International Journal of Engineering Processing & Safety Research
Published by Cambridge Research and Publications

Vol. 28 No.5
June, 2023.

DEVELOPMENT OF HYPERTHERMIA/HYPOTHERMIA AUTOMATED BLANKET DEVICE

[1]OLADOSU, D. A., [2]BELLO, A., [3]OYEDOKUN, O. M., [4]ADENIRAN, A. A

[1]Department of Computer Engineering, The Polytechnic, Ibadan [2]Department of Mechatronic Engineering, The polytechnic, Ibadan [3]Adeseun Ogundoyin Polytechnic, Eruwa, Oyo State [4]Department of Civil Engineering, The Polytechnic, Ibadan

Abstract

Over the years, hundreds of thousands of infants and adult death were ascribed to intrinsic thermal deregulation in the extremes of ambient temperature. Wrapping feverish people in wet sheets and immersing them in cool baths helped to lower body temperature.Hot water bottles and blankets were used to warm hypothermia victims. This manual control method of patient temperature in most cases is not convenient, accurate, reliable and adequate. Hence, there is need for an automated means of controlling these conditions. Today, hyperthermia/hypothermia blanket or pads which are medical devices that have in-built temperature regulator or thermostat, capable of raising or lowering the body temperature are used. Such blankets or pads circulate water through them at pre-set temperature level to increase or lower body temperature. These devices are expensive and not available in most African health care centres. In this work, the hyperthermia/hypothermia device was developed to proffer solution to temperature abnormalities in human, and to make the device available and affordable to most African health care centres.

Introduction

Body temperature is one of the four vital signs that must be monitored to ensure safe and effective care. Temperature measurement is recommended by the National Institute of Clinical Excellence as part of the initial assessment in acute illness in adults (NICE, 2007), and by the Scottish Intercollegiate Guidelines Network guidelines for post-operative management in adults (SIGN, 2004). Despite applying in all healthcare environments, wide variations exist on the methods and techniques used to measure body temperature. It is essential to use the most appropriate technique to ensure that temperature is measured accurately. Inaccurate results may influence diagnosis and treatment, lead tofailure to identify patient's deterioration and compromise patient's safety.

Centuries ago, wrapping feverish people in cold wet sheets and immersing them in cool baths helped to lower body temperature. Hot water bottles and blankets were used to warm hypothermia victims. Forced air warming devices have been used to solve hypothermia problems. Today, hyperthermia/hypothermia blankets or pads are special medical devices with an in-built temperature regulator or thermostat, capable of raising or lowering body temperature. Such blankets or pads circulate water through them at pre-set temperature levels. or raise or lower body temperature.

There are various hyperthermia/hypothermia devices. Some utilize dry cold water to lower the body temperature. They are used for only one patient and discarded. Others have special adaptor to change from heat to cold, and can be re-used. The hyperthermia/hypothermia device in this work is however designed to monitor the body temperature of the patient and then use the measured temperature as a means of feedback control to the unit so as to regulate the body temperature of hypothermia or hyperthermia victims via a blanket-seized aquathermia pad and a head pad that will be worn on the patient. The hyperthermia-hypothermia blanket raises, lowers, or maintains body temperature through conductive heat or cold transfer between the blanket and the patient. It can be operated manually or automatically.

Maintaining patient's normal temperature is a critical method of preventing surgical site infections and other complications such as metabolic acidosis, cardiovascular effects, increased respiratory distress and surgical bleeding. Maintaining body temperature beginsfrom the pre-operative phase and continues into the post-operative phase.Pre-operative hypothermia and hyperthermia, defined as a core temperature below 36°C and above 38°C respectively, hasadverse effects on patient thermal discomfort on morbidity and mortality. The use of warmed blankets is a common method of maintaining normothermia. For instance, Lane says (Lane, SCIP), the application of single heated blanketsis known to reduce heat loss by 33%. Increased skin temperature from warmed blankets helps with pre-surgical vasodilatation and aids in easier IV access. (Lane, SCIP).

Literature review

Trillions of cells in human organism are working together for the maintenance of the entire body. While cells may perform different functions, all the cells are similar in their metabolic requirements. Well-being of individual cells and the entire body requires constant body internal environmental maintenance. The varied processes by which the body regulates its internal environment are collectively referred to as homeostasis (Hagindaz, 2007).

The vital signs are indicators of one's overall health. Vital signs basically consist of the body temperature, pulse rate, perspiration rate and blood pressure. They are important components of monitoring patient's progress during hospitalization by offering clues to physiological ailment and helping evaluate progress towards recovery.Heath care professionals are fully aware of the need to frequently monitor the vital signs associated with a patient when hospitalized. Almost every hospitalized patient requires periodic measurement and logging of temperature, pulse rate, blood pressure and respiration rate. Such monitoring can be performed by having a health care worker periodically visit the bedside of the patient and measure and/or observe the patient’s vital signs using dedicated equipment that is either fixed or brought into the patient's room.

The body temperature normally fluctuates between 36°C and 37.7C° over a period of 24 hours (circadian cycle), being lowest very early in the morning and highest late afternoon and early evening. Hyperthermia occurs when the body temperature is elevated above the normal daily variation. The Hypothalamus of the brain is the control centre responsible for body temperature and when hyperthermia and hypothermia result, this centre resets the hypothalamic thermostat upwards. Hyperthermia may show a particular pattern, such as peaking each day and then returning to normal, or be intermittent when the temperature does not return to normal. Vital signs and body temperature should therefore be assessed twice daily and if any abnormality,such as hyperthermia and hypothermia which are medical emergencies, is noticed in the body temperature,there is a need for a quick therapy so as to regulate the abnormality.

Heat flow inside the human body occurs when the temperature of the body surface is lower than that of the body interior. The body supply to the skin is the chief determinant of heat transport to the skin. Heat loss occurs by the physical processes of radiation (from tissues), conduction (contact with cold surface), convection (exposure to the environment), and evaporation (respiration) (Despopoulos and Silbernagl, 2003).

All objects continually radiate energy in accordance with the Stefan-Boltzmann law, i.e. proportionately with the surface area, emissivity, and the fourth power of the absolute temperature.The net rate of heat exchange by radiation between an organism and its environment is usually expressed in terms of unit area of the total body surface.

$$q_r = \varepsilon * \sigma * (T^4 s - T^4 a) \qquad (\mathrm{W}/m^2) \qquad (1)$$

Where: Ɛ is the emissivity which is approximately equal to the absorptivity.
For incident infrared radiation, the absorptivity of human skin is very high, about 0.97, and is dependent on colour. Stefan-Boltzmann Constant, σ, is 5.67051×10-8 (W/m^2K^4).T_a is the surface temperature of the body or clothes and T_s is the temperature of surroundings.When the body shell transfers heat to the surrounding air, convection comes into play.Convective heat losses from the body are strongly dependentonair velocity. The simplest equation for characterizing convective losses is

$$q_c = h_c * (T_a - T_s) \qquad (\mathrm{W}/m^2) \qquad (2)$$

T_s is the surface temperature of the body or clothes, T_a is the temperature of surroundings, and h_c is the convective heat transfer coefficient.Heat loss by radiation and heat loss by convection alone are unable to maintain adequate temperature homeostasis at high environmental temperatures or during strenuous physical activity. Because water absorbs a great deal of heat before vaporizing, its evaporation from the body surfaces removes large amount of body heat. The water lost by evaporation reaches the skin surface by diffusion and by neuron activated sweat glands.
In human body, evaporative heat losses occur by several mechanisms:

Heat losses by diffusion of water through the skin

Water diffusion through the human skin is part of the "insensible" perspiration. This diffusion totals about 350 ml/day in an average person, and is assumed to be proportional to the difference between the vapour pressure of water at the skin temperature and the partial pressure of water vapour in the ambient air. Inouye (Cooney, 1976) gave the correlation about the diffusion heat loss per unit area.

$$q_d = \frac{4184}{3600} * (0.35) * (P_s - P_a) \qquad (\mathrm{W}/m^2) \qquad (3)$$

Where $P_s$the vapour is pressure of water at skin temperature and P_a is the partial pressure of water vapour in the ambient air. P_s and P_a are in millimetres of mercury and they are calculated from equation.

$$P_s = 1.92P_s - 25.3(\mathrm{mm}H_g) \qquad (4)$$

Where $P_a = P_v * (\%RH)(mmH_g)$

T_s is the surface temperature of the limb. It is in Celsius (°C), and P_v is the vapor pressure of water at air temperature in the condition of 1atm, and RH is the relative humidity of the air.

Heat losses by sweat secretion

When the heat loss amount is not ample to maintain the core temperature in asuitable range, an automatic mechanism of the body appears. This mechanism for increasing the heat loss is the sweating response, which provides secretion of a dilute electrolyte solution from numerous glands to the skin surface. Then, evaporation from the wetted surface then occurs (Cooney, 1976).Heat loss by sweat secretion per unit area is given by:

$$q_s = \frac{4184}{3600} * K_e * (P_s - P_a)(W/m^2) \quad (5)$$

K_e is the coefficient for evaporation heat loss from nude person in the air. It is in (kcal/m^2hr mmHg). The correlations for K_e have been experimentally determined by several investigators.

Design Consideration and Analysis

Hyperthermia/hypothermia Temperature Control Device Block Representation (figure 1) consists of power supply section, SIM900A, microcontroller, ADC0904, LM35, LCD, relays, pumping machine, electrical valves and relay drivers. The GSM has a valid SIM card and sufficient recharge amount for sending SMS to the user. The microcontroller is powered with +5V while the switching section is powered with +12V.

LM35 temperature sensor was employed to sense the body, compressor and heater temperatures. It was calibrated in centigrade and has a linear +10mV/°C scale factor with basic centigrade temperature sensor of 2°C to 150°C**.** For safety, less than 60μAdrainedcurrent used to be chosen. Human body temperature (37°C) required maximum of 50°C for the design

i.e$R_S =$ -$V_S/50\mu$, while $V_{out} =$ 250mV at 25°C (LM35 Data sheet)

At 50°C V_{out} = 250 X 2 = 500mV

Then, R_s = 10KΩ

Similarly, for R3, R2, and R1

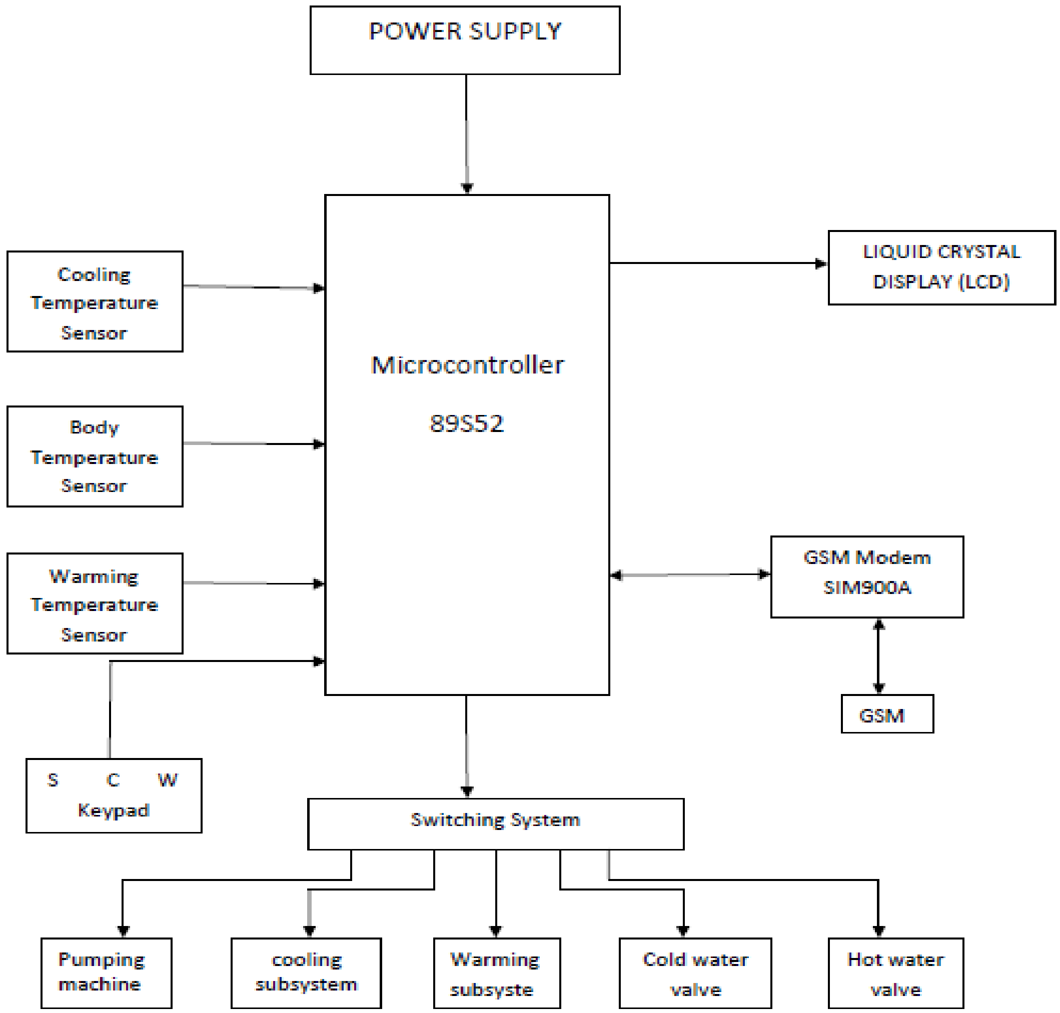

Figure 1 : Block representation of Hyperthermia/Hypothermia Blanket Device

ADC0804 was employed to digitalise temperature value . To set a particular reference value, the **Pin 9** of the microcontroller was connected to half the voltage ($V_{ref}/2$) with LM35 default value of 4V.

The Step size is 4/255 = 15.62mV

For clocking, external RC was chosen

$$\text{i.e}F_{clk} = \frac{1}{1.1RC} \quad (6)$$

Usually, R = 10KΩ (recommended) (Source: data sheet).

To avoid ADC0804 overloading, capacitor of 10μF was used.

Hence, $F_{clk} = \frac{1}{1.1\times10^{3}\times10\times10^{-6}} = \frac{10}{1.1}$

$$\text{Conversion time} = \frac{1}{F_{clk}} = \frac{1.1}{10} = 110mS$$

The 8-bit A/D converter uses successive approximation as the conversion technique. The converter features a high impedance chopper stabilized comparator, a 256R voltage divider with analogue switch tree and a successive approximation register. The 8-channel multiplexer can directly access any of the 8-single-ended analog signals. To read, write and clear the ADC, P3.5 to P3.6 were used so as to manage push bottom at P3.2 and P3.5.

Controlling and Switching Modules

In order to automate the result of LM35 to determine particular temperature of the patientfor the system to supply the required quantity and type of water, microcontroller AT89S52 was employed and it was connected as shown below (Table 1)

Table 1: AT89S52 port connections.

1	**P1.2 to P1.7**	**ULN 2003**
2	P0.0 and P0.1	LCD
3	P0.4 to P0.7	LCD
4	P2.0 to P2.7	ADC's
5	P3.5 to P3.6	ADC's to write and clear ADC

While the crystal oscillator was connected to Pin18 and Pin19 clocked with12.0MHz was used (Standard, data sheet),**ULN 2803A (**NPN Darlington Transistor), was employed as interface between Microcontroller AT89S52 andrelays (Table 1), to drive the Compressor, the heater and valves 1,2,3 and 4.

Transmission Module

The GSM/GPRS TTL UART Modem was used to automate the remote monitoring of the patient, and it was built with SIM900A, and configured to operate at a baud rate of 1900MHz with the microcontroller. Temperature range of 0°C to +50°C was used for the design. For serial communication, serial mode 1 was selected. To obtain the standard baud rate of 9600MHz, the setting of TH1 will be as follows:

$$\text{BRL} = \frac{256-2^{SMOD}\times F_{PER}}{6^{(1-SPD)}\times 32\times Baud-Rate} \quad (7)$$

$$\text{TH1} = 256 - \frac{2 \times 12 \times 10^6}{6^{(1-4)} \times 32 \times 9600 \times 12}$$
$$= 253^d$$
$$\therefore TH1 = OFDH$$

where

SMOD Serial mode (serial mode1 was used)

Fper Frequency of the oscillator used, usually 12MHz

SPD Serial power down bit (4).

Then, ASM was used for the interfacing of the microcontroller (Appendix D) with others.

Solenoid Valve

It was used to prevent mixing of hot water and cold water.The flow coefficient tabulated for each valve allows calculation of service parameters such as flow rate or pressure drop for steady-state flow.Kv is the flow rate in m3/h of water at a temperature between 5 and 30 °C, with a pressure drop of 1 bar across the valve. Its value has been determined for the different models according to VDI/ VDE 2173 guidelines and tabulated in the catalogue's characteristic data (Data sheet). The flow rate calculation is stated that:

Water at 20 °C (preset value), kv = 9.5, Δp = 3 bar

$$Q = kv \cdot \sqrt{\Delta p} \quad (8)$$

$$Q = 16.45 \text{ m3/h}$$

While the pressure drops across valve

Water at 20 °C, Q = 12m3/h, kv = 9.5

$$\Delta p = (\frac{Q}{Kv})^2 \quad (9)$$

$$\Delta p = 1.6 \text{ bar}$$ (Source Data sheet)

Cooling Sub-system

The cooling sub-system was a typical refrigeration system. The performance of a refrigerator is expressed in terms of the coefficient of performance (COP), and is defined as:

$$COP_R = \frac{desiredoutput}{requiredinput} = \frac{coolingeffect}{workinput} = \frac{Ql}{Wnet-in} \quad (10)$$

Refrigeration system can freeze 1 ton (2000 1bm) of liquid water at 0℃ (32℉) into ice at 0℃ in 24h is said to be 1 ton (Boles, 2006). One ton of refrigeration is equivalent to 211kj/min or 200Btu/min, the cooling load of a typical $200m^2$ residence is in the 3ton (10kW) range.The tubes in the freezer compartment where heat is absorbed by the refrigerant as the evaporator. The coils behind the refrigerator, where heat is dissipated to the kitchen air, serves as the condenser.The kinetic and potential energy changes of the refrigerant are usually small relative to the work and heat transfer terms, and therefore they can be neglected. The steady flow energy on a unit-mass basis reduces to:

$$Q_{in} - Q_{out} + W_{in} - W_{out} = h_{in} - h_{out} \quad (11)$$

The condenser and the evaporator do not involve anywork. Thus, the compressor can be approximated as adiabatic.

Compressor and Refrigerant Selection

For this design, a 1-horse power compressor was used alongside its equivalent size of condenser, as recommended by the manufacturer due to the small size of cooling reservoir that was used. The evaporator is coiled around the cooling reservoir and the interconnections between the compressor, condenser, expansion valve and evaporator were perfected.

The two important parameters that need to be consider in the selection of refrigerant are the temperatures of the media (the refrigerated space and the environment) with which the refrigerant exchanges heat. To have heat transfer at a reasonable rate, a temperature difference of 5°C to 10°C should be maintained between the refrigerant and the medium with which it is exchanging heat. The lowest pressure in a refrigeration cycle occurs in the evaporator, and this pressure should be above atmospheric pressure to prevent any air leakage into the refrigeration system. Therefore, a refrigerant should have a saturation pressure of 1amt or higher. Thus, **R-134a** refrigerant was used while selecting the refrigerant due to its non-toxic, noncorrosive, non-flammable, chemically stable, high enthalpy of vaporization (minimizes the mass flow rate) characteristics and its availability at low cost.

Warming Sub-System

The warming sub-system is made up of a cylindrical water reservoir, heating element and Lm35 IC as its temperature sensor. The cylindrical water reservoir is of dimension 20cm and 10cm in height and diameter respectively. The heating element has a rating of

100W and has been designed to have a temperature$\leq 50W$.After the cooling and warming sub-systems have been constructed, then the interconnections between them were made using water pipes of varying diameters and solenoid valves as earlier discussed. The interconnection is shown in fig. 3.12.

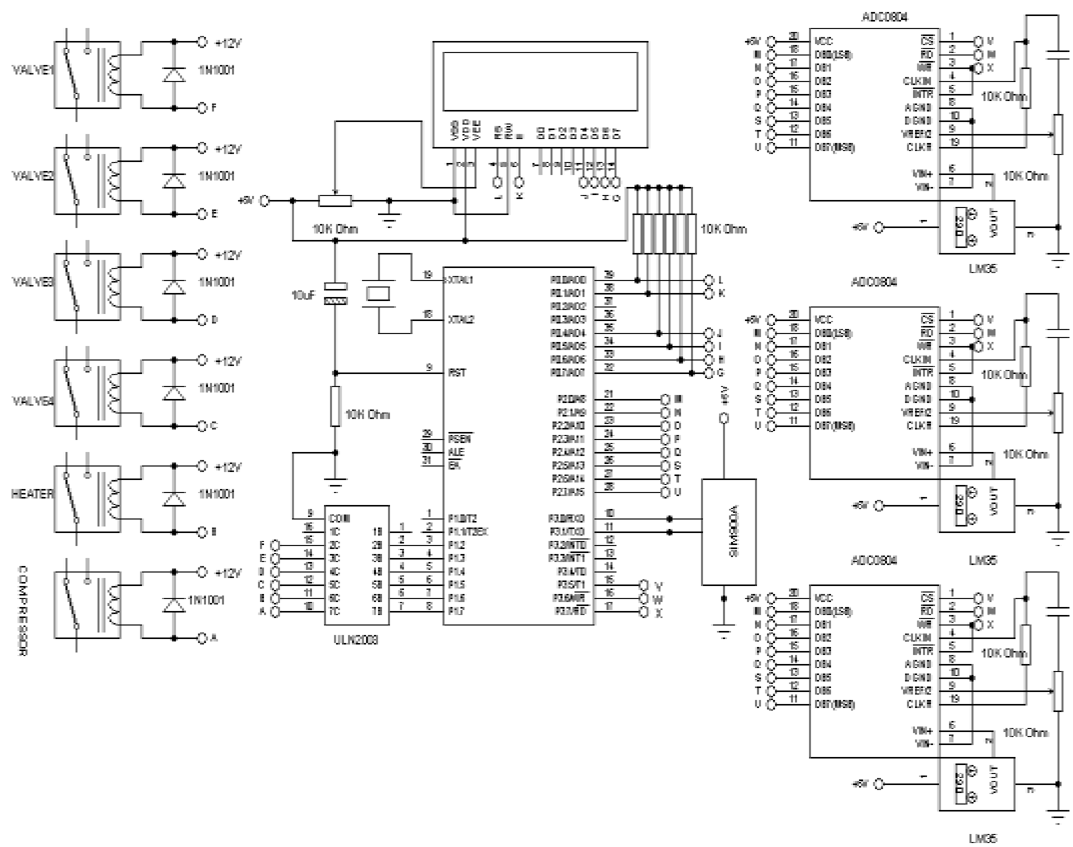

Figure 2:Circuit Diagram of **Hyperthermia/Hypothermia Automated Blanket Device**

Testing, Result Analysis and Discussions

Series of tests were carried out on various sub-systems, and those tests were repeated after coupling so as to ascertain their workable efficiency before initial switching. Some of the important areas were summarised below. In order to protect the compressor of the cooling sub-system from damaging, an overload relay was used. After the cooling sub-system was coupled, the system was tested by pouring 2liters of water into the cold-water reservoir and the system was energised with AC supply of 220V for a duration of

5minutes to test for effectiveness of the Cooling System. The result of the water temperature drops with time at an interval of 1 minute (Table 2)

Table 2: Temperature-Time Characteristics for Cooling System

Time (minute)	**Temp. (°C)**
0	30
1	29
2	28
3	27
4	26
5	25

Figure 3:Prototypeof Hyperthermia/Hypothermia Automated Blanket Device

After coupling the warming sub-system, 220V AC supply was used to energize its heating element in the water reservoir filled with 2litters of water and the temperature rising with time was observed for about 5minutes (Table 3)

Table 3: Temperature-Time Characteristics for Heating System

Time (minute)	**Temp. (°C)**
0	30
1	32
2	35
3	38
4	40
5	43

It was observed that the rate of warming the water (heating) was faster than that of cooling the water. The cooling and warming sub-systems were interconnected to the pumping machine using solenoid valves (hot and cold), pressure pipes and fittings. Here, water leakages were tested for and amendments were made (using thread tape and appropriate size of spanner) at points of leakages. Sixty (60) watt incandescent lamp was used to test power modulebefore connected to supply 5vollt to the microcontroller and other digital modules.

Thesystem was checked for water leakages and open circuit to ensure safety of the microcontroller circuit component before the final test were carried out. The body temperature of a patient was measured using the LM35 sensor probe (thermostat) of the device and this was displayed on the LCD screen and an SMS alert was sent to the doctor showing the temperature of the patient. Then,the desired temperature of the warming and cooling sub-systems were set and turned on. The measured temperature of the patient was less compared with the set temperature (default temperature in the micro-controller). So, the warming sub-system turned on with smooth switching operation, and the pumping machine started circulating water through the blanket to ensure even distribution of temperature. When this set point was reached, the warming sub-system turned off but the pumping machine was still circulating water through the blanket.

However, the temperature of water rose above the set temperature (overshoot) thereby increasing the temperature of the patient above the set temperature, the cooling sub-system switched on to bring the temperature of the patient down to the set temperature.But the temperature of the patient went slightly below the set temperature (undershoot). The system keeps alternating between the warming and cooling cycle until the temperature equals the default temperature in the micro controller (normal body temperature) and the system stops as an SMS alert is sent to the doctor.

Conclusion and Recommendations

Biomedical Engineering has helped medical science to invent and refine devices to their patients. Hence, inventions in Biomedical Engineering have become indispensable tools used by most medical practitioners in the assessment of physical health, and as means of medical intervention for their patients before or during hospitalization. The prototype of Hyperthermia/Hypothermiadevice was relatively at low cost and will make it affordable by most healthcare centres in the country. The control device is reliable, non-intrusive, and non-invasive and it shall be manufactured locally to make it affordable and available to most health care centres. The cooling sub-system of this project could be improved on by using other types of compressor sizes such as 1/4 horse power, 3/4 horse power etc. Further work could be done on getting a highly sensitive sensing element for proper automation of the device.

REFRENCES

Bas, V.B. (2009) 'Successful Temperature Management: A practical guide on how to prevent and treat hypothermia, Winterswijk.

Eda, D.Y. (2005) ' A Mathematical model of the human thermal system, Izmir Institute of Technology, IZMIR.

Boles, M.A. (2006) 'Refrigeration Cycle', in Yunus A. Cengel, M.A.B. Thermodynamic: An Engineering Approach, New York: McGraw Hill.

Bouchama, D.M. (2007) ' Cooling and hemodynamic Management in heat stroke: practical recommendation', Crit Care, vol. III, p. 11.

Fauci, A. (2008) Harrison's Principle of Internal Medicine, New York: McGraw Hill.

Beek, S.D.J. (1997) 'Hypothermia eenkoudkunstje, Winterwijk.

Ganong, W.F.(2005) 'Central Regulation of Visceral Functions', in Ganong, w.F. Review of Medical Physiology, 22^{nd} edition, Boston: McGraw Hill.

Hagindaz (2007) human physiology, 24 April.[Online], Available: http://www.Wikibooks.org [17 June 2011].

Karakitsos, K.A. (2008) 'Hypothermia therapy after traumatic brain injury in children', N. Engl. J. Med 359 (11), September, p. 1179-1180.

Laupland, K. (2009) 'fever in the critically ill medical patient', critical care medicine, no.7, July, pp. 273-378.