Heating-Gloves and Socks for The Treatment of Surgical Hypothermia in Theatre Conditions

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***Abstract*— The thermoregulation of a surgical patient's body is impaired under anesthesia, leading to an accelerated heat loss to the environment, thereby, causing surgical hypothermia. It is a condition wherein the core body temperature falls below 95ºF and hinders the wound healing process of the surgical site, leading to cardiac and cerebral dysfunctions. When the patient starts developing mild hypothermia, his hands and feet are manually rubbed to keep them warm, but this is tedious and may not be very effective. Therefore, heating gloves and socks which produce a small amount of heat to the patient's hands and feet, respectively, have been developed to keep them warm during the surgery. The gloves and socks have temperature sensors embedded in them to measure the core body temperature. Based on the temperature measured, a heating element connected to a voltage regulator based heating circuit is used to produce a controlled amount of heat to keep the hands and feet of the patient, warm.**

Keywords*— *Hypothermia; heating-gloves; heating-socks; temperature sensor

I. INTRODUCTION

Even under adverse conditions, the human body temperature is maintained within the normal range of 35ºC to 37ºC. In high-risk surgical patients, the anesthesia administered to them impairs the thermoregulation of the body. This in turn redistributes the body heat, leading to its loss to the surroundings.[1,5] This heat loss is accelerated by the increased fluid intake and the cool temperature settings in a surgical environment, causing the core body temperature to fall below 95ºF [2,7], resulting in a condition called hypothermia. [2, 11] On an average, a person loses 0.9°C to 2.7°C of his body temperature under general anesthesia. As the duration of the surgery increases, the core body temperature of the patient decreases and thus, increases the susceptibility of the patient to hypothermic conditions. This has been depicted in Figure 1, with the data collected from hopsitals. Based on the fall in the body temperature of the patient, hypothermia is classified into three types: Mild (35°C – 33°C); Moderate (33°C-28°C); and Severe (below 28°C). [3, 6]

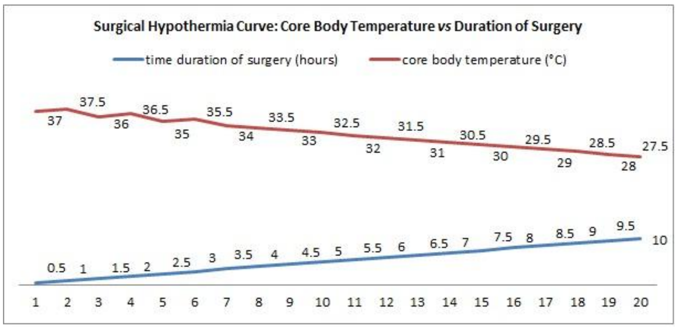

Fig. 1. Surgical hypothermia curve depicting the variation of the core body temperature with respect to the duration of the surgery

The impairment in the central thermoregulation inhibits the movement of the white blood cells (WBCs) in the body, thus, leading to a wound infection at the surgical site in the body. This prolongs the hospitalization of the patient and increases the risk of cardiac and cerebral dysfunctions. [3,12] Moreover, hypothermia may also enhance the effects of anesthetic drugs and create complications such as uncontrollable shivering, extended periods of stay in the post-operative recovery rooms and an impaired immune system. [2,3] There are active pre-warming techniques like the introduction of intravenous warming drugs to prevent the occurrence of hypothermia [2]; continuous manual rubbing of the patient's hands and legs, to increase the core body temperature, which becomes tedious and inefficient in the long run. It has been estimated that only 26% of high-risk surgical patients prone to surgical hypothermia receive active warming through manual rubbing.[1,3] In order to overcome this problem, a non-invasive technique of warming the patient's hands and feet has been developed wherein a pair of gloves and a pair of socks, embedded with a heat producing circuitry, have been designed. The heating-gloves and heating-socks have been designed in such a way that they are cost-effective, and reduce the efforts of the scrub nurses who are involved in the tedious task of manually rubbing the patient's extremities to keep them warm throughout the surgery.

II. METHODOLOGY

Heating-Gloves and Heating-Socks

A pair of cotton-blend fabric gloves and socks, each, is used to design the heating device. A temperature sensor designed to read temperatures below 20°C is embedded inside the fabric gloves and socks to measure the decrease in the core body temperature, which is indicative of hypothermia. The sensor is integrated to a heating element that is connected to a voltage regulator based heating circuit which is used to control the amount of heat produced.

Temperature Sensing Unit

The temperature sensing unit, as shown in Figure 2, consists of an LM35 [8], which is used to design the temperature sensor to measure core body temperatures, even below 20°C. It measures the changes in temperature as the difference in voltage. The electrical characteristics of LM35 that make it an excellent choice to be used as a temperature sensor are listed in Table 1. The analog voltage output is digitized using the analog-to-digital converter, ADC0804. The digitized voltage output is fed to the 8051 microcontroller that is interfaced with an LCD display, as shown in Figure 3, to display the output temperature.

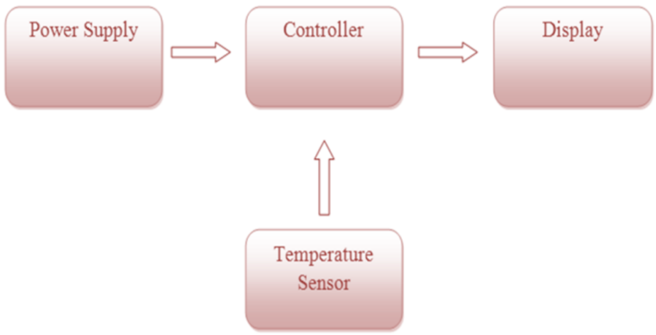

Fig. 2. Block diagram of the temperature sensing unit

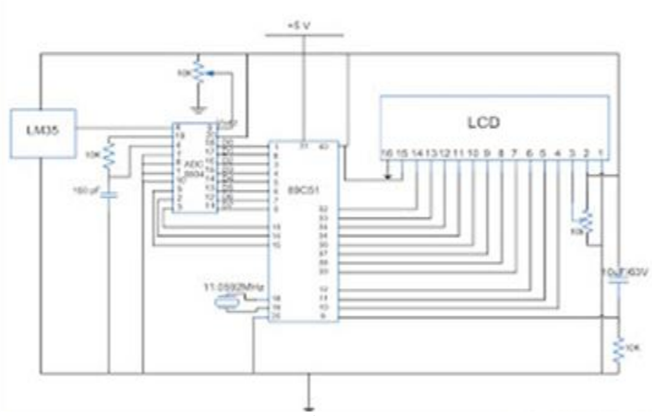

Fig. 3. Circuit diagram of the temperature sensing unit

Table 1. Electrical characteristics of LM35

Semiconductor Temperature Sensor	Pins	Accuracy of Optimum Temperature (ºC)	Input Voltage (Volts)
LM35AD	3	-55 to 150	4.2 - 35
LM35DM	8	0 to100	4.2 - 35
LM35DT/NOPM	3	0 to 150	4.2 - 30

Heating Circuit

The main heating circuit is designed using an LM317-based voltage regulator circuit. The LM317 is capable of supplying output voltages in the range of 1.25V to 37V which can be set using two external resistors. The output current obtained is greater than 1.5A. LM317 is preferred because of its ease of use.[9,10] The voltage regulator circuit has a 24V transformer that is connected to a diode bridge which comprises of four 3A diodes. Two capacitors, C1=22μF and C2=3300μF, and two resistors, R1=10KΩ and R2=220Ω are connected as shown in Figure 4.

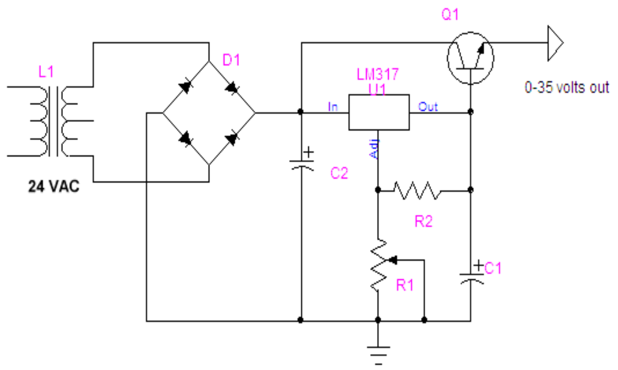

Fig. 4. Circuit diagram of the heating circuit

The output from the heating circuit is fed to a heating element that is placed inside the gloves and the socks. The heating element produces heat which is equally distributed within the gloves and the socks to warm the patient’s hands. The physical and thermal properties of the different heating elements that can be used in this circuitry are listed in Table 2. Cupronickel is the most preferable choice of heating element because of its excellent physical properties. The heat produced is controlled by the main heating circuit which in turn is regulated by the temperature sensing unit. The temperature sensing unit detects the fall in the core body temperature, and if the temperature falls below 35°C, it activates the main heating circuit. Once adequate heat is supplied to the patient’s extremities, the core body temperature of the patient increases, thus, eliminating the need for manual rubbing. Once the patient’s core body temperature rises to the normal range, the temperature sensing unit switches the main heating circuit off and thus, prevents excessive heating which could otherwise lead to burns.

Table 2. Physical and thermal properties of different heating elements

Heating element	Density (g/cm^3)	Thermal conductivity (W/m.K)	Electrical resistivity at room temperature (μΩ·m)	Melting Point (°C)
Nichrome	8.4	11.3	1.5	1400
Cupronickel	8.9	17	1.9	1240
Kanthal	5.6	30	1.45	1580

III. RESULTS AND DISCUSSIONS

The heating gloves and socks have temperature sensors embedded inside them to sense the fall in the core body temperature. The temperature sensing unit inside the gloves and socks provides the measured temperature as an input and turns the main heating circuit on. This produces a controlled amount of heat in the heating elements placed inside the gloves and socks. Once the heating elements are heated up, they distribute the heat throughout the gloves and socks, thereby, warming the hands and feet of the patient. This in turn increases the core body temperature of the patient and brings him out of the hypothermic state during surgery. The main heating circuit is turned off when the core body temperature reaches a stable, normal value of 37°C. The working model of a heating glove along with the temperature sensing unit is shown in Figure 5.

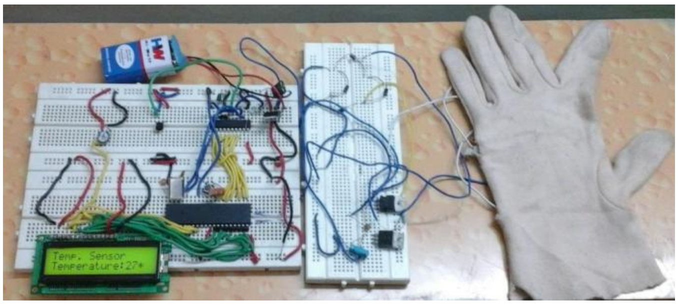

Fig. 5. Working model of a heating-glove along with the temperature sensing unit

IV. CONCLUSION

The heating-gloves and heating-socks designed are cost-effective and easy to use, with very less possibilities of skin burns. Since the gloves and socks are made of a cotton-blend fabric, they provide good comfort to the patient and prevent the occurrence of any rashes that are commonly seen in rubber-based gloves. These heating-gloves and heating-socks provide for an effective alternative to the invasive warming techniques and the tedious, manual rubbing procedures.

V. FUTURE WORK

The future of this work is aimed at fabricating a compact heating circuitry along with the temperature sensing unit, in the size of a standard metal coin and placed on the gloves and socks as shown in Figure 6, using Surface Mounted Devices (SMD) technology. The entire set up is to be incorporated into a small, disposable fabric patch which will be embedded inside the heating-gloves and heating-socks so that the physical complexities caused by the circuitry, currently designed, can be eliminated.

Fig. 6*. Standard metal coin used as reference to design the compact MEMS-based circuitry for the heating-gloves

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