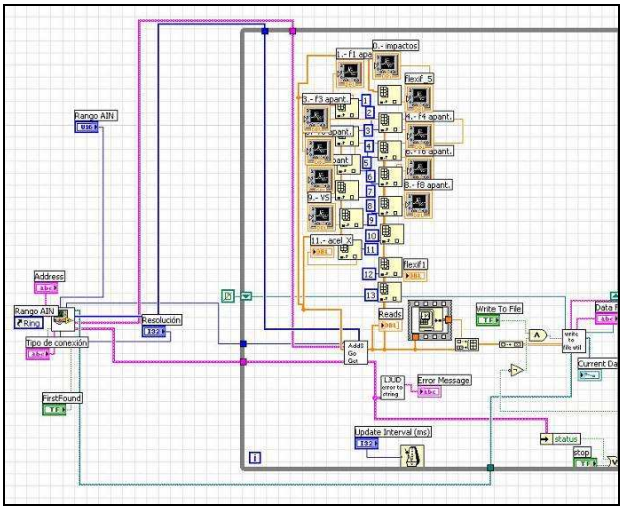

Fig. 8. Block diagram of the Monitoring System in LabView.

C. Algorithm

Separating the data flow originated by LabJack UE9 in different channels has been the first step to implement the different algorithms of the system. Due to the fact that each channel represents one sensor's output, the datalogger has 14 input channels. A binary value is created for each channel. This value will depend on whether the sensor's analogue value exceeds or not a previously established threshold. Thus, 14 binary values to be used as logic operations parameters when implementing the algorithms are obtained.

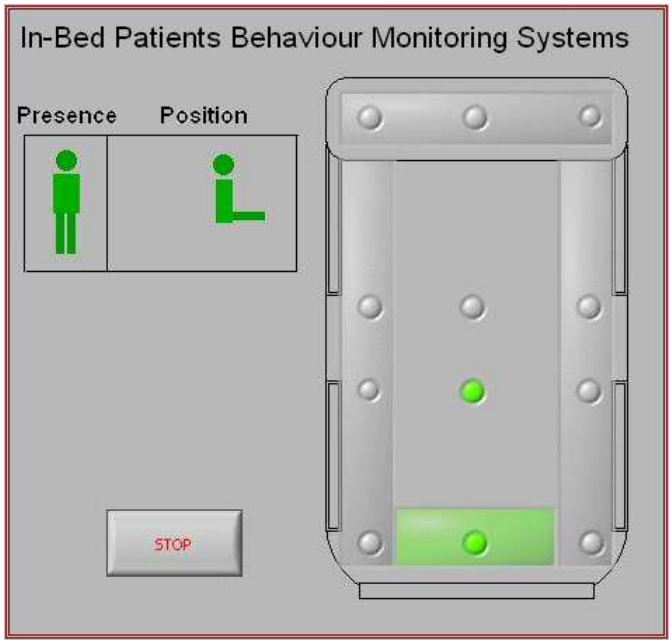

Fig. 9. Front Panel of the Monitoring System.

On the one hand, the exact location of the patient is monitored by means of luminous signals on the bed picture. Apart from that, the system determines the patients' actual position, identifying the following: presence, head leant, seated, lain down, right side of the bed, left side of the bed, bottom of the bed and anxiousness.

Besides detecting positions, whether the patient is closely together or directly over some of the hollows existing between the lateral and inferior bedrails or not is also determined.

Finally, a clock starts in the moment the system detects the patient has left the bed. This clock's aim is to count the time the patient has been outside the bed. The counter puts itself to zero once the patient returns to bed.

IV. Final System Verification Test

Four significant people, which participated in the behaviour test, have been chosen with the purpose of testing the correct operation of the final system.

In first place, each person has been asked to make habitual movements such as lying down in bed, seating, lying down towards the sides or leaving it. Next, each person has tried to escape by the empty space left by the side bars, and finally, has simulated an aggressive behaviour.

The system has correctly detected the presence or absence of the patient in bed in the 100% of the cases, activating the clock when needed.

In 80% of the cases it is suitably distinguished if the patient is seated or lied down, and the 65% of fall risk alarm cases have derived finally in a fall.

V. CONCLUSIONS

The tests made with the final system demonstrate it is possible to detect the presence of a person in bed, the position in which he or she is, and even to determine if the patient is lied down or seated.

The system detects anomalous positions that can be associated to an attempt to get out of bed and derive in a fall, like for example, when the patient is completely in the bottom side of the bed or has his entire body in the top side of it.

On the other hand, it also detects that the patient is too close or over some of the holes that are between the lateral and inferior protection bars. This is important, as the in-bed person identifies them as exit points, and in most of the cases will try to get out of the bed from those points. Finally it detects the cases in which the patient is moving abruptly or presents an excessive agitation.

Future work

Whenever the system detects an uncommon position as the ones above explained, it emits a fall risk alarm. The tests carried out indicate that in the 35% of the times the system detects a falling risk, turn outs to be a false alarm. That's why the possibility of activating a camera which visualizes the patient whenever the system emits an alarm is considered of great importance.

It would be interesting to include a fourth operation mode, so that the system emits an alert when a certain period of time has passed since the patient left the bed, instead of alerting immediately after the exit happens.

Four patients have only participated in the final system verification tests. Although they have different physical characteristics, it is considered that only four people is not enough. That's why it would be desirable to make a more complete protocol test, such as the one made for the behaviour test.

On the other hand, when all tests with LabView are finished, the implementation of this system in an embedded platform is planned, instead of the PC platform, giving certain autonomy to the complete In-Bed Monitoring System.

REFERENCES

[1] CEDITEC-ETSIT-UPM, *El hogar digital como solución a las necesidades de las personas mayores.*

[2] A.Pescador, M.Lizán, A. Romero, P. Córcoles, Registro de caídas en el complejo hospitalario de Albacete durante el año 2000.

[3] R. Tideiskaar, Phd President fallPrevent, LLC, *Bed Safety in Long Term Care.*

[4] M.Q. Vu, N.Weintraub, L.Rubesntein. *Falls in the Nursing Home: Are They Preventable?.*

[5] J.B Young, M.Robinson, S.Chell, D.Sanderson, S.Chaplin, E. Burns, J.Fear. *A whole system study of intermediate care services for older people.*

[6] E. Capezuti, G.Maislin, N.Strumpf and L. Evans, *Side Rail Use and Bed-Related Fall Outcomes Among Nursing Home Residents.*

[7] D.Oliver. *Bed falls and bedrails-what should we do?* .Age and Ageing 2002;31:415-418

[8] K.Talerico, E.Capezuti. *Myths and Facts About Side Rails*

[9] Gover I, Kingdom A(200) *The rise and fall of cot sides.* Nursing Standard.14,31,40-41.

[10] G. Powell-Cope, A.Baptiste, A.Nelson. *Modification of bed Systems and Use of Accessories to Reduce the Risk of Hospital-Bed Entrapment.*

[11] M.van leeuwen, L. Bennett, S.Wesr, V.Wiles, J.Grasso *Patient falls from bed and the role of bedrails in the acute care setting.*

[12] Skil-Care Corporation. *AirPro Bed Exit Alarm* www.skil-care.com

[13] Curbell. *CareSense Dual Monitoring System.* www.curbell.com

[14] Traversing Conductor Pressure Sensitive Switch. US5,554,835.

[15] Detection system for patient´s movements out of a chair or bed. EP 1 417 928 A1

[16] Security System for Detecting Movements. WO 9846135

[17] Switch Apparatus responsive to Pressure or Distortion. US4,484,043.

[18] Smart Caregiver Corporation. Pull String Monitor. www.smartcaregivercorp.com

[19] Powind. Bed Sentinel. www.powind.com/ccp/restraint.htm

[20] Alimed. PIR Remote Alarm and Nurse Call Unit. www.alimed.com

[21] Wespot. Intelligent CareSensor. www.wespot.com

[22] http://www.hill-rom.com

[23] http://www.ni.com/labview/whatis/

[24] www.labjack.com