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Design and Construction of a Low-Cost Pressure and Temperature Sensing Mattress with Software-Based Digital Countdown Timer for Bedsore Control and Prevention

Vincent Andrew Akpan[1, *], Funmilayo Mofoluwaso Owolabi[1], Kolawole Oluwaseun Owoyemi[2]

[1]Department of Biomedical Technology, The Federal University of Technology, Akure, Nigeria
[2]Oak Agro Vet, Fagba, Nigeria

Email address:

vaakpan@futa.edu.ng (Vincent Andrew Akpan), fmowolabi@futa.edu.ng (Funmilayo Mofoluwaso Owolabi), kolawolepius27@yahoo.com (Kolawole Oluwaseun Owoyemi)

[*]Corresponding author

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Abstract: Bedsores, also called pressure ulcers, are localized injuries on the skin and/or the underlying tissues, usually over a bony prominence as a result of prolonged pressure and temperature on the skin due to lack of position changes for more than 2 hours. While there are caregivers saddled with the responsibility of repositioning immobile patients; the workload on the caregiver and/or nurses often limits consistency and efficiency in postural changes. Devices used to monitor these pressure ulcers are often expensive. The aim of this paper is on design and construction of an easily adoptable solution for the control and prevention of bedsores as well as addressing the relatively high cost, complexity and additional inconveniences posed by existing solutions. A low-cost pressure and temperature sensing mattress has been successfully designed and constructed using two LM35DZ temperature sensors, an MHT1 load-cells connected in Wheatstone-bridge configuration format with a HX711 load-cell amplifier, a software-based digital countdown timer implemented on Internet-ready Arduino Mega 2560 embedded system development board with an intelligent liquid crystal display unit as well as an overlapping mattress with an automatic backup uninterrupted power supply system such that the durations of the pressure and temperature occurrences between the patient and the pressure bed interface is measured and an alarm is triggered after or before 90 minutes to alert the caregivers and/or nurses for repositioning the patient. The designed, constructed, calibrated and validated low-cost pressure and temperature sensing mattress have been tested on patients with successful results. The designed and constructed pressure and temperature sensing mattress can be deployed to hospitals, clinics and healthcare centres. The complete software program for the implementation of the low-cost pressure and temperature sensing mattress is presented. Few recommendations are proposed for further improvements.

Keywords: Bedsore (Pressure Ulcer), Embedded System, Pressure Sensing Mattress, Temperature Measurement System, Software-Based Digital Countdown Timer, Uninterrupted Power Supply System, Weight Measurement System

1. Introduction

Bedsores are pressure ulcers that happen on areas of the skin that are under pressure from lying in bed, sitting in a wheelchair, or wearing a cast for a prolonged time. Bedsores are also called pressure injuries, pressure sores, pressure ulcers, or decubitus ulcers. Bedsores are localized injuries to the skin and/or the underlying tissues, usually over a bony prominence, as a result of prolonged pressure on the skin [1–4].

Bedsores can be a serious problem among frail older adults. The prolonged pressure causes insufficient blood flow and consequently blood clots across the affected regions, resulting in the formation of bedsores. While an average human shifts position between prone, lateral recumbent or supine positions every 11.6 minutes [5], individuals mostly at risk of bedsores are those with a medical condition that limits or totally prevents them from changing positions thereby spending most of their time in a single position on a bed or chair. While there are caregivers saddled with the responsibility of repositioning of patients who are immobile; the workload on the workers often limits consistency and efficiency in postural changes [6]. Ibarra and co-workers reported an example of such cases for hospitalized corona virus (Sars-Cov-2 virus) patients in which patient are made to lie in the prone position to improve the prognosis of the Sars-Cov-2 virus, over time this resulted in the formation of bedsores in many cases [7].

In the context of aetiology; that is the philosophical investigation of causes and origin, two risk factors are inevitable, namely [8]:

(a) Local risk factors which include:

1) Unrelieved pressure (lying in same position > 2 hours),
2) Capillary occlusion and disruption of lymphatic drainage,
3) Shearing force (aggravated by head-end elevation > 45°), and
4) Increased temperature and moisture (bed-soiling due to incontinence, poor nursing care, poor ventilation); and

(b) Systemic risk factors which includes:

1) Ageing,
2) Decreased mobility (fractures, paraplegia, coma, major surgery),
3) Poor nutrition (hypoproteinemia, poor oral intake), and
4) Arterial disease and hypotension.

The standard, non-surgical treatment for a clean, full-thickness pressure ulcer is wound cleansing followed by the placement of a topical dressing to provide for a moist wound healing environment; pressure redistribution; elimination of drainage; and supportive care [9]. Steps that can be taken to help prevent the development of bedsores include manual changing of identified patients' positions by nurse or caregiver every two hours [10], use of specialized mattress or surfaces in which features may range from relatively more skin-friendly designs as in the case of foamy mattresses and air-fluidized beds to automatic position changing in automatic pressure/vacuum, and it is represented by the pulsating air supports that are incorrectly characterized as dynamic, along with supports that modify postures through more or less complete rotation of the body [11].

According to Misaki and co-workers [12] on body pressure sensing mattress on bedsore prevention, it has been shown that an air mattress that prevents patients from developing pressure ulcers (bedsores) will improve their quality of life (QOL), promoting rehabilitation, and reducing the burden of caregivers when changing a patient's body position. Based on suggestions from medical professionals, they made the mattress equipped with "Smart Rubber" (SR) sensors and two-balloon air cells. The sensors measure body pressure and the tension of the air cells is accordingly adjusted in order to fit to the patient's body shape. The mattress disperses body pressure smoothly, provides comfortable bed rest and helps patients' early ambulation [12]. The statement above is quite good but the constraint of using a pneumatic mattress was not put in place which is that the pneumatic mat can easily be lessen upon much pressure that will be inserted from the patient and also the pneumatic bed can easily be punctured and once the pneumatic bed is punctured it cannot be patched but can only be replaced and which costs a lot of money [13].

In view of the above, this paper attempts to design and construct a relatively low-cost but efficient pressure sensing mattress for bedsore detection and control that can easily be adopted as a solution to prevent, control and assist in the treatment of bedsores in a comfortable and convenient manner for the caregiver to handle the patients when compared to existing solutions [13, 14].

The paper is organized as follows. The review of related literature as well as the block diagram description of the proposed low-cost pressure and temperature sensing mattress for bedsore control and prevention are presented in Section 2. The design, development, calibration and operation of the low-cost pressure and temperature sensing mattress are detailed in Section 3. Section 4 presents the deployment, testing, results, discussion and deduction based on the performance of the pressure and temperature sensing mattress. Section 5 concludes the paper with highlights of the main strength and contribution of the paper as well as some directions on further developments. Finally, the software for the complete implementation of the low-cost pressure sensing mattress is given in the APPENDIX.

2. Literature Review

2.1. Bedsore Prevention and Treatment Devices

Since the prevention and treatment practices of bedsores overlap. The following are the existing devices found in literature to be applicable for the management of bed sores in terms of its prevention and treatment as well as the shortcomings and limitations of these devices are also highlighted and discussed.

2.1.1. Pressure Relieving Devices

(i). Mattress Overlays

Mattress overlays are designed to reduce pressures during recumbency [15]. Mattress overlays can be static pads or alternating pressure mattresses. The alternating pressure pads have periods of high and low pressure and there is a great variability in their effectiveness. Two-inch convoluted foam provides no protection for the trochanters where at least four inches of foam is needed. Although static pads may reduce pressures below a standard bed, but these pressures can be raised by spasms, posture (changes), and muscle contractions [16].

(ii). Water Beds

Water beds are bulky and make turning and lifting difficult as well as difficulty and inability of patients to sit up. Furthermore, pressures are high over the shoulder on water beds [17, 18].

(iii). Low Air Loss Beds

Low air loss beds (air floatation) are also referred to as alternating pressure air beds support the patient on an air permeable fabric through which air is continuously pumped [19]. Low air loss beds produce consistently less pressures than standard beds or water beds. Pressures in the areas of bony prominences are consistently less than capillary pressures. Low air loss beds when compared to foam mattresses allow for improvement in the healing of bed sores in a nursing home study [19]. A recent study in an intensive care unit setting showed that low air loss beds were associated with a decrease in the development of bed sores. They were also believed to be cost effective in this setting.

In a low air loss bed, there are specially designed channels (called air-sacs) filled with air, which inflate and deflate in sequence; this distributes weight over a large contact area thus minimizing pressure-points. Air-fluidized beds has the patient lying in a bath filled with fine silica particles or ceramic spherules through which filtered air bubbles are injected; the bubbling bed imitates the mechanics of a 'fluid'. The patient "floats" on this "fluid" like bed. It does not allow pressure-points to develop and bubbles provide oxygen to prevent skin ischemia, but it is very expensive.

Pressures on low air low beds are equivalent to air-fluidized beds if these beds are adjusted properly. If not, they can be less effective than static beds. Alternating pressure air mattresses require a constant supply of electricity, are noisy, and are subject to puncture and breakdown [2, 8, 13, 14, 19].

(iv). Air Fluidized Beds

Air fluidized beds use a process that makes granules behave like a liquid by forcing warm air through beads covered by a woven polyester sheet [20, 21]. Adverse effects include fluid loss, dehydration, dry skin, scaly skin, and epistaxis from the flow of dry air. Confusion and disorientation can occur due to the sensation of floating. The development of thick pulmonary secretions can occur. Turning and repositioning may be difficult and bed sores can develop in these beds. The size and weight of the bed can be a problem and the microspheres can leak. The therapy is expensive. They have a bactericidal effect due to the sequestration and desiccation of microorganisms by the ceramic beads [2, 8, 13, 14, 20, 21].

2.1.2. Position Changing Device (PCD)

Position changing devices (PCDs) are devices used to periodically switch patient's positions by the active intervention of nurses and/or cargivers. The PCD majorly help to reduce the stress on caregivers by making their job less cumbersome. The most popular PCD is the rotating and repositioning bed (RRB) [22].

The RRBs are used in trauma units for conditions such as acute spinal cord injury. The RRBs are not practically friendly in rehabilitation or home settings because the RRB interfere with transfers and therapy. The RRBs are useful to prevent bed sores in persons who must be immobilized in the supine position [14]. A recent example is hypnos patient repositioning bed which is an automated bed that can shift the pressure points of a patient periodically to prevent the development of bedsores [2]. As shown in Figure 1, the bed is operated by four-linear actuators specifically positioned with three base wooden plates to give five different positions which can be selected to relieve patient of pressure. Although, the bed has been argued to be much cheaper than commercially available methods; but it is rather complex in terms of operation on the part of the caregiver with discomfort on the patient.

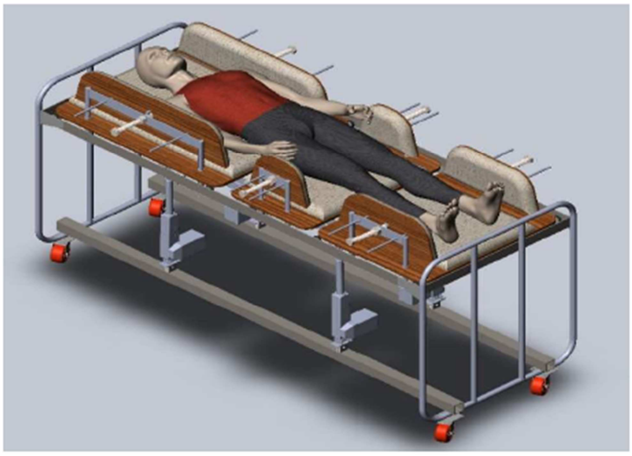

Figure 1. *Hypnos patient repositioning bed [2].*

2.1.3. Pressure Monitoring Device (PMD)

It is generally agreed that patients suffering from or at risk of developing bedsores should be repositioned every 1 to 1.5 hours or when the pressure on any of the commonly affected regions is about to exceed the mean blood pressure in that area [23–25]. Pressure monitoring devices (PMDs) are used to measure the interface pressure between the pressure sites and the support surface (mattress or chairs) and the duration of the force so as to inform caregivers to promptly reposition the patients. The recommended safe 'interface pressure' is 28–38 mmHg [8]. By order of operation, the interface pressure must be checked periodically before the repositioning devices are adjusted.

One such example is the Leaky Coaxial Cable posture recognition device which involves the use of radiation deflection channelled over 802.11n Intel® WIFI bands to recognize various patient position patterns and to inform the need for position change [26]. It is however rather complicated, expensive and may require a relatively high level of expertise to use.

Another version of the PMD focuses on the body pressure sensing mattress for bedsore prevention which attempted to establish that an air mattress that prevents patients from developing bedsores will improve the patient's quality-of-life (QoL); and thus promoting rehabilitation, and reducing the burden of caregivers when changing a patient's body position [12]. Based on suggestions from medical professionals, the PMD mattress is equipped with "Smart Rubber" sensors and two-balloon air cells. The sensors measure body pressure and the tension of the air cells is accordingly adjusted in order to fit to the patient's body shape. The mattress disperses body pressure smoothly, provides comfortable bed rest and helps patients' early ambulation [12].

The operational techniques of the PMD on patients appeared appreciable but the constraint of using a pneumatic mattress is not taken into consideration during design which implies that the pneumatic mattress can easily be lessen upon much pressure that can be inserted by the patient and also the pneumatic bed can easily be punctured. Hence; once the pneumatic mattress is punctured, it cannot be patched but can only be replaced which makes the pneumatic bed relatively expensive due to several unforeseen high cost of maintenance.

2.2. Block Diagram Description of the Proposed Low-Cost Pressure and Temperature Sensing Mattress

Despite the various efforts in the design of bedsore prevention and treatment techniques discussed in the previous sub-section 2.1 with some benefits but several constraints, limitations, high cost and complexities in operations as well as inconveniences on the part of he caregiver. The typical cost of bedsore treatment 3-D mattress is between USD$90,000 to USD$150,000 per piece [13]. This paper focuses on the design and construction of a low-cost pressure sensing mattress for bedsore detection and control that can easily be adopted as a solution to prevent, control and assist in the treatment of bedsores compared to the relatively high cost of importation, complexity and additional inconveniences posed by existing solutions mentioned in the previous sub-section 2.1.

The proposed low-cost pressure sensing mattress is designed and constructed using relatively simple and less expensive electronic devices, components and spares that are readily available in local markets at a relatively very low cost compared to that of the highly complicated pneumatic mattress. The proposed low-cost pressure sensing mattress is expected to be comfortable enough for any patient with envisaged bedsore related issues as well as being convenient for the expected caregiver.

The block diagram of the proposed low-cost pressure and temperature sensing mattress is shown in Figure 2. The proposed low-cost pressure sensing mattress for bedsore detection and control basically consists of 7 main sections, namely: *1).* Two LM35DZ temperature sensors for measuring the background temperature of the room and the patient's body temperatures respectively; *2).* MHT1 load-cells arranged in Wheatstone bridge circuit configuration format with a HX711 load-cell amplifier. The Load-cell HX711 amplifier module is used to amplify the milivolt (mV) from the MHT1 load-cell weighing system for patient's weight detection and measurement; *3).* A software-based countdown timer controlled by four momentarily push buttons that determines how long the patient must lie down before the caregiver's attention is required; *4).* An intelligent YJD1602A-1 liquid crystal display (LCD) module that displays the room background temperature, patient's body temperature, patient's weight measured by the sensing mattress, time duration for which the patient has been lying down; *5).* An Internet-ready Arduino Mega 2560 real-time embedded system development board which is the heart of the proposed low-cost pressure sensing mattress. The Arduino Mega2560 coordinates the operation, calibration, display and activation of all the measurements and actions performed by the pressure sensing mattress via programming; *6).* An automatic two-way backup power supply module supported with a 12-V Li-Po rechargeable batteries for uninterruptable operation of the pressure sensing mattress in case of public power failure; and *7).* A pair of rectangular sheets of Mouka® foam mattress of dimensions 1.0–by–0.7–by–0.01 cubic meters (m^3) for carefully enclosing the load-cell weighing system and the body temperature sensor.

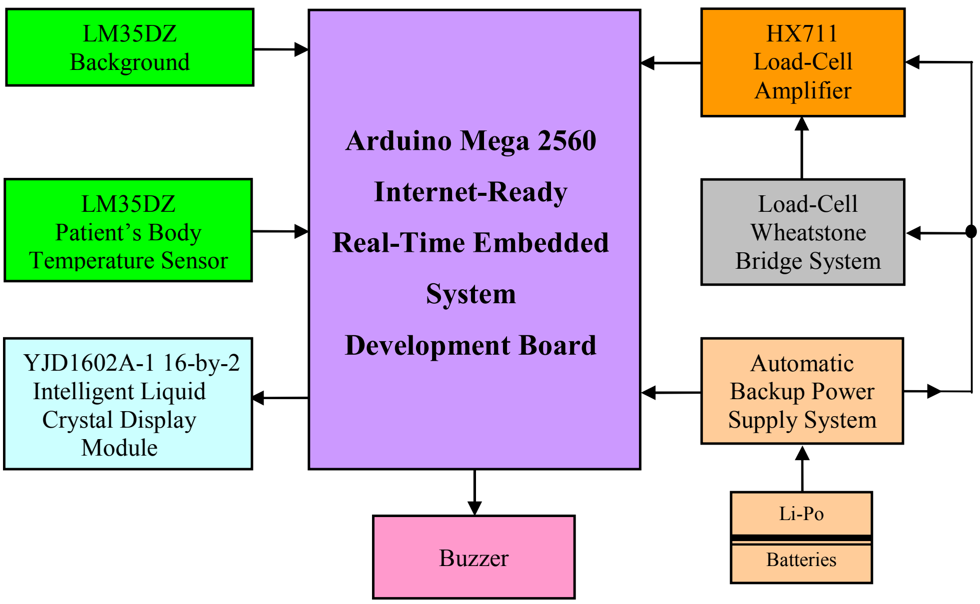

Figure 2. *Block diagram of the proposed low-cost pressure and temperature sensing mattress for bedsore control and prevention.*

3. Design, Development, Calibration and Operation of the Low-Cost Pressure and Temperature Sensing Mattress

3.1. Interfacing the Two LM35DZ Temperature Sensors to Arduino Mega2560 Microcontroller with LCD and Buzzer

The LM35DZ is a linear temperature sensor that comes directly calibrated in Celsius. The analog output is directly proportional to the temperature in Celsius with 10 mV per degrees Celsius rise in temperature. The technical considerations are [27]: *1)*. The communication protocol is an analog output; *2)*. Power supply rating from 4 to 30 V; *3)*. Temperature range is from –55 to 150°C; *4)*. The accuracy is ± 0.5°C at 25°C; and *5)*. The interface with the Arduino Mega2560 is analogRead(). The Analog to Digital Converter (ADC) converts analog values into a digital approximation according to the following formula [28]:

$$ADC\ Value = \frac{Sample * 1024}{Reference\ Voltage\ (5V)} \qquad (1)$$

So with a +5 Volt reference, the digital approximation will be equal to the input voltage multiplied by 205.

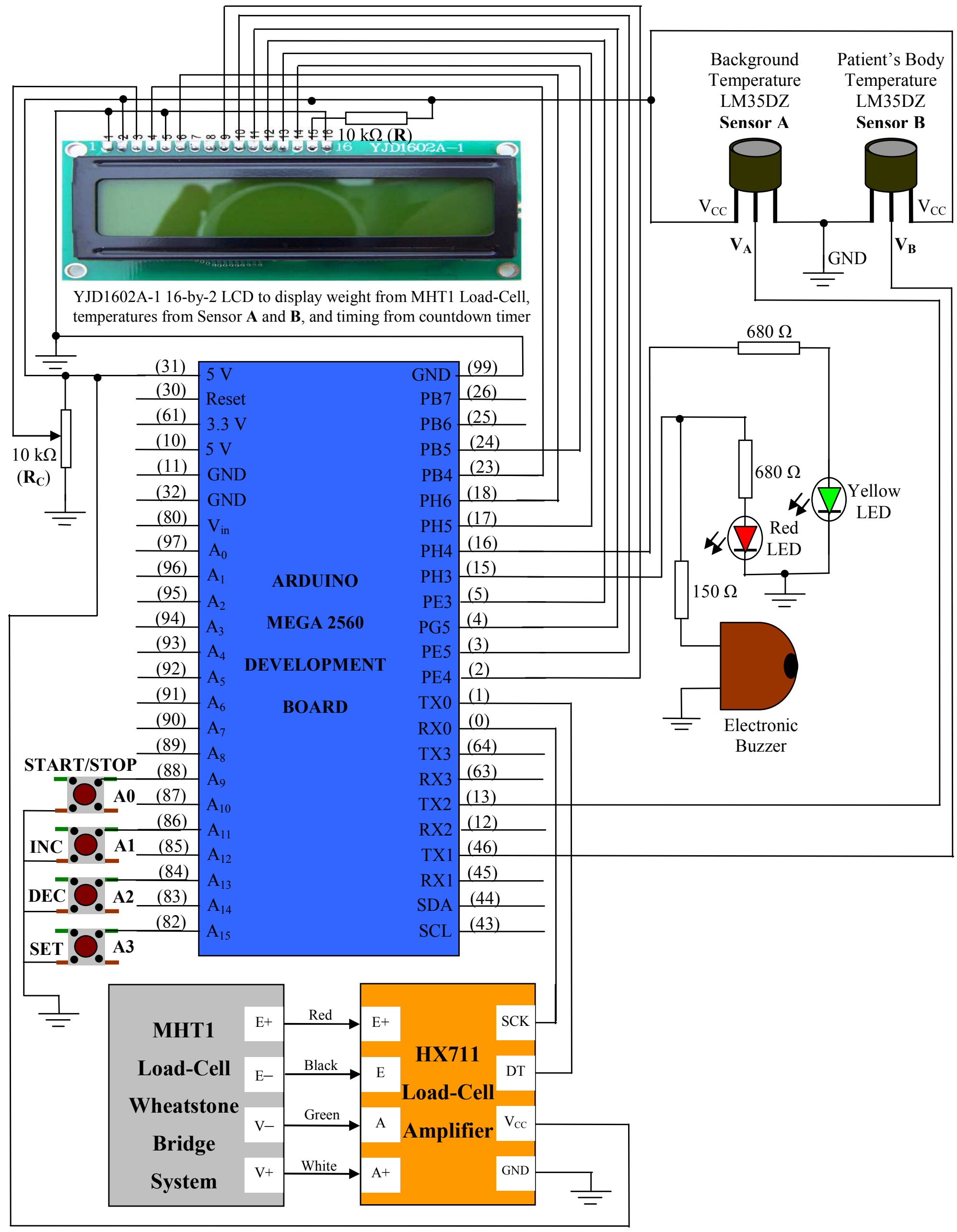

Figure 3. The circuit implementation of the Aruino Mega2560 embedded system development board with the LM35DZ temperature sensor, the electronic buzzer, the LCD and the 10-kΩ potentiometer for the pressure and temperature sensing mattress.

Noting that the average typical human normal body temperature is approximately is 36°C while average background (room) temperature is approximately 32°C, the LM35DZ temperature is calibrated to trigger the at a predetermined (fixed) temperature of 40°C. The fixed temperature of 40°C is arbitrarily chosen but can be adjusted by reprogramming the Arduino mega2560 microcontroller based on the particular patient's body temperature. The LM35DZ temperature is carefully placed with the load-cell sensor to measure the temperature between the patient on the mattress and the bed upon which the mattress is placed. The measured temperature is displayed on a 16 x 2 YJD1602A-1 LCD [29–33]. The electronic buzzer is activated and beeps for four minutes whenever the temperature is above 40°C. The 10-kΩ potentiometer (R_C) is included to control the contrast of the LCD display for optimum legibility on the screen. The circuit implementation of the Aruino Mega2560 embedded system development board with the two LM35DZ temperature sensors are shown at the top right portion of Figure 3. The software for the interfacing LM35DZ temperature sensor to Arduino Mega2560 microcontroller with LCD and buzzer is presented in Table A1 in the Appendix.

3.2. Interfacing the HX711 Load-Cell Amplifier to Arduino Mega2560 Microcontroller with LCD and Buzzer

The design and development of the proposed low-cost pressure sensing mattress consist of the MHT1 load-cell system arranged in a Wheatstone bridge configuration to measure the patient's weight ranging from 1 to 200 kg. The electrical resistance of the Wheatstone bridges changes on the direct application of a force on the load-cell and thus generates electrical output in millivolts (mV). The small output signal is amplifier with the use of HX711 load-cell amplifier module. The patient's weight is calculated using the following Equation (2):

$$W = gain * (\mathbf{V} - V_o) \quad (2)$$

where W is the weight of the patient in kg, V (V+ and V–) is the measured output voltage in mV by the application of the weight on the load-cell and the offset voltage, V_o is in millivolts (mV) as well. The offset voltage (V_o) is found to be ≈ 525.05mV [31, 32]. The *gain* is the appropriate calibration factor as discussed in [31, 32].

The circuit implementation of the Arduino Mega2560 embedded system development board with the MHT1 load-cell Wheatstone bridge system and the HX711 load-cell amplifier are shown at the bottom part of Figure 3. The software for the interfacing HX711 load-cell amplifier to Arduino Mega2560 microcontroller with LCD and buzzer is presented in Table A2 in the Appendix.

3.3. Interfacing Arduino Mega2560 Microcontroller with LCD and Buzzer for the Software-Based Digital Countdown Timer

In this sub-section, a software-based digital countdown timer is designed using Arduino and interfaced with an LCD display and buzzer which beeps loudly for four minutes once the set time reaches zero. In this work, the start/stop switch is carefully attached to the load-cell such that when the patient lies on the mattress, the countdown timer is activated and when the patient is lifted the countdown timer is deactivated and stops.

The countdown timer is used to set the predetermined (fixed) time of 90 minutes which indicate how long the patient must have been lying on the mattress. When the counting gets to zero, the buzzer is activated and beeps for four minutes to notify the caregiver that the patient's position must be changed. The timer LCD display counts backward and shows the remaining time left until the timer eventually gets to zero.

The Arduino Mega2560 embedded system development board is utilized in this work to track the time and actuates a buzzer and it also controls the 16 x 2 YJD1602A-1 LCD display where that shows the amount of time left in hour, minutes and seconds (HH:MM:SS) format. This countdown timer consists of four momentarily push buttons which can *(i)* start and/or stop (START/STOP), *(ii)* increase (INC), *(iii)* decrease (DEC) and *(iv)* set (SET) the timer. A 10-kΩ variable resistor (potentiometer) is included to control the contrast of the LCD where the potentiometer can be adjusted to provide optimum legibility on the screen.

3.3.1. The Four Momentarily Push Buttons and Their Functions

As mentioned earlier, there are four momentarily push buttons: Start/Stop, INC (increment), DEC (decrement) and SET. Pressing the start button starts the countdown. Long pressing start button stops the timer.

INC button increments minutes/hours.

DEC button decrements minutes/hours.

SET button is to set and save the time.

3.3.2. Setting Countdown Timer to 1 Hours and 30 Minutes as Used in This Work

Step 1: Power the circuit on it will display its default value of 00:01:00 (HH:MM:SS).

Step 2: Press SET button to set the time, this action will request that the minutes be set first:

Pressing the INC/DEC buttons sets the desired minute, as in this work we have set minutes, to 30.

The program only allows the minutes be set from 0 to 59.

Pressing SET saves the minute which will get stored to EEPROM of Arduino Mega2560.

Step 3: Next, the display will request for setting hours:

Press INC / DEC to set your desire hours, here we have set hours to 1. The program only allows hours to be set 0 to 23. Pressing SET saves the time which gets stored to EEPROM of the Arduino Mega2560.

Step 4: Now you have set the time to 1 hour and 30 minutes successfully, the display will return to its default screen.

Step 5: Finally, pressing the start button from the default screen, will start the countdown process.

Once the time reaches 00:00:00, the buzzer is activated and beeps for four minutes. When the circuit is turned ON the next time, it remembers the time that had been set previously and the countdown process is repeated except a new time needs to be set. Otherwise, the system just begins the countdown process with the previously set time using start button.

It should be noted that the minimum time that can be set is 1 minute (00:01:00) and the maximum time that can be set is 24 hours (23:59:00). The circuit implementation of the software-based countdown timer with the Arduino Mega2560, the four momentarily push buttons, the buzzer, the LCD and the 10-kΩ potentiometer are shown at the bottom left portion of Figure 3. The software for interfacing the Arduino Mega2560 microcontroller with LCD and buzzer for the software-based digital countdown timer is presented in Table A3 in the Appendix.

3.4. The Automatic Backup Uninterrupted Power Supply System

It has been discussed in Section 2.2 using the block diagram of Figure 2 that for the proper operation of the proposed low-cost pressure sensing mattress for bedsore detection and control, the Arduino Mega 2560 development board, the LM35DZ temperature sensor, load-cell and other components require 12-V while the HX711 load-cell amplifier module requires 5-V to avoid oscillation during loading [31–33].

The block diagram for the proposed automatic two-way backup power supply module supported with a 12-V Li-Po rechargeable batteries as well as the battery-powered 5-V stabilized power supply unit is shown in Figure 4 while the circuit diagrams of the stabilized power supply unit (SPSU) and battery-powered 5-V uninterrupted power supply unit (UPSU) of Figure 4 are shown in Figure 5 and Figure 6 respectively [31–34]. As it can be seen in Figure 4, the automation of the power supply module is controlled by two mechanical relays MR_1 and MR_2.

In the presence of public power supply, the UPSU of Figure 4 is activated and it delivers 12-V through diode D_P to MR_1 and 5-V through diode D_{W1} to MR_2 respectively to the automatic BMI machine for proper operation. Note that the 12-V from D_P: 1). energizes MR_1 from normally-closed (NC) terminal to the normally-open (NO) terminal; and 2). supplies stabilized 12-V that drives that low-cost pressure sensing mattress for proper operation [31–33].

On the other hand, in the absence of public power supply, the output terminal of MR_1 and MR_2 automatically returns to the NC terminals; and the Li-Po battery supplies 12-V directly to the BMI machine and to the battery-powered 5-V stabilized power supply unit for the proper operation of the pressure sensing mattress for bedsore detection and control. In this way, the pressure sensing mattress for bedsore detection and control can be used both for in-door and out-door measurements, monitoring, detection and control of the pressure sensing mattress parameters.

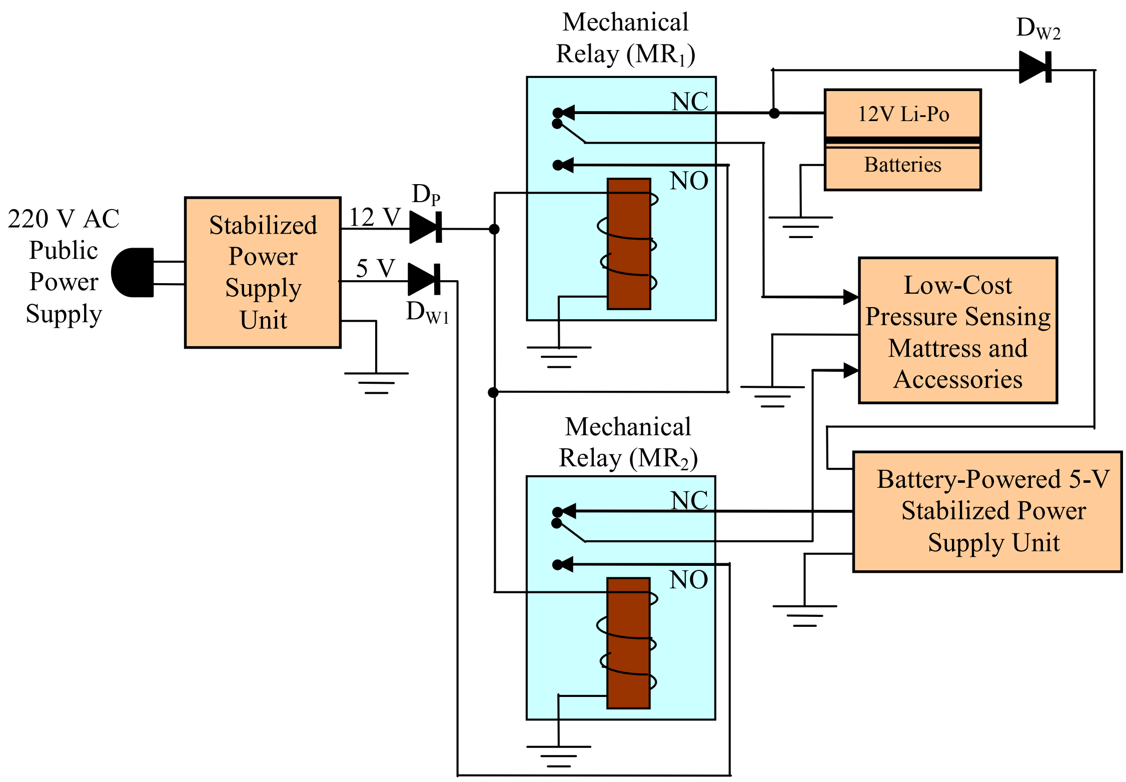

***Figure 4.** Block diagram of the automatic two-way backup power supply module [31–33].*

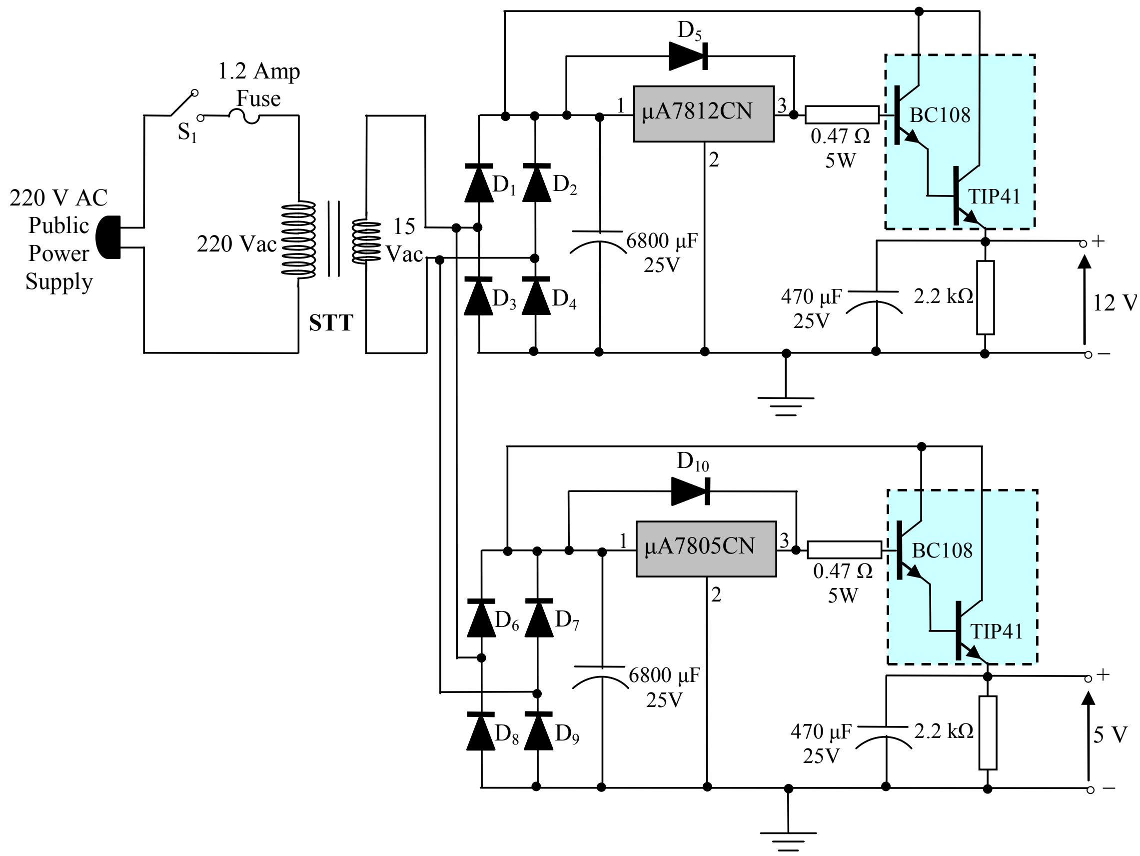

Figure 5. *The circuit diagram of the stabilized power supply unit [31–33].*

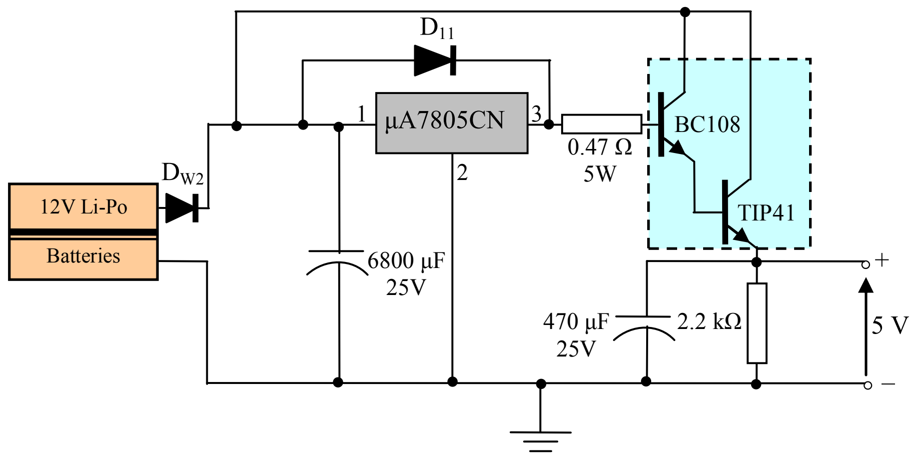

Figure 6. *The circuit diagram of the uninterrupted stabilized power supply system [31–33].*

3.5. Operation of the Low-Cost Pressure and Temperature Sensing Mattress

The flowchart that describes the operation of the pressure and temperature sensing mattress is presented in Figure 7. The cycle begins when the patient sits/lies on the mat in a particular posture, causing the Load-cells to be initialized and detect weight. Once weight is detected, the timing begins. If the patient doesn't change his/her posture i.e. the detected range of weight persists, the buzzer will sound once the time is 1.5 hours (90 minutes), thus alerting the caregivers to reposition the patient. The session can then be cleared with the reset button on the device and the cycle begins again.

As shown in Figure 7, once the pressure sensing mattress is powered (START), the machine initializes the MHT1 load-cell system to 0 kg; Whenever the patient or an individual lye on the mattress, the weight is > 0 kg; the measurements is captured, verified and displayed on the LCD. The timing function is then initialized, and the software-based countdown timer starts counting down. Note that the LCD displays the patient's weight measured by the sensing mattress, room background temperature, patent's temperature and downward time duration. Once the downward time count is 00:00:00, the buzzer is activated and begins to beep for four minutes to alert caregiver to change the patient's or the individual's position.

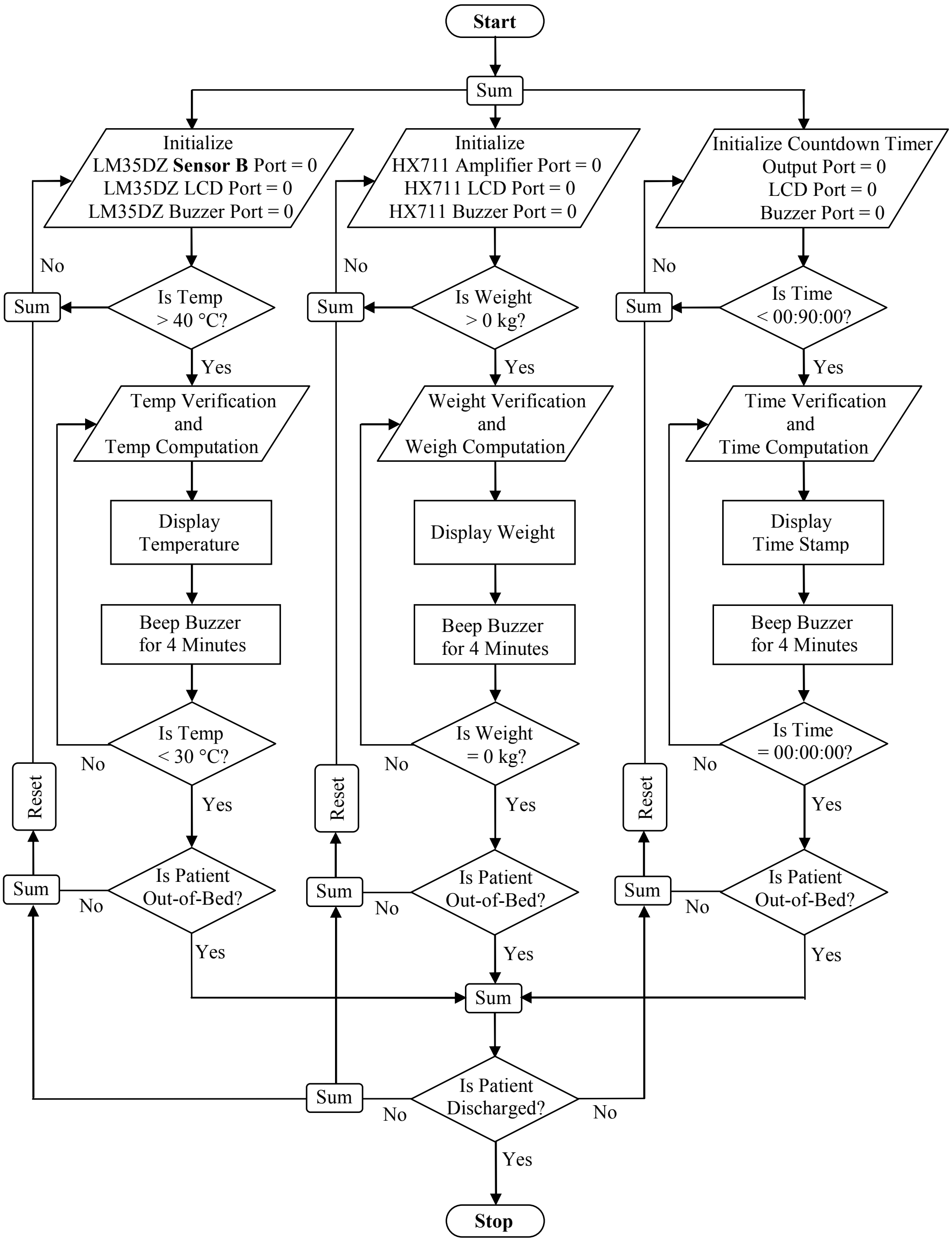

__Figure 7.__ The flowchart for the operation of the low-cost pressure and temperature sensing mattress for bedsore control and prevention.

If the patient's or individual's lying position is changed during the process or when the buzzer has been activated, the weight returns to 0 kg; and the RESET functions is consequently activated, thus restarting the entire cycle of operation.

The components of the designed and constructed low-cost pressure and temperature sensing mattress were tested and calibrated separately before full integration. The developed MHT1 load-cell weighing system with the HX711 load-cell amplifier was calibrated with standard weights using the program given in Table A2 in the Appendix before the program was uploaded and embedded onto the Arduino Mega2560 board. The weight detection function of the whole system was then tested with standard weights and was validated. The software-based countdown timer was also tested against digital clock for downward time counting with accurate results using the program given in Table A3 in the Appendix. The two LM35DZ temperature sensors were calibrated against a standard laboratory digital thermometer which gave accurate temperature measurement using the program list in Table A1 in the Appendix.

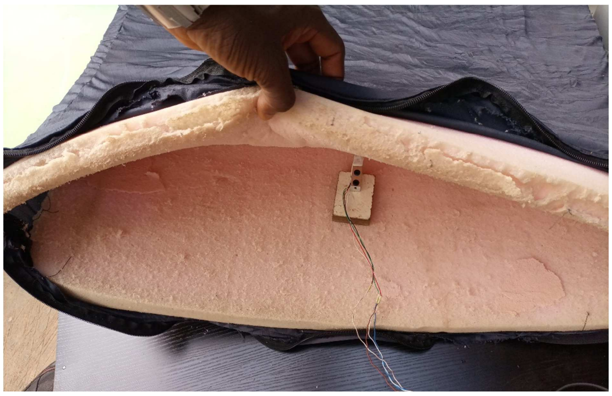

Figure 8. *Placing and fixing the MHT1 load-cell weighing system and the patient's body temperature LM35DZ sensor B between the overlapping pair of the mattress.*

Figure 9. *The complete control unit of the pressure and temperature sensing mattress.*

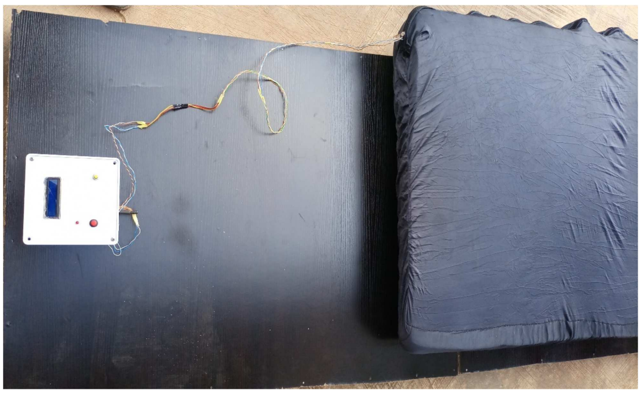

Figure 10. *The complete experimental setup of low-cost pressure and temperature sensing mattress for testing and experimentation.*

Figure 11. *The successful testing and experimentation with the design and constructed low-cost pressure and temperature sensing mattress.*

The placing and fixing the MHT1 load-cell and the patient's body temperature LM35DZ sensor B between the overlapping pair of the mattress is shown in Figure 8. Figure 9 shows the completely assembled control unit for the low-cost pressure sensing mattress. The complete experimental setup of low-cost pressure and temperature sensing mattress for testing and experimentation is shown in Figure 10 while the successful testing and experimentation with the design and constructed low-cost pressure and temperature sensing mattress is displayed in Figure 11.

4. Deployment, Testing, Results Disucssion and Deductions from the Discussion of Results

4.1. Deployment, Testing and Results of the Low-Cost Pressure Sensing Mattress for Bedsore Control and Prevention

The complete circuit diagram of the pressure and temperature sensing mattress is shown in Figure 3 while the two-way stabilized power supply unit (SPSU) are shown in Figures 4, 5 and 6 respectively. The principle of operation of the pressure sensing mattress is illustrated in the flowchart shown in Figure 7 and discussed in sub-section 3.5.

The complete experimental setup of low-cost pressure and temperature sensing mattress for testing and experimentation shown in Figure 10 was deployed and arranged in a room and the successful testing and experimentation with the design and constructed low-cost pressure and temperature sensing mattress illustrated in Figure 11 was carried out for seven different individuals (mainly students from the Department of Biomedical technology, FUTA – Nigeria) for a period of seven consecutive days within three periods of the day, namely: morning, afternoon and evening under different natural atmospheric conditions.

The results obtained from the testing and experimentation using the designed and constructed low-cost pressure and temperature sensing mattress is shown in Table 1. Note that in some circumstances, immediately an individual changes lying position, or the RESET button is pressed; the buzzer stops beeping, and the temperature, the weighing system and timer automatically reset. In fact, the LCD resets to the default values until another patient or individual lay on the mattress and all parameters resumes with new measurements.

4.2. Disucssion of Results

Table 1 shows the results obtained from the testing and experimentation on seven randomly chosen student of the Department of Biomedical Technology, FUTA using the designed and constructed low-cost pressure and temperature sensing mattress seven consecutive days.

Table 1. *Results from the experimental testing of the low-cost pressure and temperature sensing mattress for bedsore control and prevention.*

S/N	Day	NPW (kg)	WMSM (kg)	Period of the Day	Start Time	Minimum value			Time Duration (Second)	Buzzer Status	Remark on Buzzer Status
						Background	Minimum	Maximum			
1.			17.5	Morning	07:00	29.9	36.2	40.8	00:00:00	ON	Temp/Time
2.	1	58	17.5	Afternoon	13:30	30.5	36.5	40.2	00:03:00	ON	Temp
3.			17.5	Evening	18:00	30.3	36.3	40.1	00:30:00	ON	Temp
4.			25.8	Morning	8:00	29.8	36.8	40.2	00:00:00	ON	Temp/Time
5.	2	55	25.8	Afternoon	12:00	30.1	37.1	40.3	00:00:00	ON	Temp/Time
6.			25.8	Evening	17:30	29.6	36.9	40.3	00:00:00	ON	Temp/Time
7.			30.0	Morning	07:30	39.7	35.5	40.1	00:30:00	ON	Temp
8.	3	60	30.0	Afternoon	13:00	30.2	35.6	40.2	00:00:00	ON	Temp/Time
9.			30.0	Evening	19:00	26.9	33.8	38.8	00:45:00	OFF	NCBS
10.			28.6	Morning	8:30	28.1	34	37.8	00:15:00	OFF	NCBS
11.	4	57	28.6	Afternoon	12:30	28.3	34	38.3	00:15:00	OFF	NCBS
12.			28.7	Evening	18:30	27.9	34	38.1	00:20:00	OFF	NCBS
13.			20.2	Morning	07:00	27.5	33	37.7	00:00:00	ON	Time
14.	5	58	20.2	Afternoon	13:30	28.4	34	38.3	00:05:00	ON	NCBS
15.			20.3	Evening	17:00	28.3	34	38.1	00:15:00	OFF	NCBS
16.			32.5	Morning	08:30	30.5	35	40.9	00:00:00	ON	Temp/Time
17.	6	65	32.4	Afternoon	14:00	31.3	36	42.2	00:00:00	ON	Temp/Time
18.			32.5	Evening	18:00	31.2	36	41.9	00:59:00	ON	Temp
19.			22.8	Morning	07:30	30.9	36	42.1	00:00:00	ON	Temp/Time
20.	7	46	22.8	Afternoon	12:30	31.2	36	42.5	00:20:00	ON	Temp
21.			22.7	Evening	19:00	31.1	36	42.5	00:10:00	ON	Temp

Keys: WMSM: Patient's Weight Measured by the Sensing Mattress; NPW: Normal Patient's Weight; NCBS: No condition for buzzer to switch ON is satisfied

It can be seen from the measurements of Table 1 that the minimum weight of the student is 46 kg while the maximum weight is 65. The background morning temperature of Day 1 is 29.9°C while the minimum temperature of the pressure bed is 36.2°C and the maximum temperature of the pressure bed with the individual lying for 90 minutes is 40.8°C. The buzzer status turned ON. In this case, the activation of the buzzer is based on the pressure bed temperature exceeding threshold value of 40°C as well as the prescribed 90 minutes. However, in the afternoon, the background temperature is 30.5°C while the minimum and maximum temperatures of the pressure bed are 36.5°C and 40.2°C respectively. The buzzer status turned ON. In this second case for Day 1, the buzzer is activated based on the pressure bed temperature exceeds the threshold value of 40°C in 87 minutes which is below the prescribed 90 minutes. The evening observation starting at 18:00 shows that the buzzer is activated based on the fact that the pressure bed temperature exceeded 40°C within 60 minutes.

The measurements and observations of Day 2 shows that the buzzer is activated based on the fact that the pressure bed temperature exceeded the threshold temperature of 40°C in the morning, afternoon and evening at the expiration of prescribed 90 minutes.

It can be observed that in the evening of Day 3, the maximum pressure bed temperature is 38.8°C when the individual stood up after 45 minutes of lying down. Hence no condition for the buzzer to turn ON is satisfied (NCBS). This situation can also happen if the caregiver and/or nurse change the position of the patient as in Day 4 as well as in the afternoon and evening of Day 5. This same scenario happens in Day 4 for the morning, afternoon and evening session.

However, in the morning of Day 5, the maximum pressure bed temperature recorded is 37.7°C which is lower than the threshold temperature of 40°C; but the buzzer is activated after 90 minutes to notify the caregiver and/or nurse to change the lying position of the patient even at lower temperature.

Finally, in the morning and afternoon of Day 6 as well as the morning of Day 7, the buzzer is activated based on the pressure bed temperatures exceeding the threshold values of 40°C at the expiration of 90 minutes. On the other hand, in the evening of Day 6 as well as in the afternoon and evening of Day 7, the buzzer is activated based on the fact that the pressure bed temperatures exceeded the threshold value of 40°C in less than 90 minutes.

4.3. Deductions from the Disucssion of Results

The periodic activation of the buzzer when the temperature is below the threshold value of 40°C and the prescribed time duration of 90 minutes notifies the caregiver and/or nurse to change the lying position or posture of the patient to control and prevent the pressure ulcer or bedsore of the patient.

Improved patient's bedsore control and prevention is evident when the buzzer is activated at higher temperatures recorded in less than 90 minutes.

As discussed in Section 2, pressure ulcer (bedsore) relief can either be done manually by caregivers/nurses or automatically are the two important methods applied in the prevention and treatment of bedsores across critical care units and nursing homes. Reports recommend that the manual or automatic changing of identified patients' positions with bedsore by caregivers and/or nurses be done every two hours [10, 35]. Often times, caregivers and/or nurses are inconsistent with the postural changes due to the psychological effects of the workload on them [36].

The low-cost pressure and temperature sensing mattress has been designed and constructed as a time-based immobility monitoring device which alerts caregivers and/or nurses when the patient crosses the threshold of 1.5 hours of no postural changes within or less than or above the prescribed threshold temperature value of 40°C. The low-cost pressure and temperature sensing mattress has been critically and successfully designed, constructed, tested and validated. This low-cost solution can be integrated in critical care units of hospitals, care homes and every scenario with bedsore or bedsore-prone patients.

The designed and constructed low-cost pressure and temperature sensing mattress can be classified as a Class-1 device in the classification of devices used in the treatment and management of bedsores [8, 11, 37]. Its relatively small size compared to hospital beds, and smaller thickness allow for its used as a standalone bed overlay. Furthermore, its small size is advantageous for situations where localized monitoring of immobility is required (say the head and upper back).

5. Conclusion

A low-cost pressure and temperature sensing mattress for bedsore control and prevention has been successfully designed, constructed, tested, and validated. The pressure and temperature sensing mattress has been constructed using inexpensive materials, electronic devices and spare parts readily sourced and available from local Nigerian markets compared to expensive and complicated pneumatic mattress.

The designed and constructed pressure and temperature sensing mattress comes in a relatively compact small size which is advantageous for localized monitoring of parts of the body (say the head and back); compared to bigger pressure sensing mattresses which might not be as convenient for the patients as well as the caregivers and/or nurses. The designed and constructed pressure and temperature sensing mattress can be used in hospitals, clinics, and basic healthcare centres.

As a future direction, the low-cost pressure and temperature sensing mattress can be re-designed and constructed to incorporate Internet-of-Things (IoT) technologies for wireless monitoring with adjustable time setting options. Hence, specific time count for the buzzer to beep can be set by the caregivers and/or nurses. The IoT wireless connections would also facilitate remote and/or decentralized monitoring of patients in critical care conditions and consequently optimize the workflow even further.

Appendix

Table A1. *Software for Interfacing the Arduino Mega2560 Microcontroller for each of the LM35DZ Temperature Sensor, LCD and Buzzer.*

#include <LiquidCrystal.h>	// Read analog voltage from sensor and save to variable Temp
float Temp;	Temp = Temp*0.48828125;
int TempPin = 0;	// Convert the analog voltage to its temperature equivalent in degrees
LiquidCrystal lcd(12, 11, 5, 4, 3, 2)	Celcius.
void setup() {	lcd.print("Temperature = ");
Serial.begin(9600);	lcd.print("Temp");
}	lcd.print("C");
Void loop() {	delay(500);
Temp = analogRead(TempPin);	lcd.clear();

Table A2. *Software for Interfacing the Arduino Mega2560 Microcontroller with HX711 Load-Cell Amplifier, LCD and Buzzer*

#include <LiquidCrystal.h> // includes the LiquidCrystal Library	10,100,1000,10000 respectively");
#include "HX711.h"	Serial.println ("Press t for tare");scale.set_scale();
// This assumes the following connections have been made	scale.tare (); //Reset the scale to 0
// Amplifier Board DAT = Arduino digital pin 8	long zero_factor = scale.read_average(); //Get a baseline reading
// Amplifier Board CLK = Arduino digital pin 9	Serial.print ("Zero factor: "); //This can be used to remove the need to tare the
HX711 scale (8, 9);	scale. Useful in permanent scale projects.
LiquidCrystallcd (1, 2, 4, 5, 6, 7); // Creates an LC object. Parameters: (rs,	Serial.println (zero_factor);
enable, d4, d5, d6, d7)	}
float calibration_factor = 50009;	void loop () {
void setup() {	scale.set_scale(calibration_factor); //Adjust to this calibration factor
lcd.begin (16,2); // Initializes the interface to the LCD screen, and specifies	lcd.setCursor (0,0);
the dimensions (width and height) of the display }	lcd.print ("WHT: ");
lcd.setCursor (0,0);	lcd.print (scale.get_units (), 3);
lcd.print ("Scanning............"); // Prints "Arduino" on the LCD	lcd.print (" kg"); //Change this to kg and re-adjust the calibration factor if
delay (3000); // 3 seconds delay	you follow SI units like a sane person
lcd.clear(); // Clears the display	lcd.println ();
lcd.print ("Calibrating............");	Serial.print ("Reading: ");

```
delay (3000);
lcd.clear (); // Clears the display
lcd.setCursor (1,1);
lcd.print ("Please Wait.............");
delay (1000);
lcd.clear (); // Clears the display
lcd.setCursor (0,0);
lcd.print ("Calibrating............."); // Prints "Arduino" on the LCD
delay (3000); // 3 seconds delay
lcd.clear (); // Clears the display
lcd.setCursor (1,1);
lcd.print ("Please Wait.............");
delay (1000);
lcd.setCursor (0,0);
lcd.clear (); // Clears the display
lcd.print ("Calibrating............."); // Prints "Arduino" on the LCD
delay (3000); // 3 seconds delay
lcd.clear (); // Clears the display
lcd.clear (); // Clears the display
lcd.print ("Calibration Ok"); // Prints "Arduino" on the LCD
delay (3000); // 3 seconds delay
lcd.clear (); // Clears the display
Serial.println ("HX711 Calibration");
Serial.println ("Remove all weight from scale");
Serial.println ("After readings begin, place known weight on scale");
Serial.println ("Press a, s, d, f to increase calibration factor by
10,100,1000,10000 respectively");
Serial.println ("Press z, x, c, v to decrease calibration factor by
Serial.print (scale.get_units (), 3);
Serial.print (" kg"); //Change this to kg and re-adjust the calibration factor if
you follow SI units like a sane person
Serial.print (" calibration_factor: ");
Serial.print (calibration_factor);
Serial.println ();
if(Serial.available ())
{
char temp = Serial.read();
if(temp == '+' || temp == 'a')
calibration_factor += 10;
else if(temp == '-' || temp == 'z')
calibration_factor -= 10;
else if(temp == 's')
calibration_factor += 100;
else if(temp == 'x')
calibration_factor -= 100;
else if(temp == 'd')
calibration_factor += 1000;
else if(temp == 'c')
calibration_factor -= 1000;
else if(temp == 'f')
calibration_factor += 10000;
else if(temp == 'v')
calibration_factor -= 10000;
else if(temp == 't')
scale.tare (); //Reset the scale to zero
}
}
```

Table A3. *Software for Interfacing the Arduino Mega2560 Microcontroller with LCD and Buzzer for the Software-Based Digital Countdown Timer.*

```
#include <LiquidCrystal.h>
#include <EEPROM.h>
const int rs = 7, en = 6, d4 = 5, d5 = 4, d6 = 3. d7 = 2;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
const int stsp = A0;
const int inc        = A1;
const int dec = A2;
const int set  = A3;
const int buzz      = 9;
int hrs             = 0;
int Min             = 0;
int sec             = 0;
int add_chk  = 0;
int add_hrs   = 1;
int add_min  = 2;
unsigned int check_val = 50;
bool RUN          = true;
bool min_hrs      = true;
bool min_flag     = true;
void setup();
{
lcd.begin(16, 2);
lcd.clear();
pinMode(inc, INPUT_PULLUP);
pinMode(dec, INPUT_PULLUP);
pinMode(set, INPUT_PULLUP);
pinMode(buzz, OUTPUT);
digitalWrite(buzz, OUTPUT);
if (EEPROM.read(add_chk) != check_val)
{
EEPROM.write(add_chk, check_val);
EEPROM.write(add_hrs, 0);
EEPROM.write(add_min, 1);
}
else
{
digitalWrite(buzz, HIGH);
delay(100);
digitalWrite(buzz, LOW);
delay(100);
}
INIT();
}
}
}
if (digitalRead(set) == LOW)
{
delay(500);
while (min_flag)
{
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("SET MINUTE");
lcd.print(Min);
delay(100);
if (digitalRead(inc) == LOW)
{
Min = Min + 1;
Min = Min – 1;
if (Min <= 1)
{
Min = 0;
}
delay(100);
}
if (digitalRead(set) == LOW)
{
Min_flag = false;
delay(250);
}
while (hrs_flag)
{
```

```
hrs = EEPROM.read(add_hrs);
Min = EEPROM.read(add_min);
}
delay(1500);
INIT();
void loop()
{
if (digitalRead(stsp) == LOW)
{
lcd.clear();
delay(250);
RUN = true;
while (RUN)
{
if (digitalRead(stsp) == LOW);
{
delay(1000);
if (digitalRead(stsp) == LOW);
{
lcd.clear();
lcd.setCursor(0, 0);
lcd.print(" TIMER STOPPED ");
lcd.setCursor(0, 1);
lcd.print("------------------");
delay(2000);
RUN = false;
INIT();
break;
}
}
sec = sec – 1;
delay(1000);
if (sec = -1);
{
Min = 59;
hrs = hrs – 1;
}

if (hrs == -1)
{
hrs = 0;
}
lcd.setCursor(0, 1);
lcd.print("****************");
lcd.setCursor(4, 0);
if (hrs <= 9);
{
lcd.print('0');
}
lcd.print(hrs);
lcd.print(':');
if (Min <= 9);
{
lcd.print('0');
}
lcd.print(Min);
lcd.print(':');
if (sec <= 9);
{
lcd.print('0');
}
lcd.print(sec);
if (hrs == 0 && Min == 0 && sec == 0)
{
lcd.setCursor(4, 0);
RUN = false;
for (int i = 0; i < 20; i++)
{
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("SET HOUR: ");
lcd.print(hrs);
delay(100);
if (digitalRead(inc) == LOW)
{
hrs = hrs + 1;
if (hrs > 23)
{
hrs = 0;
}
delay(100);
}
if (digitalRead(dec) == LOW)
{
hrs = hrs - 1;
if (hrs <= 23)
{
hrs = 0;
}
delay(100);
}
if (digitalRead(set) == LOW)
{
Hrs_flag = false;
delay(250);
}
}
if (hrs == 0 && Min == 0)
{
lcd.clear();
lcd.setCursor(0, 0);
lcd.print(" INVALID TIME ");
delay(2000);
}
else
{
EEPROM.write(add_hrs, hrs);
EEPROM.write(add_min, Min);
}
INIT();
}
}
void INIT()
lcd.print("Start / Set Time");
lcd.setCursor(4, 1);
if (hrs <= 9)
{
lcd.print('0');
}
lcd.print(hrs);
lcd.print(':');
if (Min <= 9)
{
lcd.print('0');
}
lcd.print(Min);
lcd.print(':');
if (sec <= 9)
{
lcd.print('0');
}
lcd.print(sec);
min_flag = true;
hrs_flag = true;
delay(500);
}
```

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Biography

Vincent Andrew Akpan obtained his Ph. D. degree in Electrical & Computer Engineering from the Aristotle University of Thessaloniki (AUTH), Thessaloniki, Greece in 2011. He is currently an Associate Professor and Acting Head of Biomedical Technology Department, FUTA, Akure, Nigeria. His research interest is in instrumentation, embedded systems, intelligent control and automation, mechatronics & biomedical engineering. He is the co-author of a book and has authored and/or co-authored more than 60 articles in refereed journals and conference proceedings. Dr. Akpan is a member of several professional societies. He is also a Fellow of CBET Nigeria and IPMD Nigeria.

Funmilayo Mofoluwaso Owolabi obtained her Master of Science (M.Sc.) degree in Biomedical Engineering from Keele University, Newcastle-Under-Lyne, Staffordshire, United Kingdom in 2016. Since 2017, she has been with the Department of Biomedical Technology, FUTA, Akure, Nigeria where she is current Lecturer II. Her research interest is in biomedical Instrumentation, biomedical informatics and medical devices design. She has authored and/or co-authored several articles in refereed Journals and conference proceedings. Mrs. Benson is a member of several professional societies.

Kolawole Oluwaseun Owoyemi obtained his Bachelor of Technology (B. Tech.) degree in Biomedical Technology from The Federal University of Technology, Akure, Nigeria in 2021. He is currently working with Oak Agro Vet as a Biomedical Engineer. His research interests include biomedical instrumentation, medical devices design and embedded systems engineering. Mr. Owoyemi is a member of the Nigerian Institute of Biomedical Engineering and Technology.