Design and testing of a vibration sensor to detect excessive motion preventing fall-risk patients from leaving their beds

Chen Si Chia Jeaneve (A0130053B), Leong Jia En (A0127088Y), Ng Yun Lin (A0131328N)

ABSTRACT

It is not uncommon for patients staying in the hospital to fall off their beds while attempting to get off without the assistance of the nurses. It has become an increasingly significant problem as the consequence, when serious, might even lead to death. In this paper, we present a sensor system to detect excessive motion of the patients on the bed so as to alert the nurses and prevent patients from falling off the bed. From technical and clinical specifications, we designed and developed a sensor system, equipped with an electrical circuit and a piezoelectric sensor to detect motion signals in the range of 0 - 6V. A mechanical model of the system has been developed and motion tests have been executed on the hospital bed to assess the mechanical and electrical characteristics of the sensor system. Experimental results revealed that the sensor system is able to distinguish between excessive motion and normal motion on the patient's bed. This not only aids the nurses in monitoring the patient's sleep pattern but also alerting when patients are having excessive motion which can be related to trying to get off the bed or due to discomfort.

1. Introduction

1.1 Objectives

Patients falling down in hospitals are not uncommon, especially for the elderly, with a statistic showing 30% of these patients being 65 years old and above. [1] These are frequently observed even when hospitals have taken precautions, such as grouping the patients together in a single multi-bedded room with close supervision by ward nurses. It becomes more difficult during the night, when the number of nurses are reduced and close supervision of the patients is not feasible. The consequences of falling are serious due to the old age, and this may cause prominent disability, loss of independence or even lead to death in serious cases. [2]

This project aims to develop a sensor system that detects excessive movements of the bed, which indicates that the patient might be attempting to get out of bed, or signalling discomfort. The signals detected due to the excessive movements will trigger an alarm and LED system which will alert the nurses of the patient's intention, and potentially prevent patients from falling off the bed. This project is collaborated with Tan Tock Seng Hospital (TTSH), where experiments and testing of our sensor system are done.

1.2 Current Situation in Tan Tock Seng Hospital (TTSH)

In TTSH, fall risk notice are placed at the bed front for patients that are categorized under fall risk patients so that nurses will be able to take extra notice. According to the nurses in TTSH, railings are secured at all times during the night to prevent patients from getting off the bed themselves. However, patients are still able to slip out of the bed through the small opening at the end of the bed.

Currently, a bed sensor pad is placed on the mattress of the hospital bed with an electronic device connected to it. The device indicates 'Monitoring...' when the patient is detected on the pad and 'Fall Risk!' when the patient is not detected on the pad. A sound and light alarm system will be trigger when the patient is not on the sensor pad, alerting the nurse that the patient is trying to get off the bed.

However, the alarm system only sounds when the patient is completely off the detection mat, and it is often too late for the nurses as the patients would have already fallen off the bed when the nurses arrive. Due to the movements of the patients when in bed, the sensor pad may have folded up which will compromise the accuracy of the sensor pad.

2. The Sensor System

2.1 Mechanical Design

The sensor system consist of 3 components, namely the piezoelectric sensor, the electrical circuit and the DAQ. These 3 components are placed on 2 different acrylic boards, separating the piezoelectric sensor from the electrical circuit and the DAQ.

Fig.1 and Fig.2 show the complete setup of the mechanical design of the sensor system, with the components on different acrylic board. The acrylic boards are secured to the bed railings using velcro strips as it provides easy removability for the nurses.

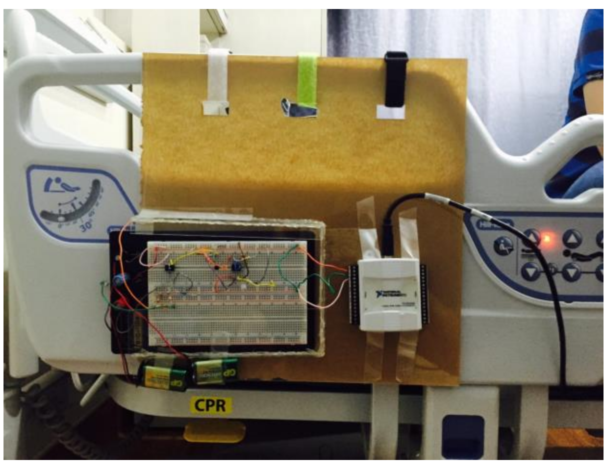

Fig.1. Electrical circuit and DAQ attached on the acrylic board hanging at the side railing on the hospital bed

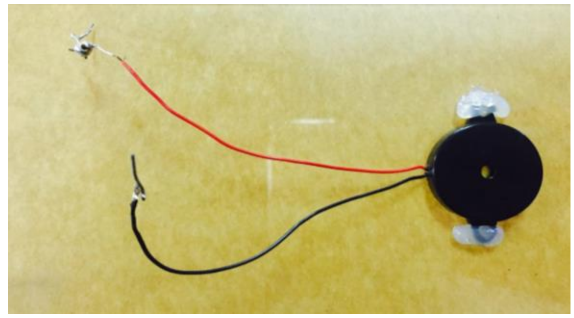

Fig.2. Piezoelectric sensor attached to an acrylic board

2.2 How it works

According to our observations in our initial hospital visit, we noticed that the bed frame and railings vibrate when patients are moving on the bed and when attempting to get off the bed. By hanging the acrylic board with the piezoelectric sensor on the side railing of the hospital bed, vibrations of the side railing produced by the movements of the patients are detected by the piezoelectric sensor. The signals will be detected and recorded when the side railings of the bed vibrates and hit the acrylic board. When the acrylic board is hit by the bed railing, it swings backward and forward. The returned forward motion hits the side railing, producing more vibrations and signals.

The acrylic board containing the electrical circuit and the DAQ will be attached to the railings of the bed front through 3 velcro stripes. The piezoelectric sensor is placed separately from the electrical circuit and DAQ. This is because when all 3 components are placed on a single acrylic board, the movement of the acrylic board is damped by its heavy weight. This results in a lower accuracy in detecting the vibrations, which in turn produces a smaller signal that is not easily being detected or having no signals at all.

2.3 Principle of Piezoelectric Sensor

A piezoelectric sensor was used to detect vibrations from the bed providing the input to the electronic circuit shown in Fig.3. Piezoelectric sensors uses the piezoelectric effect to convert mechanical stresses into electrical signals. The stress can be caused by a pressure applied to the polarized crystal, the resulting mechanical deformation results in an electrical charge. [3]

The piezoelectric effect occurs when the charge balance within a material's crystal lattice is altered. When there is no applied pressure on the material, the positive and negative charges are evenly distributed so there is no potential difference. When pressure is applied, the charge imbalance creates a potential difference. The voltage induced from the pressure is proportional to the applied pressure. [4]

2.4 Electronics Design

The electronics consist of 3 different parts, namely the differential amplifier, the NPN transistor and the 555 timer as shown in Fig.3. First, signals from the piezoelectric sensor is input into the differential amplifier. Then, the V_{out} of the differential amplifier is connected to the base of the NPN transistor. Lastly, the V_{ce} from the NPN transistor is input into the trigger pin of the 555 timer which will turn on the LED and sound system. These 3 components make up the sensor electronics design and the specifics of each component will be further described below.

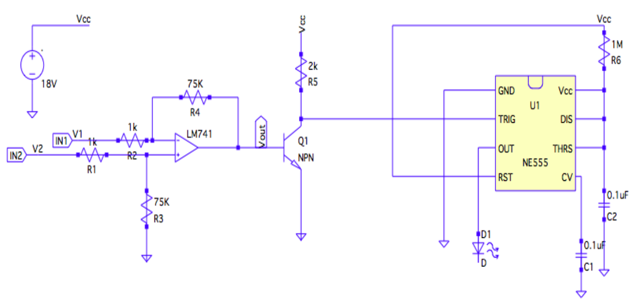

Fig.3. Electronics circuit consisting of differential amplifier, NPN transistor and 555 timer

Vibrations of the bed made by the patient will be detected by the piezoelectric sensor which converts into electrical signals, serving as the input into the differential amplifier as shown in Fig.4. A differential amplifier is a combination of inverting and non-inverting amplifier. It amplifies the difference between the two input voltages. The voltage output, V_{out} is proportional to the difference between the input voltages and can be obtained by,

$$V_{out} = \frac{R_4}{R_2}(V_2 - V_1) \tag{1}$$

Where gain of our amplifier is,

$$G = \frac{R_4}{R_2} = \frac{75K}{1K} = 75 \tag{2}$$

Differential amplifiers provide immunity to external noise because it rejects common-mode voltages, which is an advantage for low voltage systems such as our sensor system. [5]

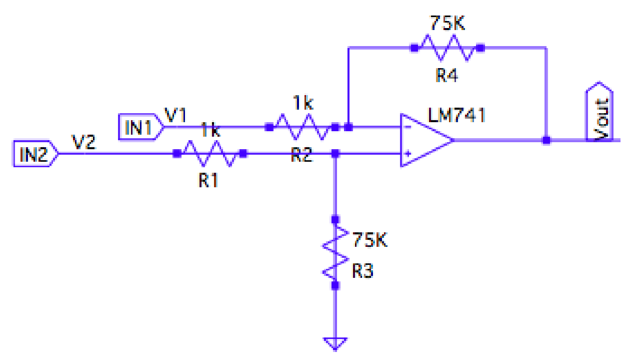

Fig.4. Circuit of the differential amplifier

The NPN transistor works as a switch to the monostable multivibrator as seen in Fig.6. When no V_{out} from the differential amplifier is supplied into the base of the NPN transistor, the circuit is 'open' and $V_{CE} = V_{CC}$. However, when vibrations are detected and a pulse is applied, the differential amplifier will supply a V_{out} to the base of the transistor, 'closing' the circuit. This draws the V_{CC} down to the ground, reducing the value of V_{CE}. V_{CE} is input into the trigger pin of the 555 timer.

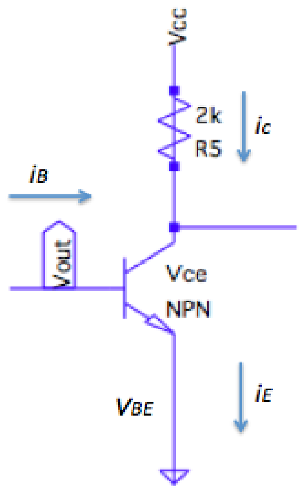

Fig.5. NPN transistor

Initially, when no vibrations are detected, the monostable multivibrator will be in the stable state, where $V_{CE} = V_{CC}$ and the trigger pin voltage is high. When V_{CE} is high, the discharge pin allows current to flow to ground and prevents charge from building up on C_2, shown in Fig.6. When vibrations are detected, the NPN transistor 'closes' the circuit, causing V_{CE} to decreases. When V_{CE} drops below $\frac{1}{3}V_{CC}$, the input switches from the stable state to an unstable state and the output is turned on. The discharge pin turns off, removing the short circuit across C_2, thereby allowing C_2 to charge through R_6. When the voltage across it is below $\frac{2}{3}V_{CC}$, the threshold pin remains low so the output pin stays on. When the charge builds up enough to make voltage across C_2greater than$\frac{2}{3}V_{CC}$, the threshold pin switches off the output pin. At the same time, the discharge pin switches back on and prevents the capacitor from charging until another vibration is detected. Thus, the input returns back to stable state. [6]

The length of time the LED remains on is a function of the time it takes for the capacitor to charge to $\frac{2}{3}V_{CC}$. It is also determined by R_6, since the resistor prevents the flow of current to the capacitor and thus increases the time it takes for the voltage across it to reach $\frac{2}{3}V_{CC}$.

Our circuit is a monostable multivibrator where there is only one stable state and produces a single output pulse when it is triggered by the vibration of the bed. Monostable multivibrators return to their original and stable state after a period of time determined by the time constant of the RC coupled circuit. [7]

$$t = 1.1R_6C_2 = 1.1(1M)(0.1\mu F) = 1.1s \qquad (3)$$

The output of the 555 timer is connected to a LED, where the LED will be turned on for 1.1s when vibrations are detected.

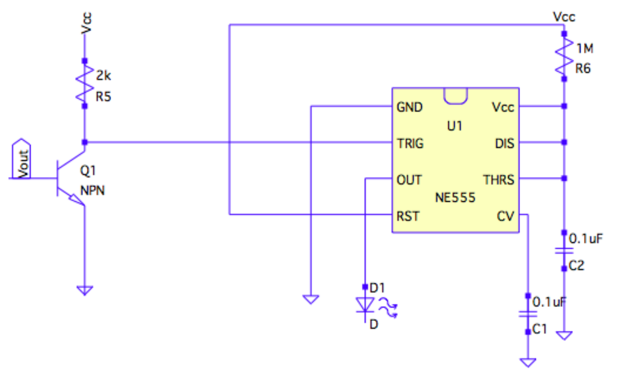

Fig.6. Circuit of NPN transistor and 555 timer

3. Experimental Results

3.1 Testing of Placement of System using the Red Pitaya Oscilloscope

Using the Red Pitaya Oscilloscope and a piezoelectric sensor, tests were conducted at different positions of the bed to decide the placement of the sensor. Tests were done by securing the vibration sensor at the bed front, bed side and on the bed. Signals were recorded when the test subject is stationary and when the test subject was moving off the bed.

According to the testing done, the most optimal placement of the sensor is at the side railings, where the signals were the greatest compared to the other positions tested as shown in Fig.7. This explains for the position where the piezoelectric sensor is placed which is at the side railing to obtain the most vibrations and signals.

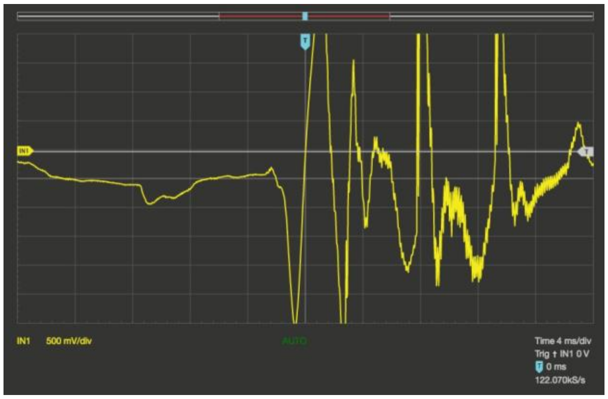

Fig.7. Signals detected due to movement when sensor placed on the side bed frame

3.2 Testing of System using LabVIEW

After using the Red Pitaya to decide on the optimal position to place the piezoelectric sensor, LabVIEW was used to monitor and analyse the results of the vibration sensor system. The output signals produced by the vibrations were inputted into LabVIEW for observation and analysis through a DAQ.

Tests were carried out on a TTSH hospital bed, with our sensor system hanging on the side railings as shown in Fig.1.

Tests were executed under four situations, namely when the test subject is lying stationary on the bed, flipping around on the bed, producing excessive motions, and attempting to get down from the bed. The voltages of the respective situations were measured over a period of 10 seconds with an interval of 0.001 seconds. The results were recorded using LabVIEW and all the data points are consolidated in Fig.8.

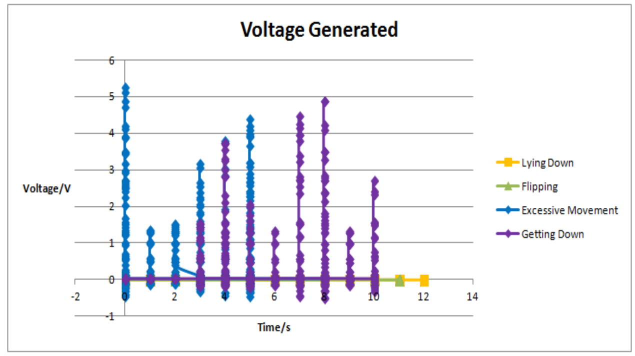

Fig.8. Voltage recorded from LabVIEW

As all the results are taken with an interval of 0.001 seconds, there are multiple data points per second. For easy analysis, the maximum voltage generated per second was extracted and plotted in Fig.9.

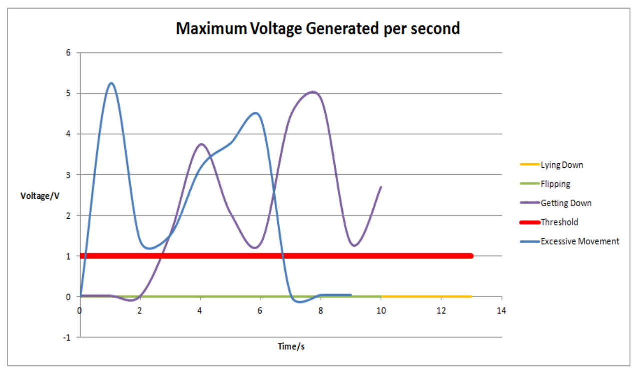

Fig.9. Graph showing maximum voltage recorded by the sensor system under the 4 conditions

Based on the results from Fig.9, both situations of test subject lying stationary or flipping on the bed registered low maximum voltage values of less than 1V, whereas in situations where the test subject is having excessive movement and when the test subject is attempting to get out of bed, majority of the maximum voltage registered were more than 1V. Our sensor system is able to effectively distinguish between regular patient movements such as regular flipping and slight movements while sleeping or resting on the bed, and differentiate those with excessive movements from aggressive actions. This is optimum as our sensor system will not sound unnecessarily and cause any unnecessary disturbances or inconvenience for the nurses and patients.

As our sensor system is designed to detect 2 situations, which are when the patient is attempting to get out of the bed and when patients are producing excessive movements which could be due to discomfort. These 2 situations are of significance because the nurses need to be alerted in both situations. According to the results tabulated in Fig.9, a threshold of 1V can be placed in LabVIEW as majority of the signals under these 2 situations are above 1V. When the voltage registered exceeds 1V, there will be a beeping sound produce from the laptop to alert the nurses, as shown by the red data points in Fig.10.

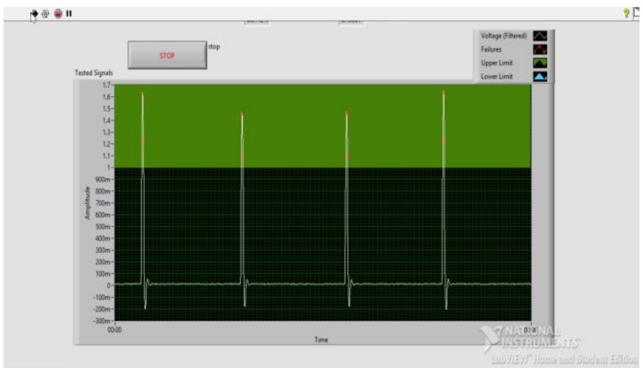

Fig.10. Voltage exceeds the threshold of 1V

4. Conclusion and discussions

4.1 Conclusion

In conclusion, we have successfully developed a sensor system that is able to detect 2 situations, which is when the patient is attempting to get out of the bed and when patients are producing excessive movements, through receiving signals that are more than the threshold of 1V. When signals received from the vibrations exceed the threshold, a beeping sound will be produced to alert the nurses.

Other than acting as an alarming system to notify the nurses of the patients’ movement, the sensor system also allows the nurses to monitor the patient's’ sleep pattern throughout the night, which would be essential for the nurses to know whether the patients are well rested.

4.2 Possible future developments

Currently, our sensor system are situated on 2 separate acrylic boards. This can be further improved to have all components of the sensor system to be situated on a single acrylic board instead. This will aid the nurses in attaching the system on the bed railings as it is now compacted into a single item.

For a future phase of our sensor system, the movement of all patients can be monitored in real time using a common interface such as a displaying screen outside the ward. This will not only allow the nurses to monitor the patients’ regular movements but also notify them when patients are having excessive motion or attempting to get out of the bed through an alarm system linked to the sensor system.

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Appendix

Appendix A

Maximum Voltage recorded with LabVIEW, with respect to the 4 conditions, measured in voltage.

Time/s	Lying Down	Flipping Over	Excessive Movement	Getting Down
0	0.005521	0.004485	0	0.020302
1	0.004636	0.003201	5.245027	0.020772
2	0.005376	0.004352	1.353582	0.020602
3	0.004674	0.004448	1.517425	1.553737
4	0.005459	0.004725	3.170033	3.742469
5	0.005574	0.004574	3.77522	2.043242
6	0.006627	0.004785	4.384216	1.312551
7	0.003881	0.004333	0.035875	4.461268
8	0.004426	0.003828	0.035904	4.874113
9	0.006182	0.003696	0.035797	1.312263
10	0.008804	0.004029		2.694367