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Design of a Warm and Cold Compress Device Based on Microcontroller

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ABSTRACT: One of the methods for reducing the rising human body temperature due to hyperthermia, and pain due to rheumatoid arthritis or fracture is by compressing the patient's body parts. Traditional compress tool is a wet warm/cold towel. However, the temperature of the traditional compress tool is easy to change, making it inefficient to do because a user must soak again the towel into hotter/colder water repeatedly. The research aims to propose the design of a warm and cold compress device in which a microcontroller manages the operation to keep the required temperature stable. The user must select the device operation as a warm or cold compress by turning the selector.

By design, the compressing device has a small silicone pack containing water at a specific temperature. The silicone pack is attached to the patient's body to compress. If a user selects the device as a warm compress, the microcontroller automatically turns on the Peltier element to heat the water to 43 °C – 45 °C. On the contrary, if a user selects the device as a cold compress, the microcontroller reverses the input voltage polarity of the Peltier element so the Peltier element can cool the water to 21 °C – 23 °C. Furthermore, the water mini pump continuously circulates warm or cold water through a flexible hose toward the silicone pack for compressing the patient's body. Besides, the device has an LCD showing the compressing temperature for the user.

The results show that the device can operate appropriately as a warm or cold compress as the user selects. As a cold compress, the duration is 5.5 minutes to reach 21 °C from 31 °C of the initial room temperature. Meanwhile, it takes 3 minutes for a warm compress to reach 45 °C from 31 °C of the initial room temperature. Besides, the device has a 1.43 % average error in displaying the compressing temperature against the actual temperature of the silicon pack's surface, at which the standard thermometer measures.

KEYWORDS: Arduino, Compress, Microcontroller, Peltier, Temperature Sensor

I. INTRODUCTION

Hyperthermia increases the core human body temperature above normal 36.7 °C - 37.5 °C, usually caused by infection, resulting in fever, and is the most common manifestation. Besides, many people feel pain due to rheumatoid arthritis or fracture. Compress is a method that can be used to reduce human body temperature, which rises due to hyperthermia and reduces pain due to rheumatoid arthritis or fracture. There is two types of compress method, namely cold compress and warm compress, which each of them has specific function.

In the traditional compress method, the towel used as a compress tools needs to be frequently soaked again in colder/hotter water because the temperature of the towel can easily lose and return to the patient's temperature. This traditional method is ineffective to do, and makes a nurse inconvenient to do.

Based on the results of several previous studies [1], cold temperatures of 15 °C - 27 °C can reduce the increasing human body temperature. Meanwhile, warm temperatures of more than 40 °C can reduce the increasing human body temperature and pain due to rheumatoid arthritis or fracture.

II. RELATED WORK

Lilis Lismayanti et al. [2] described body temperature changes in hyperthermic patients after warm compress was applied. Hyperthermia increased the core human body temperature above normal 36.7-37.5 °C, usually caused by infection, resulting in fever, and was the most common manifestation. The review results showed that the warm compress method had a positive effect in lowering body temperature in the nursing process in patients with hyperthermia.

Meanwhile, Hariati et al. [3] revealed that a warm compress on the rheumatoid joint will deactivate the nerve fibers that cause muscle spasms and pain. This study aims to determine the effect of warm compresses on the scale of pain in

the elderly with rheumatoid arthritis. This research design using quasi experiment with one group pre–posttest design. The conclusion is that warm compresses affect the scale of pain in the elderly with rheumatoid arthritis. Thus, nurses can use warm compress as a non-pharmacological intervention in reducing pain scales in elderly people with rheumatoid arthritis.

In the other research, Rinawati et al. [4] described that fracture is a type of trauma that often occurs in a person, where the highest incidence is usually due to trauma that affects the bone area around the body resulting in a fracture called a fracture. The purpose of this study was to see whether the cold compress method was effective in overcoming the clinical conditions felt by patients with fractures. The conclusion in this study is that cold compress can be used to treat swelling, edema and pain in patients with fractures but there are other therapies that are more effective and comprehensive.

Meanwhile, Ida Rahmawati and Doby Purwanto [1] observed the effectiveness of giving warm and cold compresses to changes the children body's temperature in the Edelweiss room of the hospital "dr. M. Yunus". The study uses a quasi-experimental design with two groups pretest and posttest design. The population in this study were all pediatric patients who experienced an increase in body temperature. The results showed the effectiveness of giving a warm compress to body temperature in children is more effective for lowering body temperature.

M. Alam et al. [5] revealed that the current cooling system still uses refrigerant, which damages the ozone layer. The thermoelectric based cooling system can be used as an alternative since it produces sufficient temperature difference on both sides by considering its advantages that is more environmentally friendly. This research is aimed to design and built a cooling and heating system using a thermoelectric Peltier TEC 12715 based on microcontroller Arduino uno. This system uses the Peltier thermoelectric effects as coolant and warmer because it produces temperature difference on both sides [6]. Based on this research, in the no load condition the system can produce a cold temperature of 21.3 °C and a hot temperature of 80.2 °C in the 40th minute of use. When given a load of 300 ml and 220 ml drink bottles, the system can produce a cold temperature of 22.2 °C and a hot temperature of 70.7 °C in the 40th minute of use. The TEC 12715 Peltier component used in this research produces the optimal temperature if a voltage of 12 volts and a current of 15 amperes are applied to each Peltier component. The designed system is able to operate repeatedly, properly, and continuously since it is directly connected to alternative current power which is common in households.

Oghoghorie and Okonmah [7] describe the details design and fabrication of a Thermoelectric refrigerator with 12 Peltier modules, 5 exhaust fans working with 12V DC voltage, a fridge and freezer compartment. The thermoelectric refrigerator's operating power is sourced from an Alternating Current power outlet; an applied electrical power of 57 W was used. The Peltier modules were used to cool the compartments of the refrigerator. The approach intended to exploit the Peltier effect with the use of Peltier modules, to generate a cooling effect in the refrigerator compartments. The results showed that the thermoelectric refrigerator's fridge and freezer compartments were able to achieve temperatures of 6.9 °C and -5.3 °C respectively after 2 hours of usage while being loaded.

Pangaribuan and Porman [8] revealed that a traditional compress uses a warm wet towel applied on the human body part. The towel lost its heat so the people must soak the towel into warm water and compress repeatedly. Repeating the process was not efficient to do. Solving the problem was by designing a thermoelectric based compress. By using thermoelectric, electrical energy can be converted into heat energy, which heats the compress device. The DS18B20 temperature sensor measured the actual temperature of the compress. Controlling the compressing temperature used Arduino Uno microcontroller working with fuzzy logic. The result showed that the hot compress device worked properly and produce a stable temperature in the range of 37 °C - 40 °C in 2 minutes 6 seconds.

III. METHODOLOGY

To achieve the research objective, step of research consists of system design, implementation, and testing. Moreover, troubleshooting and improvement are conducted if improper function of the system occurs.

Figure 1 shows the miniature design of a warm and cold compress device based on a microcontroller. Meanwhile, Figure 2 shows the block diagram of the system. The system consists of a control unit completed with a power supply and switch enabling the user to select a warm or cold compress operation, two Peltier elements, a water block, two heatsinks, two exhaust fans, a temperature sensor, a mini water pump, a flexible hose, and a silicon pack containing water.

When used, the silicone pack is attached to the patient's body to compress. If a user selects the device as a warm compress, the microcontroller automatically turns on the Peltier element to heat the water to 43 °C – 45 °C. On the contrary, if a user selects the device as a cold compress, the microcontroller reverses the input voltage polarity of the Peltier element so the Peltier element can cool the water to 21 °C – 23 °C. Furthermore, the water mini pump continuously circulates warm or cold water through a flexible hose toward the silicone pack for compressing the patient's body. Besides, the device has an LCD showing the compressing temperature for the user.

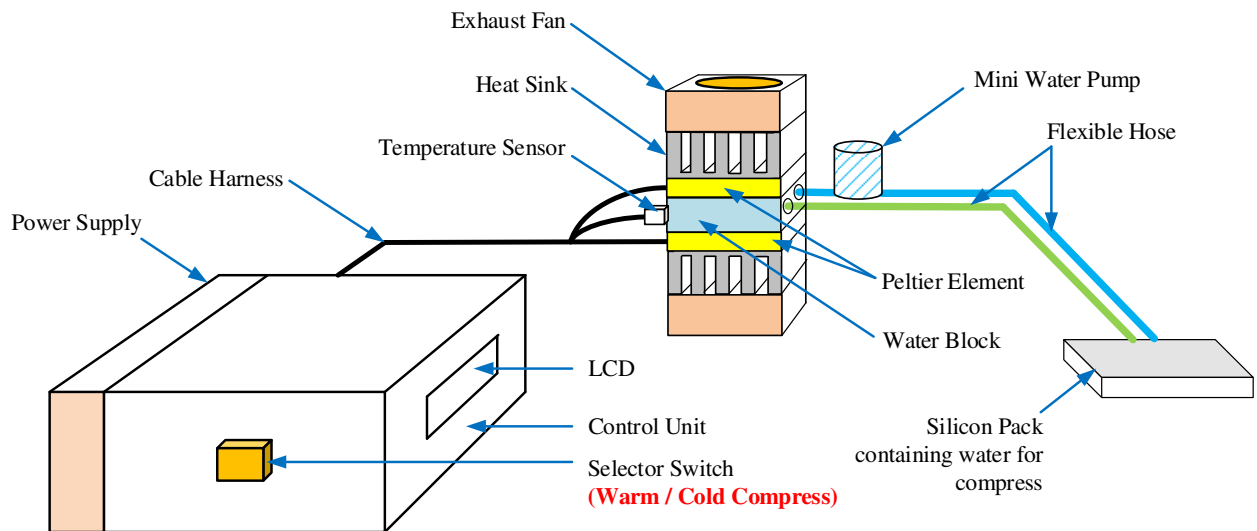


Fig. 1: Miniature Design of the Warm and Cold Compress Device Based on Microcontroller

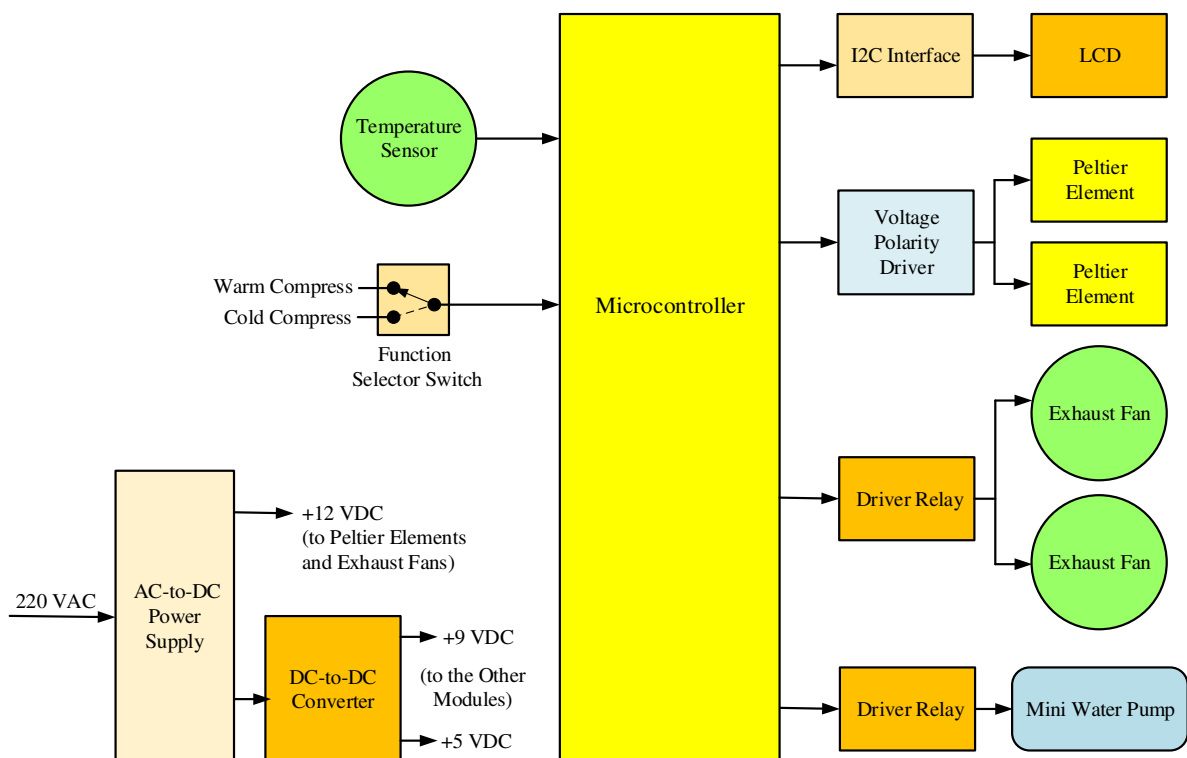


Fig. 2: Block Diagram of the Warm and Cold Compress Device Based on Microcontroller

The warm and cold compress device can operate appropriately because the software follows the hardware. Figure 3 below shows the system wiring diagram, while Figure 4 shows the system software flowchart, which the software coding follows.

As shown in Figure 3, the warm and cold compress device uses an AC-to-DC power supply whose output voltage is +12 VDC, while the input voltage is 220 VAC. The +12 VDC output voltage is fed to the Peltier elements, exhaust

fans, and the DC-to-DC converter XL4015, converting +12 VDC to +9 VDC. Then, the +9 VDC output voltage is fed to the Arduino Mega 2560 module and LM7805 voltage regulator module. Finally, the +5 VDC output of the LM7805 voltage regulator module is fed to the sensor, LCD, and other modules.

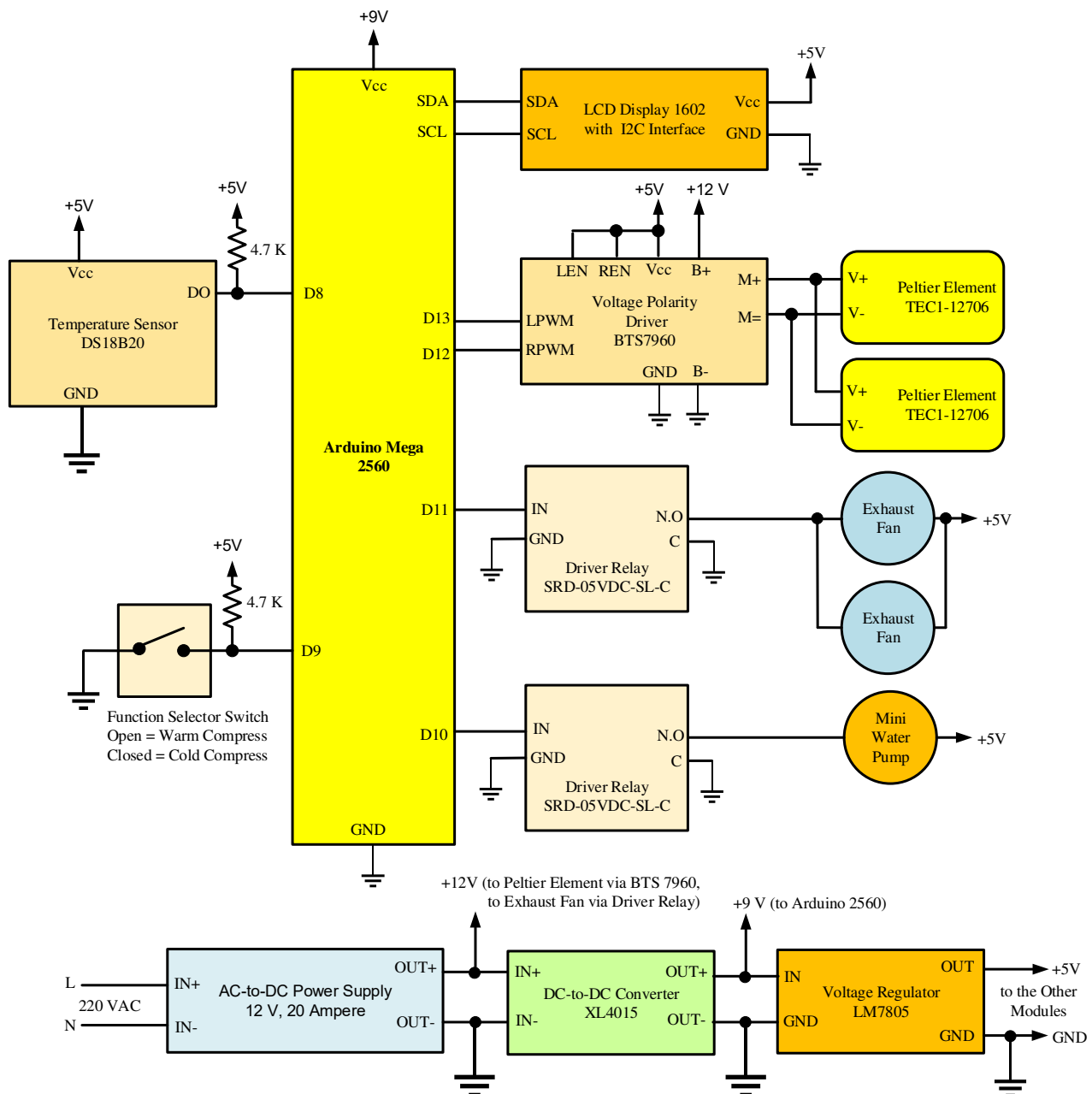


Fig. 3: Wiring Diagram of the Warm and Cold Compress Controlled by Microcontroller

The system utilizes a DS18B20 digital temperature sensor. By design, the temperature sensor attaches to the aluminum water block, where the inside water circulates towards the silicon pack and vice versa via a flexible hose. Based on the experiment result, the temperature difference between the water block and the silicone pack is 2 °C. On the other hand, the main concern in this research is the temperature in the silicone pack because the silicone pack is part of the device that directly contacts the patient's body. Hence, obtaining the silicone pack's temperature value needs a correction factor of 2 °C against the temperature reading result at the water block.

When a user selects the device as a cold compress, the microcontroller turns on the Peltier element by providing +12 VDC voltage so that one side of the Peltier element becomes cold and cools the water in the water block. Next, the

mini water pump circulates the cold water towards the silicone pack and vice versa. It needs to obtain optimal cold at one side of the Peltier element. Hence, the microcontroller turns on the exhaust fan to suck in the heat that arises on the other side of the Peltier element. For use as a cold compress, the microcontroller always maintains the temperature of the silicone pack in the range of 21 °C – 23 °C by turning on and off the Peltier elements on time.

On the other hand, if a user selects the device as a warm compress, the microcontroller turns on the Peltier element to heat the water in the water block by reversing the polarity of the +12 VDC voltage provided to the Peltier element. While heating water, the microcontroller turns off the exhaust fan. For use as a warm compress, the microcontroller always maintains the temperature in the silicone bag in the range of 43 °C – 45 °C by turning on and off the Peltier element on time. Besides, the microcontroller sends serial data to the LCD using an Inter-Integrated Circuit (I2C) technique to display the temperature value on the LCD. The serial data is sent via the SDA line. Meanwhile, the microcontroller controls the data transfer speed by setting the clock frequency in the SCL line.

Moreover, Figure 4 shows the system software flowchart to which the software coding refers.

System function and temperature reading accuracy tests are conducted to ensure that the compress device is proper for operation. The accuracy test compares the temperature reading result by the compress device to the reading by standard measuring equipment (Digital Thermometer, brand: Omron, model: MC-343). The amount of error in temperature reading is calculated using Equation (1).

$$Error(\%) = \left| \frac{T_{device} - T_{std}}{T_{std}} \right| \times 100\% \quad (1)$$

where:

$Error(\%)$ = Error percentage in temperature reading by the compress device against the standard measuring equipment

T_{device} = Temperature reading value by device

T_{std} = Temperature reading value by standard measuring equipment

Finding the average error (%) is by summing the total error (%) and then dividing the total error by number of measurement.

As described before, the microcontroller-based system works by using the dedicated software. Figure 4 shows the software flowchart to which the software coding based on the Arduino programming language refers.

At first, the microcontroller checks the selector switch, of which a user selects the device and acts as a warm or cold compress. Suppose a user selects the device as a cold compress. In that case, the microcontroller reads the temperature sensor attached to the water block, adds the 2 °C correction factor to the temperature reading result, turns on the exhaust fans, and turns on or off the Peltier elements such that the temperature of the silicon pack is in the range 21 °C – 23 °C.

On the contrary, if a user selects the device as a warm compress, the microcontroller reads the temperature sensor attached to the water block, adds the 2 °C correction factor to the temperature reading result, turns off the exhaust fans, and turns on or off the Peltier elements such that the temperature of silicon pack is in the range 43 °C – 45 °C. Turning on the element Peltier for a warm compress operation is conducted by reversing the +12 VDC voltage polarity supply.

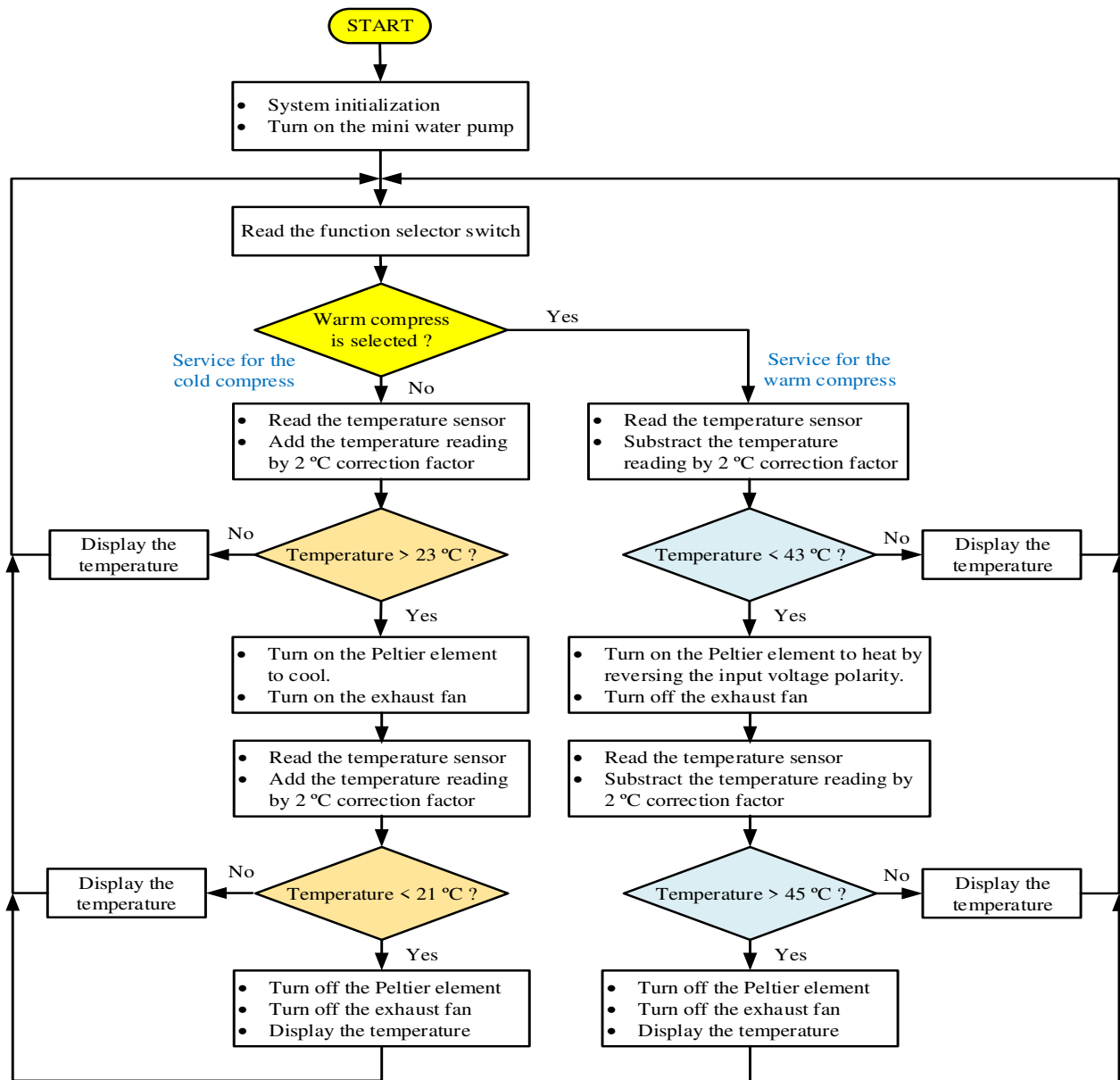


Fig. 4: Software Flowchart of the Warm and Cold Compress Based on Microcontroller

IV. EXPERIMENTAL RESULTS

4.1 Design Implementation

Figure 5 shows the design implementation of the warm and cold compress device. The silicon pack contains water, and the microcontroller controls the water's temperature. The silicone pack will be attached to the patient's body part.

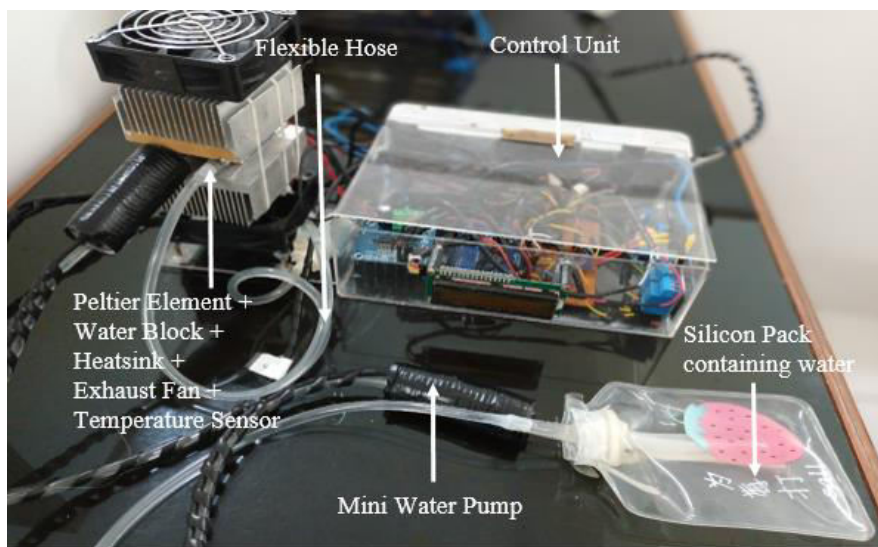


Fig. 5: Model of the Warm and Cold Compress Based on Microcontroller

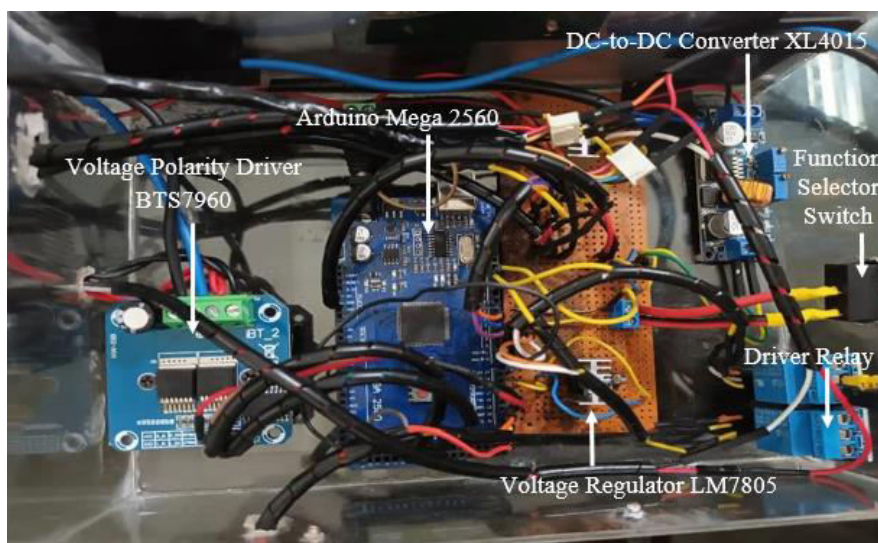


Fig. 6: Design Implementation of the Control Unit of the Warm and Cold Compress Device

As shown in Figure 5, the warm and cold medical device consists of a control unit, a silicone bag filled with water, a flexible hose, a mini water pump, 2 Peltier elements for heating or cooling the water, 2 heatsinks, 2 exhaust fans to suck in the heat in the heatsink, temperature sensor, and water block. The compress device uses an AC-to-DC power supply, which converts 220 VAC to +12 VDC.

Figure 6 shows the design implementation of the control unit of the warm and cold compress device, which contains an Arduino Mega 2560 module as the central processor, a BTS7960 module for reversing the voltage polarity provided to the Peltier element, an LCD + I2C interface for displaying temperature values, a selector switch for selecting a warm or cold compress operation, a DC-to-DC converter XL4015 to convert the +12 VDC voltage to +9 VDC, a voltage regulator LM7805 to convert +9 VDC voltage to +5 VDC, and a relay driver module to control on/off the exhaust fans.



4.2 Functional Test Result

The function of the compress device is verified by observing the operation of the subsystem and the compressing temperature displayed on LCD when the compress device operates under the following conditions:

- a. The user selects the device as a cold compress, and the silicone pack attaches to the patient's body, whose temperature is 36.5 °C – 37.0 °C.
- b. The user selects the device as a warm compress, and the silicone pack does not attach to the patient's body, whose temperature is 36.5 °C – 37.0 °C.

Observation is conducted for 9 minutes at 31 °C room temperature. Table 1 below shows the results of the system function test when the device operates as a cold compress and the silicone pack attaches to the patient's body, whose body temperature is 36.5 °C – 37 °C.

Table 1: System Functional Test Result for Cold Compress and Attaching Silicon Pack to the Patient’s Body

| N o. | Test Input | System Response | Remarks |
|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | <ul style="list-style-type: none"> • User operates the device as a cold compress. • Initial room temperature = 31 °C. • The silicon pack attaches to the patient's body, whose temperature is 36.5 °C – 37 °C. | <ul style="list-style-type: none"> • LCD shows the following temperature: <ul style="list-style-type: none"> ○ Temperature = 31.0 °C at 0.5 minutes ○ Temperature = 30.2 °C at 1.0 minute ○ Temperature = 29.3 °C at 1.5 minutes ○ Temperature = 28.3 °C at 2.0 minutes ○ Temperature = 27.2 °C at 2.5 minutes ○ Temperature = 26.1 °C at 3.0 minutes ○ Temperature = 25.2 °C at 3.5 minutes ○ Temperature = 24.2 °C at 4.0 minutes ○ Temperature = 23.0 °C at 4.5 minutes ○ Temperature = 22.0 °C at 5.0 minutes ○ Temperature = 21.0 °C at 5.5 minutes ○ Temperature = 22.0 °C at 6.0 minutes ○ Temperature = 23.0 °C at 6.5 minutes ○ Temperature = 22.2 °C at 7.0 minutes ○ Temperature = 21.0 °C at 7.5 minutes ○ Temperature = 22.1 °C at 8.0 minutes ○ Temperature = 23.0 °C at 8.5 minutes ○ Temperature = 22.0 °C at 9.0 minutes • Silicone pack becomes cold. • The Peltier element cools the water in the water block. • Exhaust fan is on. • The mini water pump continuously circulates water from the water block to the silicone pack and vice versa. | <ul style="list-style-type: none"> • System response complies with the design. • The temperature is stable at 21 °C – 23 °C, suitable for a cold compress. • A temperature of 21 °C is reached within 5.5 minutes from an initial temperature of 31 °C. |

Table 1 above shows that operating the device as a cold compress and attaching the silicon pack to the patient’s body, whose body temperature is 36.5 °C – 37 °C remains to provide a stable compressing temperature of 21 °C – 23 °C. The temperature of 21 °C is reached in 5.5 minutes from the initial temperature of 31 °C.

Table 2 below shows the results of the system function test when the device operates as a warm compress and the silicone pack attaches to the patient's body, whose body temperature is 36.5 °C – 37 °C.



Table 2: System Functional Test Result for Warm Compress and Attaching Silicon Pack to the Patient’s Body

| No. | Test Input | System Response | Remarks |
|-----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | <ul style="list-style-type: none"> • User operates the device as a warm compress. • Initial room temperature = 31 °C • The silicon pack attaches to the patient's body, whose temperature is 36.5 °C – 37 °C. | <ul style="list-style-type: none"> • LCD shows the following temperature: <ul style="list-style-type: none"> ○ Temperature = 31.0 °C at 0.5 minutes ○ Temperature = 33.0 °C at 1.0 minute ○ Temperature = 35.9 °C at 1.5 minutes ○ Temperature = 39.1 °C at 2.0 minutes ○ Temperature = 43.0 °C at 2.5 minutes ○ Temperature = 45.0 °C at 3.0 minutes ○ Temperature = 44.0 °C at 3.5 minutes ○ Temperature = 43.0 °C at 4.0 minutes ○ Temperature = 44.1 °C at 4.5 minutes ○ Temperature = 45.0 °C at 5.0 minutes ○ Temperature = 44.0 °C at 5.5 minutes ○ Temperature = 43.0 °C at 6.0 minutes ○ Temperature = 44.1 °C at 6.5 minutes ○ Temperature = 45.0 °C at 7.0 minutes ○ Temperature = 44.2 °C at 7.5 minutes ○ Temperature = 43.0 °C at 8.0 minutes ○ Temperature = 44.1 °C at 8.5 minutes ○ Temperature = 45.0 °C at 9.0 minutes • The silicone pack becomes warm. • The Peltier element heats the water in the water block. • Exhaust fan turns off. • The mini water pump continuously circulates water from the water block to the silicone pack and vice versa. | <ul style="list-style-type: none"> • System response complies with the design. • The temperature is stable at 43 °C – 45 °C, suitable for a warm compress. • A temperature of 45 °C is reached within 3 minutes from an initial temperature of 31 °C. |

Table 2 above shows that operating the device as a warm compress and attaching the silicon pack to the patient’s body, whose body temperature is 36.5 °C – 37 °C remains to provide a stable compressing temperature of 43 °C – 45 °C. The temperature of 45 °C is reached in 3 minutes from the initial temperature of 31 °C.

4.3 Accuracy Test Result in Displaying the Compressing Temperature

The accuracy test of the compressing temperature display is conducted by comparing the temperature displayed on the LCD with the actual temperature on the surface of the silicone pack, which the digital thermometer (brand: Omron, model: MC-343) measures, displays, and acts as a reference in measurement. The error in displaying the temperature is calculated based on Equation (1).

Table 3 below shows the accuracy test result in displaying the compressing temperature.



Table 3 Accuracy Test Result in Displaying the Compressing Temperature

| No. | Temperature Displayed by The Compress Device (°C) | Actual Temperature at the Surface of Silicon Pack Measured by Standard Thermometer (°C) | Error (%) |
|--------------------------|---------------------------------------------------|-----------------------------------------------------------------------------------------|-------------|
| 1 | 21.0 | 21.5 | 2.33 |
| 2 | 22.1 | 22.5 | 1.78 |
| 3 | 23.0 | 23.4 | 1.71 |
| 4 | 24.1 | 24.5 | 1.63 |
| 5 | 25.2 | 25.6 | 1.56 |
| 6 | 26.0 | 26.4 | 1.52 |
| 7 | 27.1 | 27.5 | 1.45 |
| 8 | 28.2 | 28.6 | 1.40 |
| 9 | 29.2 | 29.7 | 1.68 |
| 10 | 30.1 | 30.6 | 1.63 |
| 11 | 31.0 | 31.0 | 0.00 |
| 12 | 33.1 | 32.6 | 1.53 |
| 13 | 35.9 | 35.4 | 1.41 |
| 14 | 37.3 | 36.9 | 1.08 |
| 15 | 39.1 | 38.5 | 1.56 |
| 16 | 40.1 | 39.6 | 1.26 |
| 17 | 42.3 | 41.7 | 1.44 |
| 18 | 43.0 | 42.4 | 1.42 |
| 19 | 44.4 | 43.9 | 1.14 |
| 20 | 45.0 | 44.5 | 1.12 |
| <i>Average Error (%)</i> | | | 1.43 |

Table 3 shows that the compress temperature value displayed by the compress device has an error of 1.43 % to the actual temperature in the silicone pack as measured using a standard thermometer.

4.4 Discussion

Table 1 shows that the compress device can function as a cold compress properly, and the compressing temperature is stable at 21 °C – 23 °C when the silicone pack is attached to the patient's body, whose temperature is 36.5 °C – 37 °C. The compressing temperature of 21 °C is reached in 5.5 seconds from the initial room temperature of 31 °C.

Similarly, Table 2 shows that the compress device can function as a warm compress properly, and the compressing temperature is stable at 43 °C – 45 °C when the silicone pack is attached to the patient's body, whose temperature is 36.5 °C – 37 °C. The compressing temperature of 45 °C is reached in 3 seconds from the initial room temperature of 31 °C.

The phenomenon above occurs because the hardware components work well, and the software algorithm is correct. As a result, the device performance complies with the design.

As shown in Table 1 and Table 2, reducing the compressing temperature from 31 °C to 21 °C in a cold compress operation requires 5.5 seconds, which is longer than the time to increase from 31 °C to 45 °C in a warm compress operation, which only requires 3 seconds. The longer time to change temperature also means that cold compress

operations require more electrical energy than warm compress operations because the total energy consumption is always proportional to the time required.

Table 3 shows that the average error in displaying the compressing temperature is 1.43 % against the actual temperature on the surface of the silicone pack as measured using a standard thermometer. The error of 1.43 % is relatively small (less than 5 %), so users can still accept it. The temperature error arises due to the length of the flexible hose, which causes the temperature in the water block to be different from the temperature in the silicone pack. The longer the flexible hose, the longer the area affected by the ambient room temperature. Hence, the water block and the silicone pack have a more significant temperature difference. Besides, the silicone pack has thermal resistance in passing the water temperature from the inside of the silicone pack to the outer surface of the silicone pack.

V. CONCLUSION

Based on the test results and analysis, the research concludes as follows:

1. The compress device can operate as a warm or cold compress according to the user's selection.
The compressing temperature is stable at 21 °C – 23 °C when used as a cold compress. To reach a temperature of 21 °C from the initial room temperature of 31 °C, it takes 5.5 minutes.
When used as a warm compress, the compressing temperature is stable at 43 °C – 45 °C. To reach a temperature of 45 °C from the initial room temperature of 31 °C, it takes 3 minutes.
2. The compressing temperature displayed by the compress device has an average error of 1.43 % to the actual temperature on the surface of the silicone pack as measured using a standard thermometer.

For future work, the research needs to add the facility for setting the compressing temperature so a user can obtain the required temperature for compressing.

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