International Journal of Sensors and Sensor Networks
2014; 2(5): 42-47
Published online December 18, 2014 (http://www.sciencepublishinggroup.com/j/ijssn)
doi: 10.11648/j.ijssn.20140205.11

Implementation of capacitive touch sensing safety system for electric adjustable beds

Mohamed M. El Rayes[1], Tamer M. Nassef[2, 3, *]

[1]Electronics and Communication Dept., Fayoum University, Fayoum City, Fayoum, Egypt
[2]Computer and Software Engineering Dept., Misr University for Science and Technology, 6th of October City, Giza, Egypt
[3]Electronics and Communication Engineering, October High Institute of Engineering and Technology, 6th of October City, Giza, Egypt

Email address:
mohamed-rayes@hotmail.com (M. M. E. Rayes), tamer@ieee.org (T. M. Nassef)

To cite this article:
Mohamed M. El Rayes, Tamer M. Nassef. Implementation of Capacitive Touch Sensing Safety System for Electric Adjustable Beds. *International Journal of Sensors and Sensor Networks.* Vol. 2, No. 5, 2014, pp. 42-47. doi: 10.11648/j.ijssn.20140205.11

Abstract: Electric adjustable beds may be dangerous if used without good and effective safety system. Many safety solutions were developed, but none of them can provide a complete protection against injuries. We have developed a new protection system for electric adjustable beds to ensure the safety of the users and their pet animals when using these beds. This safety system applies capacitive touch sensing technique on all metal parts of the bed base in addition to the perimeter of the bed frame to stop the bed if a human or an animal touches these parts. Enabling capacitive touch sensing on this large metal surface besides manufacturing constrains, is a challenging problem. This paper addresses the design of this embedded safety system and illustrates solution of the problems associated with implementing capacitive touch sensing technique in electric adjustable beds.

Keywords: Safety System, Capacitive Touch Sensing, Electric Adjustable Bed, Embedded System

1. Introduction

Safety is the most important feature that customers look for in any product. Electric adjustable beds are built from large metal parts and strong mechanical system to lift the bed up and down and the head and leg sections. These parts can cause severe and dangerous hurts to any human or bet animal if part of his/its body gets between these moving metal parts; So many safety methods were developed to reduce the possibility of injuries. The simplest solution to this problem was covering the lower part of the bed with thick cloth. It is not effective solution especially for pet animals in addition to wearing of the covering material due to movement of the bed sections. Recently some studies are using electrical sensors to increase computational analysis accuracy with both hardware and software sensory setup for their studies [1-4]. Latest electrical solution to that problem, implemented by Leggett & Platt, was to put capacitive touch sensor on the perimeter of the bed frame to stop the bed if it detects a touch from human or pet animal body. This solution is effective only if something gets between the bed and its frame, in addition to its relatively easy design. There is no protection from the metal parts under the bed, which are of more importance; besides, the detection algorithm depends on the rate of change of measured capacitance and that will seize its ability to detect pets reliably because they introduce low capacitance change at slower rate. In this paper, a newly developed system converts all metal parts of the bed to capacitive touch electrode is presented, moreover to the frame perimeter to detect any human or pet animal touch and stop the bed immediately using an intelligent adaptive algorithm, where computer will be used to assist the designers to implement this algorithm as used in [5-9]. Gray parts in “Fig. 1” represent the metal parts and it is easy to notice that many areas under the bed represent danger for children and pets during the adjustable bed operation. Therefore, the proposed solution provides complete protection in all situations and enables the user to use the bed even without its frame safely.

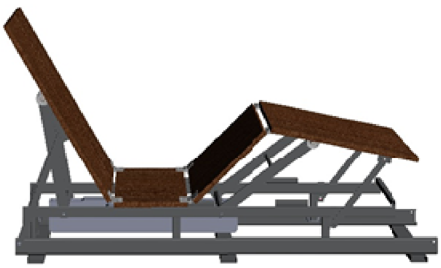


Fig. 1. *.Adjustable Bed [1].*

2. Materials and Methods

2.1. System Hardware

The hardware consists of two main sections: touch sensing subsystem and bed control subsystem.

2.1.1. Touch Sensing Sub-System

There are two challenges in developing capacitive touch sensing for bed base. The first one is connecting all parts to each other tightly. The second one is enabling capacitive touch sensing on this large mass of metal because the capacitance of that large metal surface is very large compared to small human touch capacitance.

There are two types of connection between different parts. The first one is special combination of bolts, washers and nuts on unpainted regions to connect parts mechanically and electrically. The second type is using helical wire, which provides high reliability and fatigue resistance, with special connectors to connect moving parts electrically.

The idea behind capacitive touch sensing is detection of the increased measured capacitance by the sensor due to touch of human or animal body. The sensitivity of the system is the ratio between the capacitance differences to the capacitance of untouched electrode. Because of large capacitance of the metal electrode, capacitance introduced by human or pet animals touches, must be high enough to be measured reliably. The solution is to apply a thin layer of epoxy painting to the entire metal surface, which is considered an insulator material. The increase of capacitance due to a touch is inversely proportional to the thickness of the insulation material. So, in this way, we make sure that touch effect is maximized and still have a simple manufacturing process.

This large touch electrode is connected to a capacitive touch sensor circuit. The circuit consists of a capacitance-measuring sensor IC, a LDO voltage regulator with noise filtering design and bi-directional level shifter for interfacing to the control sub-system.

The Low-Dropout regulator circuit [10] has capacitor C1 on the input pin to reduce input voltage noise. Capacitor C2 is used to form a low pass filter in conjunction with the internal resistor. Capacitor C3 is chosen to stabilize the internal control loop. Stable supply voltage is extremely important in this application.

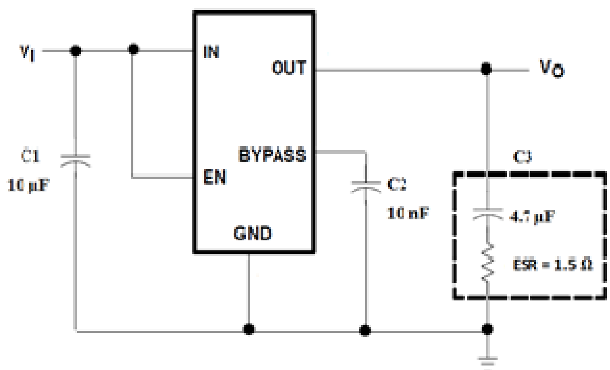


Fig 2. *Low-Dropout Voltage Regulator Circuit [10].*

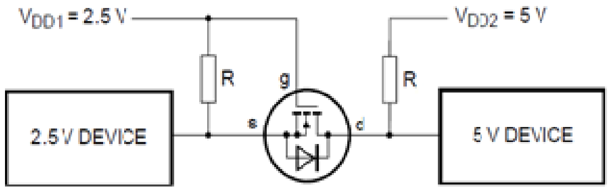


Fig. 3. *Basic building block of the bi-directional level shifter [14].*

The bi-directional level shifter circuit [11] is designed to convert the 5-volt signals coming from the control subsystem to the 2.5-volt level that the touch sensor operates on. The capacitive touch sensor is in fact a capacitance-measuring device [12, 14]. It consists of precise current source to charge the electrode and timing control system to precisely select the electrode charging current. The measured signal is passed through configurable filters to reduce the effect of noise, which is represented by random fluctuations in the measured signals. The sensor reads the voltage on the electrode, which represents the amount of capacitance, by the integrated 10-bit A/D converter.

The capacitance is inversely proportional to voltage on the electrode. Therefore, when a human touches the electrode (bed base), the capacitance increases and the measured voltage reading decreases. The amount of decrease in voltage reading should be high enough so that it can be differentiated from noise. The key point in the design for large electrode capacitance is to tune the sensing parameters, such as charging time, charging current, number of samples,… etc., to get ADC reading around the middle point to balance the sensitivity requirements and the speed of detection and power consumption.

The system tuned the touch sensor parameters to meet desired requirements by using a capacitive touch sensing development system design for that purpose [14].

2.1.2. Bed Control Sub-System

Its main task is to receive measured capacitance date, analyze them and take the appropriate action depending on the status of the bed movement.

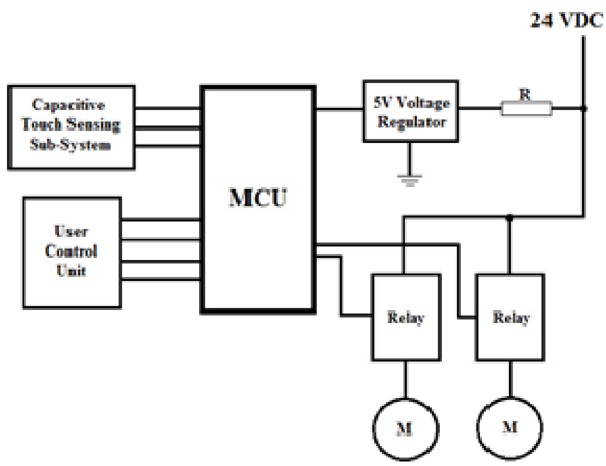


Fig. 4. *Diagram of the bed control system*

The control sub-system consists of a microcontroller, voltage regulator circuit and relays to control the motors. The series resistor at the input of the voltage regulator is very important because it limits the power wasted in the regulator due to high voltage difference between the input and the output terminals by reducing the voltage at the input terminal thus reducing the heat generated by the regulator and eliminating the need for heat sink.

The MCU runs at 48MHz clock to provide fast response to detects touches and stops the bed. The MCU controls the relays through drivers consist of nMOS transistor connected to the relay coil, which is driven by the input +24V. The user control unit gives the MCU information about required motor to be enabled.

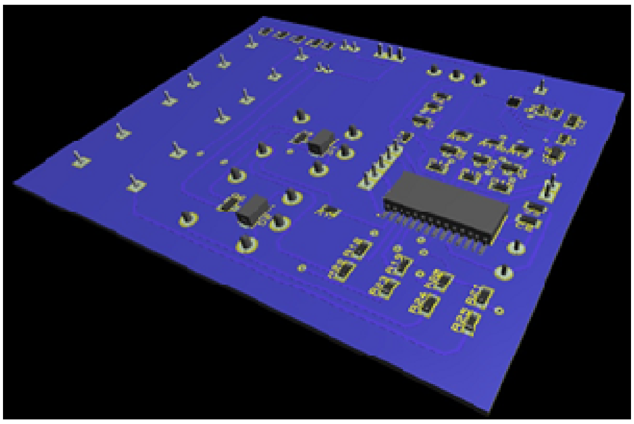


Fig. 5. *Top layer of the final PCB*

Relays are selected to handle about 10A DC current because the maximum current for any motor at the maximum load is about 6A DC and this value was measured precisely using an automated testing system designed for adjustable electric beds [1].

2.2. System Software

Using embedded C programming language [15] and MATLAB software [5,6,8,9], we developed the firmware to provide fast response of the safety device and maintain low power consumption.

At the startup of the device, the microcontroller initializes all parameters of the touch sensor and then the sensor measures the capacitance of the untouched electrode (the bed base) to get a base value of the electrode capacitance. The MCU receives multiple readings to determine the noise range and eliminates its effects on the touch detection threshold. After that, the MCU puts the sensor in sleep mode and all relays drivers are not active at this point to save the power. Starting motors decisions are taken by another controller connected to the user control unit and this safety system is responsible for allowing these decisions to take place.

When the user press a button on the user control unit, the microcontroller will enable capacitance measuring in the sensor and check the received data to make sure that nothing is touching the bed base.

If the electrode is not touched, the controller will enable the required relay driver to provide power to the targeted motor. However, if it detects a touch, the motor relays will not activated ant a warning light will be activated instead.

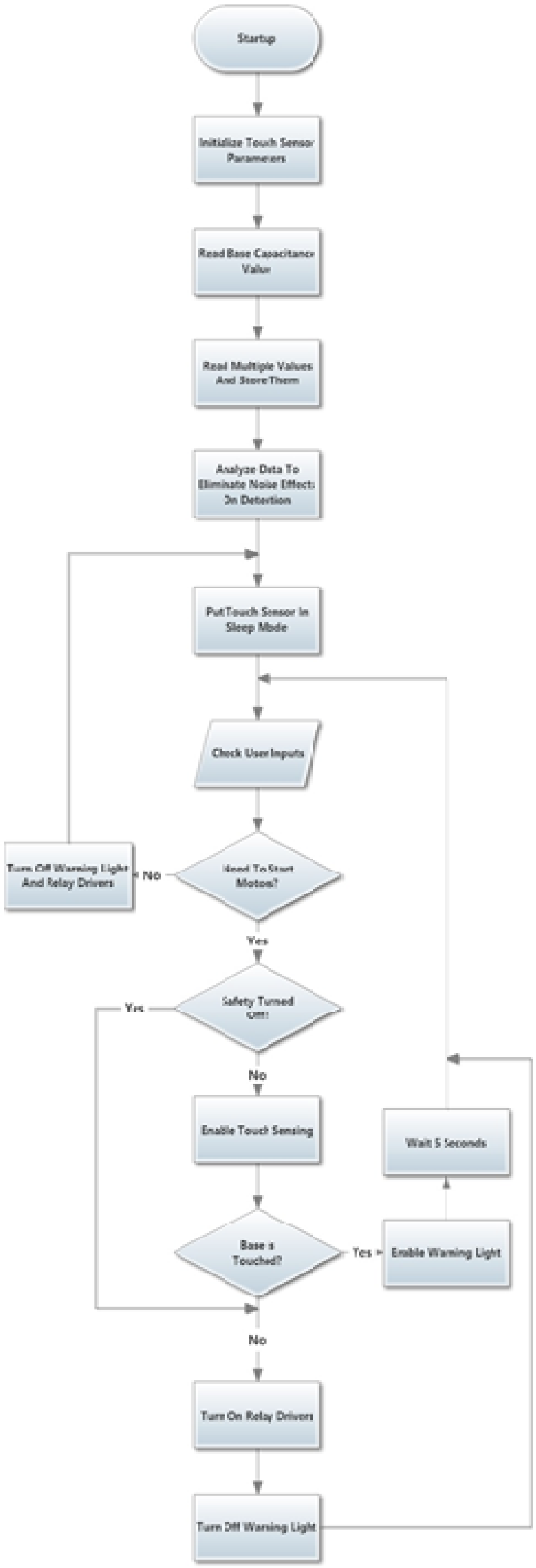


Fig. 6. *Software flowchart*

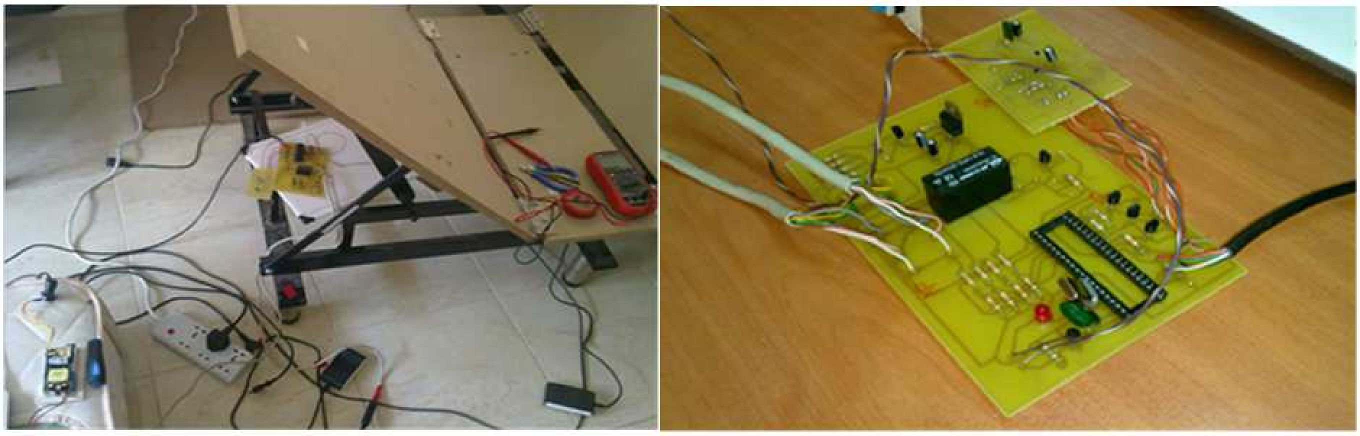
During the movement of any part of the bed, the MCU is monitoring the capacitance of the touch electrode to stop the--motors if anybody or any animal touches the bed base. The MCU is dedicated to touch status monitoring to ensure speed and reliability. If the user does not want to use this feature, he can disable it using a switch.

3. Implementation and Results

From “Fig. 8” and “Fig. 9”, one can notice the effect of noise on the output signal. The fluctuations in the output signal should always be above the touch threshold to prevent-fake touches and in the same time, the threshold should not be very low to allow the system to detect the touches of the body of a man wearing his clothes or pet animal’s body with relatively thick fur.

The detection algorithm monitors the change of the measured capacitance which enables the system to detect low touch effects caused pets or humans wearing thick clothes; in contrary to Leggett & Platt technique which use capacitance change rate. That was achieved by implementing self-calibration function, which determines the bed base, frame capacitance, eliminates the effect of noise, and puts an optimum threshold to enable detection of smallest touch effect on measured capacitance.

Fast response and reliable are guaranteed. The hardware design and software algorithm fulfills these requirements by having a dedicated capacitive touch controller that measures the capacitance value and converts these analog signals to digital ones. Then, these values are passed to microprocessor to analyze data and take the appropriate decision.



(a) (b)

Fig. 7. *(a) Testing the system on an electric adjustable bed, (b) The circuit prototype*

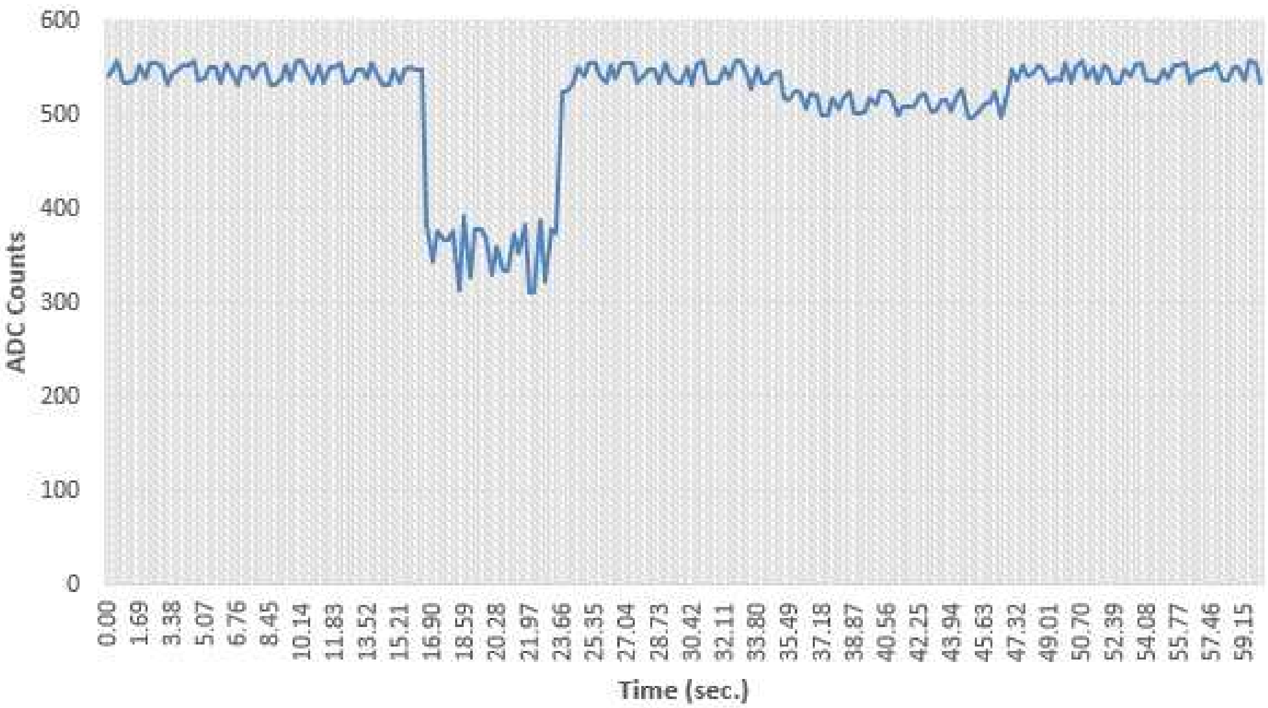


Fig. 8. *Output ADC reading showing the effect of human hand touchs*

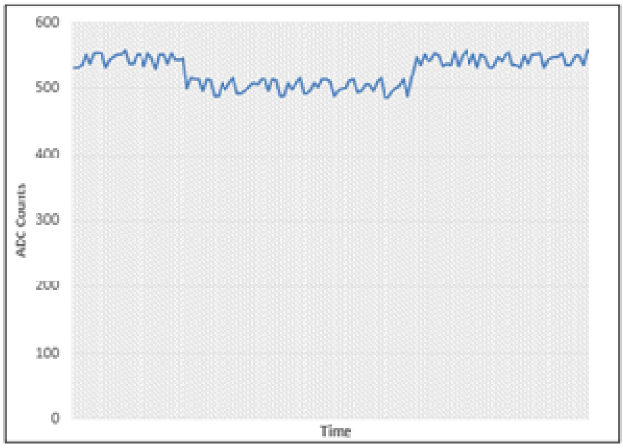


Fig. 9. *Output ADC reading showing the effect of the touch of a cat body.*

Fig. 10. *The cat that was used in testing pet animals touches*

For previous results, the microprocessor set the touch threshold to 525 ADC counts. Therefore, if the A/D converter reading for the electrode capacitance is below that threshold, the microprocessor will consider it as a touch and will issue a motors-stop signal. From "Fig. 9", it is obvious that the system will detect the touch of the cat.

4. Conclusion

Capacitive touch sensing is the most widely used technique in touch sensing applications. The method used in this system provides immunity to water drops, moisture and dust. Enabling capacitive touch sensing for this large surface electrode could be little easier, where a thin film of metal is used instead of the metal structure of the bed, but that will lead to manufacturing difficulties because this thin metal layer should be electrically isolated form metal structure and then painting should be applied on this film, which will result in low finishing quality or very complex manufacturing process. We used a thin layer of painting on the metal structure of the bed to maximize the effect of a touch on the total capacitance of the bed base.

Connecting metal parts tougher tightly is one of the important factors affecting the success of enabling touch sensing, because it will lead to large fluctuations in the measured signal and may cause fake touches due to changes in electrode capacitance. The big advantage of this system is that it is universal regarding bed control system and bed size. The proposed system can be adapted to be connected to any adjustable bed control system. It also can be sued with any bed size without any special adjustments thanks to its auto-calibration feature; so, this safety system is superior to any other system in the market today. This system can almost prevent any injuries that could happen to humans or pet animals when using electric adjustable beds in homes. In addition, adjustable beds, this safety system can be used in any furniture that requires protection against injuries such as riser recliner chairs.

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