Detecting Falls Among Elderly Patients in Nursing Homes by Using Wireless Sensor Networks

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ABSTRACT

Accidental falls among the senior population are the leading cause for seniors' admission to hospitals. Wireless Sensor Networks (WSN) can be used to efficiently detect falls of senior patients in nursing homes. While some fall detection methods focus on the acceleration of the patient, others register acceleration and body position to detect falls. In this paper, we describe a novel alert system using WSN capable of detecting falls based on the body position and bed occupancy. The system was created according to data collected in MoteView from seven test subjects. Accordingly, it was designed to sense three possible conditions: (1) patient being active; (2) patient lying in bed; or (3) if the patient has fallen down. The experimental portion of this research was performed at a nursing facility to further validate measurements previously collected in the laboratory. Furthermore, the system has been tested on three subjects for different types of falls and was found to detect all types of falls with high accuracy. In order to provide caregivers with constant alerts regarding patients' conditions a graphic user interface was created in LabView. Design of this system maximizes the capabilities of Memsic's Wireless Sensor Network Developmental Kit consisting of MICAz and MIB520 base station. Overall, the system provides a very simple and effective solution that yields high accuracy for detecting falls.

I. Introduction

Accidental falls represent a major issue in nursing homes. According to the Centers for Disease Control and Prevention, on the average there are 100 to 200 reported falls each year in nursing homes with 100 beds [1]. Accidental falls among elderly have massive socio-economic impacts. Most elderly patients admitted to hospitals are victims of falls. Accidental falls are among the primary cause of death among the elderly. Furthermore, falls might seem not to have immediate consequences but the long-wait on the floor can increase the risk of death. Thus, falls detection and real-time monitoring to enable first-aid as quick as possible is urgently needed in nursing homes and other elder care facilities.

The issue of accidental falling can be vastly improved through the use of sensors which monitor patient activities and remotely communicate any and/or all information to attending physicians or caregivers in charge. For instance, sensors placed on a patient's body and/or around the patient alert caregivers immediately upon the occurrence of a fall. There is substantial research available in the field of fall detection. Qiang Li[3] has classified this research in two categories. The first class analyzes only acceleration for fall detection and the second class uses both acceleration and body orientation to detect falls.

In this paper, the system is based on a Wireless Sensor Network that continuously monitors and analyzes a patient's movement. Our method is created in such way where it maximizes the capabilities available through the Memsic Wireless Sensor Network Starters Kit. A dual axis accelerometer is used which is placed on the test subject's chest. Another sensor was placed on the patient's bed which informs of actual occupancy. Our system is based on the logic that if the patient is in not in a horizontal position and the bed is unoccupied, then the person has fallen down. This approach is characterized with simplicity and accuracy in determining falls. Finally, we have designated a software interface to process and analyze data and report emergency situations to the monitoring station. The remaining parts are outlined as follows: Section II provides detailed information on the network's hardware; Section III presents the method and measurements; (3) Section IV underlines the software interface, and Section V is the conclusion and further development.

II. Hardware implementation:

A. System Architecture

For this research, we have worked on one of the MICA platform called MICAz Mote. This work is composed by a set of MICAz Motes with IRIS OEM module (M2110). The MICAz is a 2.4 GHz Mote module used for enabling low-power wireless sensor networks. MICAz is used to test for Light, Temperature, RH, Barometric Pressure, Acceleration/Seismic, Acoustic, and Magnetic based on the sensor/data acquisition board. These motes have a radio transceiver, a microcontroller, a sensor board (MTS400CC) and power supplied by double AA batteries. The microcontroller is an 8-bit ATMega 1281 which contains and runs the firmware which implements the 802.15.4 specification. The sensor board MTS400CC has a set of three sensors: The Accelerometer, Light sensor, and Temperature sensor.

MoteView was designed to be the primary user interface between a user and a deployed network of wireless sensors. MoteView provides an easy means of logging wireless sensor data to a database, analyzing, and plotting sensor readings. Data presented in Figures 4, 5 and 6 have been exported from Moteview to Excel.

B. Hardware Components

Figure 1 presents the hardware connections and network topology used in this work. One of the Motes works as a base station and it is attached on the station called MIB520. The base station is connected to the PC via USB adapter and allows the aggregation of sensor network data onto the PC. The sensor nodes collect data (light, acceleration etc.) from the environment and send this data directly to the base station which in turn forwards it to the computer within every user defined time interval.

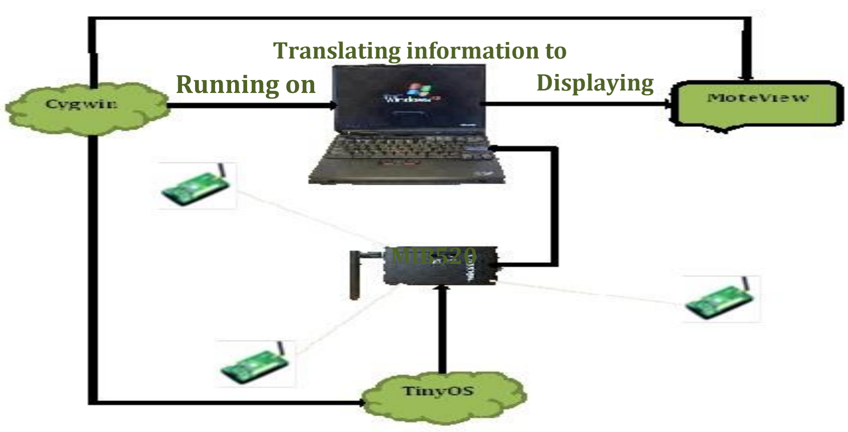


Figure 1. Hardware connections and communications of MICAz

III. Algorithm and Measurements

As mentioned in introduction we will use Memsic WSN to detect 3 different **situations**: if **patient is active**, if **patient is lying in the bed**, or **if patient has fallen down**. These situations are outcomes of 4 different **events**: **patient torso is in upright position, patient torso is in horizontal position, bed is occupied, bed is not occupied**. Depending of the joined outcomes of these events we can determine which one of previously mentioned situations has occurred. This logic is displayed in Table 1.

In order to record first two events (patient torso in upright or horizontal position) we have placed MICAz sensor node on the chest of the patient. MICAz has MTS400CC sensor that is equipped with Dual-axis Accelerometer ADXL202JE. We have placed the sensor on the chest of the patient in such way that positive y-axis is going towards the ground, and x axis is perpendicular to in and parallel to the floor. According to the Figure 2, the orientation of the sensor node varies with the body position of the patient. The ‘x’, ‘y’ and ‘z’ are acceleration axis which represents the orientation of the wireless sensor on the patient. Even though the wireless sensors we are using in this project have acceleration only in ‘x’ and ‘y’ direction, we included z axis in the above diagram for better visualization of the orientations of the sensors. When the patient is standing, positive y axis is going straight to the ground so in that event we have recorded acceleration of $Acc_y \approx 10m/s^2$. When patient is laying y axis is parallel to the ground $Acc_y \approx 0m/s^2$ as illustrated in Figure 2.

Despite limited daily activities of nursing home patients, we studied all possible activities that normal elderly patients would do. For each activity we have recorded accelerations in y axis. We had seven different sample data from seven (7) different individuals have been collected. Even though our study is about fall detection of patients in nursing homes, studying the whole possible body movement of patients is very important to draw a distinction line between a fall and all other activities of patients. List of patient activities studied: (1) walking; (2) walking with cane; (3) standing straight; (4) lying on the back; (5) lying on left side; (6) sitting; (7) running; (8) sitting and watching TV; (9) tying shoes; (10) lying on the right side; (11) eating from a table; and (12) sitting on the bed.

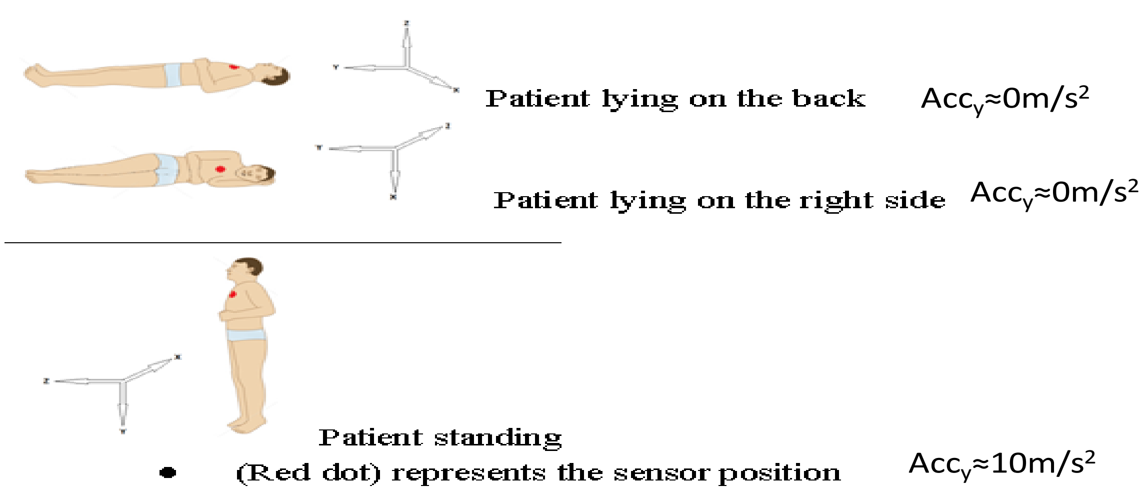


Figure 2. Axis orientation of bi-axial accelerometer which is placed on the patient

Table 1: Fall Detection Depending on 4 events

IF the position of patient torso **IS**	**AND IF** the patients bed **IS**	**Then** the situation **IS**
Upright	Occupied	PATIENT ACTIVE
Uptight	Unoccupied	PATIENT ACTIVE
Horizontal	Occupied	PATIENT IN BED
Horizontal	Unoccupied	PATIENT HAS FALLEN DOWN

The above list of activities has been demonstrated by seven subjects for certain fixed duration of time allocated to each activity. The graph of acceleration in y axis for all subjects is similar and one example is shown on the Figure 3.

According to Victorian Government health information, fall is unintentionally coming to the ground or some lower level and other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure. In this paper a fall is detected by the position of the patient's body using wireless sensors. As the last position of body in the case fall is horizontal in line with the floor or lower level the patient fall on, horizontal position of a body means a fall according to the data from the wireless sensors.

After careful analysis of our data we have concluded that when body is in horizontal position acceleration in 'y' axis is always ranging between $-4 m/s^2$ and $+4 m/s^2$ and any other activities previously mentioned on this paper gives acceleration over $7\ m/s^2$. Example of this can be seen in Figure 3. Values of acceleration are shown in Table 2.

TABLE 2: Body position determined from sensor acceleration in y-axis

Acc_y (acceleration in y-axis)	Body position
$Acc_y > 7\ m/s^2$	Patient in upright position (patient active)
$Acc_y < 4\ m/s^2$	Patient in horizontal position (patient laying)

Furthermore different ways of falls have been studied and our threshold has been tested on 3 individuals. All falls have been recorded and we didn't have any falls alarms. The graph for patient falling from a bed as in Figure 4 and falling from standing position are shown as in Figure 5.

Having a clear distinction line between lying down and other activities, the next step is to distinguish between a lying on the bed (normal sleep) and lying on the ground (falling). Since both lying on the bed and lying on the ground assumed to result in horizontal body position, there should be a mechanism to distinguish between lying on the bed and lying on the ground which will be discussed next.

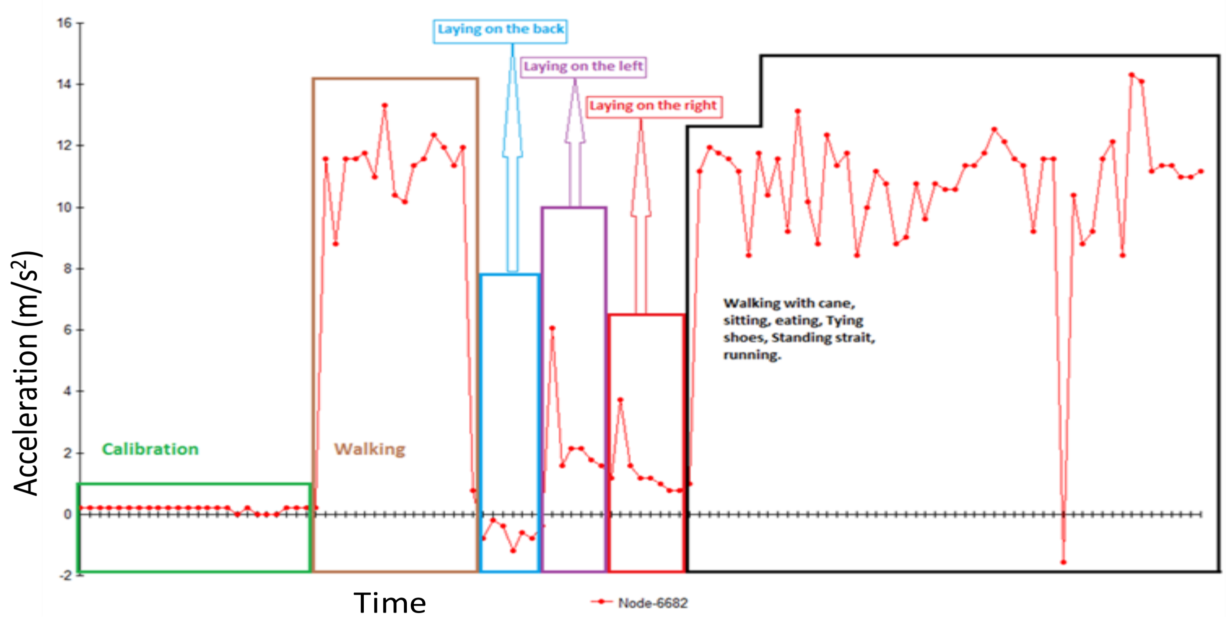


Figure 3. Acceleration in Y-axis of One Test Subject for Various Activities.

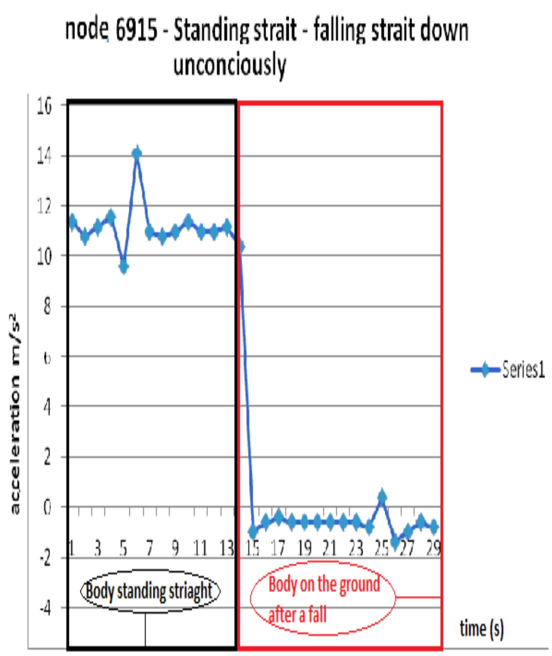


Figure 4. Falling to the ground from a standing body position

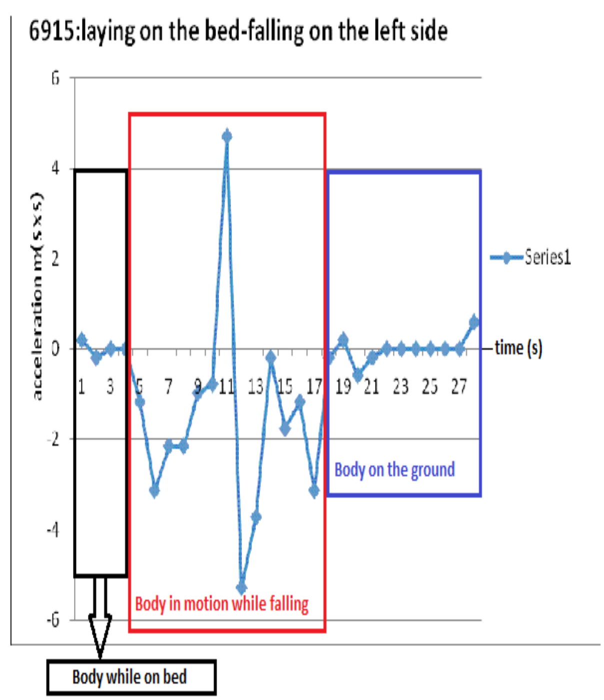


Figure 5 Falling from a bed to the ground

III B System developed to distinguish between lying on the bed and on the ground

As mentioned previously, first node that is placed on patient chest is determining if patient is active (in vertical position) or lying (in horizontal position). When patient is horizontal position, second system will help us to differentiate between laying on the ground (which is a fall) and lying on the bed which is assumed to be sleeping (not a fall). Schematic of this system is shown in Figure 7.

Switch placed on the bed of the patient is used to detect the occupancy of the bed. Once the patient lays on the bed, he will depress the switch connected in DC circuit with 4.5V battery in 8 LED lights. Led lights are placed in a box that is constructed from opaque material to prevent light coming from outside, and in such way only the light that is coming from the LED lights is controlling the light intensity in the box. MICAz node is placed in the box and it is sending light intensity data to MIB520 base station. If the light intensity is under 1Lux, that is a signal LED's are not emitting light and that bed is not occupied. If light intensity is above 10Lux that is a signal that LED's are emitting light and that bed is occupied. So now we have all necessary technology to determine 4 events that will tell us if patient is active, if patient is laying down or if patient has fallen down. Once again this logic was displayed in Table 1.

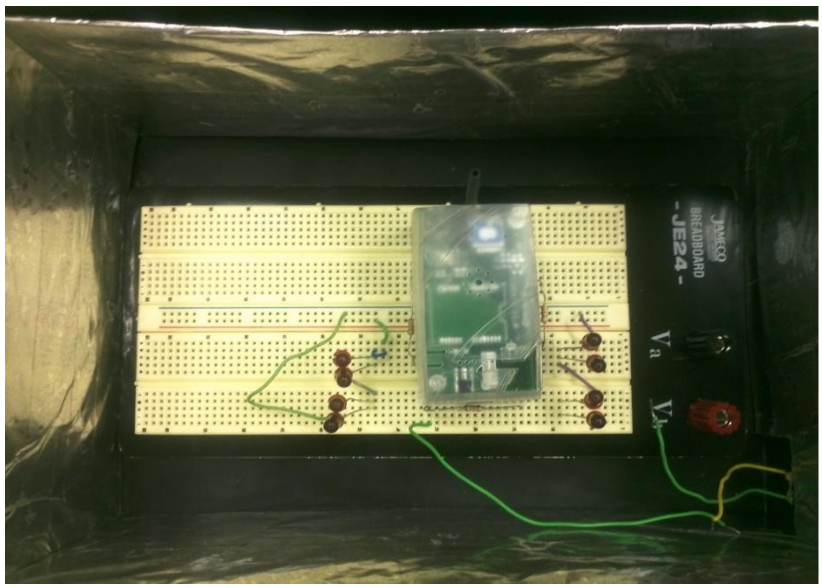


Figure 6: Device for detection if bed if occupied.

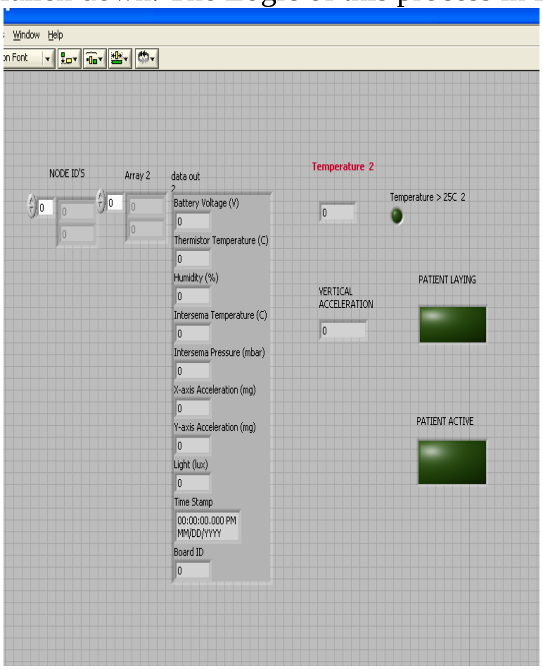
IV. Data processing and creation of alerts in software with user interface

In this part of the project we have used a program to process the data that are received from Memsic WSN. Software used is Labview2010. LabVIEW is a graphical programming environment that is used to develop sophisticated measurement, test, and control systems using intuitive graphical icons and wires that resemble a flowchart.

In the current stage of this research there are two graphical user interfaces created. In the first interface LABVIEW receives data from Memsic WSN and MICAz node that is placed on patient chest, and then it compares values from acceleration in y-axis with our set thresholds. Depending on those values, two alerts are possible: patient is in laying ($y_{acc} < 4m/s^2$) or patient is active ($y_{acc} > 7m/s^2$). This front panel can be seen in Figure 7. Furthermore these values have been coupled in two consecutive time intervals (y_{acc} (T), y_{acc} (T+1)) in order to get more accurate information. Second graphical user interface has been created for data received from node that detects bed occupancy. If flux is under 1lux that there will be an alert that bed is unoccupied. If Light flux is above 10 Lux second alert will prompt that bed is occupied. Front panel for these values can be seen in Figure 8.

Development of this program had several stages. First we had to acquire third party drivers [4] for communication between crossbow and LABVIEW. These drivers weren't provided by National Instruments. Schematic (block diagram) that was made premade this 3rd party software had to be optimized for our sensor board. Board MTS300 was changed to the board MTS400. Wiring and array had to be changed so we could manipulate with the data. Finally, we made thresholds, and made warnings on front panel.

Next stage of this research project will focus on creating a LabVIEW graphical user interface with capabilities of processing data from two nodes simultaneously. Once that is achieved, there will be one interface that will present three alerts: patient is active, patient is in bed, patient has fallen down. The Logic of this process in Labview is shown in Flowchart 1.



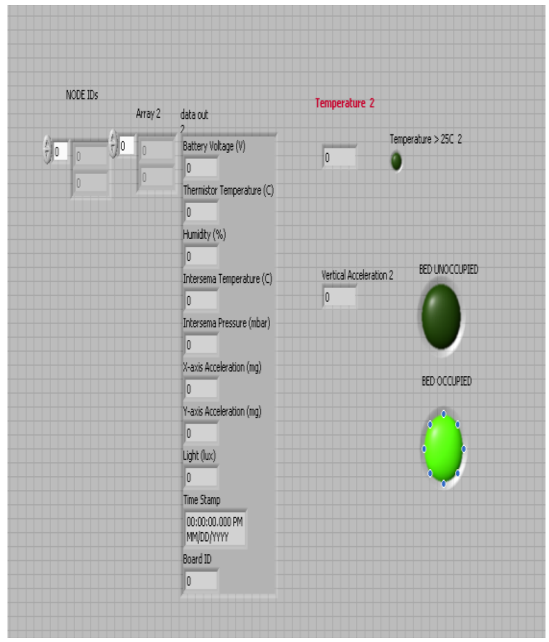
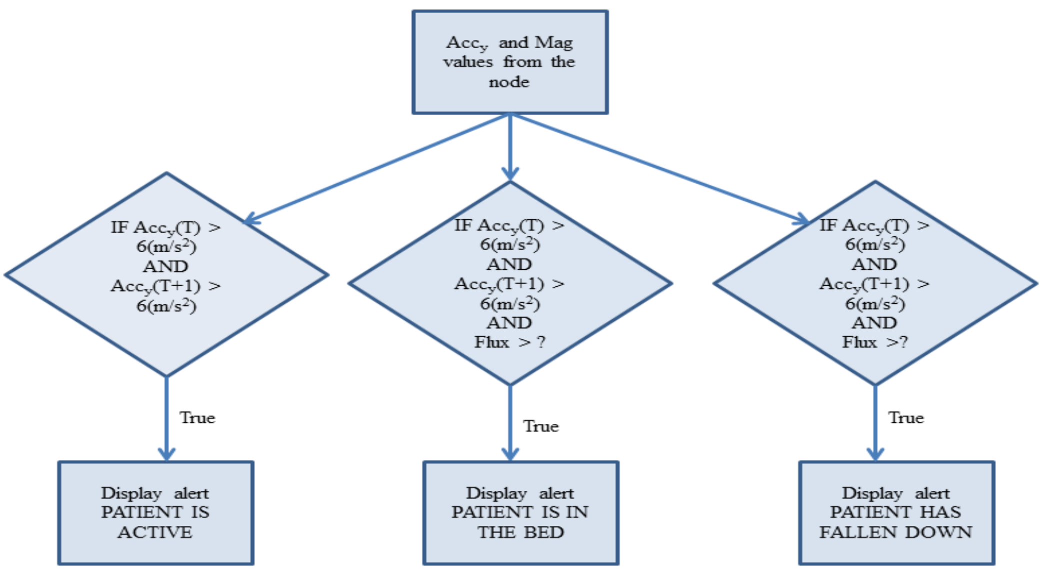


Figure 7. LabVIEW graphical user interface showing patient position.

Figure 8. LabView graphical user interface showing bed occupancy.



Flowchart 1: Algorithm in LABVIEW

V. Conclusion and Future Work.

Accidental falls represent serious issue among the senior population. Timely detection of these events in nursing home significantly improves treatment of injuries and reduces costs to healthcare system. The aforementioned paper is a clear demonstration of a simple and effective Wireless Sensor Network (WSN) system which detects senior patients falling in nursing homes. Behavior of senior patients was observed in nursing home and used to create list of possible activities that senior patients engage in daily activities. Then the system was created based on data from seven test subjects, and then system capabilities were verified on three test subjects. System has detected every fall, and didn't have false alarms.

In further research we will concentrate on creating user interface that will be able to simultaneously process data acquired from two nodes and provide care givers with alerts about conditions of patients. Also, we are developing circuit with 555 timer that will prolong life of our 9V battery. Furthermore, there is an idea to use MTS420 sensor board equipped with GPS tracking device that will provide inform us not only about condition of the patient, but also with their accurate position.

VI. Acknowledgements

This research was supported by the Office of Naval Research, Department of Defense Grant W911NF-11-1-014.

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