Jurnal Kejuruteraan 33(4) 2021: 1061-1067
https://doi.org/10.17576/jkukm-2021-33(4)-28

Energy Management and Temperature Control for The Thermoelectric Therapy Device

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Received 18 June 2020, Received in revised form 25 May 2021
Accepted 20 June 2021, Available online 30 November 2021

ABSTRACT

Cryotherapy is one of most popular treatments for treating injuries using cold applications due to various advantages that have been accepted by medical professionals like safe to use and able to reduce pain and inflammation if the treatment is given according to medical specifications. The existing devices in the market such as cryo-cuff will become more efficient if it is capable to control important parameter like cooling temperature during the treatment. Therefore, a study of the therapeutic device control system using thermoelectric module was carried out. This system is based on microcontroller Arduino which makes it convenient for the users to control the gel temperature during the treatment. The aim of the study is to design a cooling therapy device using thermoelectric module for cryotherapy, to design a system that can control temperature and to develop a prototype that can control the desired temperature of gel using Arduino. This prototype uses thermoelectric-cooler (TEC) which will convert electric energy to temperature difference on both sides of the TEC. The PID controller is implemented in the coding of Arduino to obtain a constant gel temperature. In conclusion, the prototype is able to control the temperature reading consistently. In this study, when the temperature is set to 8°C by the Arduino, the result shows the average temperature reading is 8.668°C. Thus, it can be concluded that this thermoelectric therapy device can control the gel temperature set by the user.

Keywords: Cryotherapy; Thermoelectric-cooler (TEC); Arduino UNO; temperature of gel; PID controller

INTRODUCTION

Nowadays, application of cryotherapy has been used throughout the world due to its low cost, easy to use and its effectiveness. Ice is believed to be able to control the pain by triggering local anesthesia. Soft tissues injuries, DOMS (Delayed Onset Muscle Soreness) and post orthopedic surgery are examples for cryotherapy treatment. The cryotherapy has the benefit of treatment if it starts shortly after injury and care should be taken regarding the exposure time to ice because prolonged exposure to a very low temperature should be avoided as this can cause serious side effects, such as frozen injury (Collins 2008; Swenson et al. 1996).

Although existing therapy device such as cryo-cuff (Figure 1) is harmless and effective to reduce the injury, the price for one unit of cryo-cuff is slightly expensive compared to conventional ice packs. Moreover, patients are experiencing difficulties with existing therapy device because of its heavy weight, meaning that the apparatus is difficult to carry anywhere and even the procedure to maintain the temperature is complicated. For example, this device requires a medium such as water to recycle each hour manually or by using a pump and also the ice tank need to be elevated so that the cuff can expand well (McDowell et al. 1994).

Finally, the existing therapy device uses manual method to control cooling temperature. Because of this feature, doctors or patients cannot monitor and control important parameters such as cold level or temperature for the ice (°c) according to specification of the treatment during the process of therapy.

FIGURE 1. Cryo-cuff
Source: (firstaid4sport n.d.)

In this project, the thermoelectric therapy device is a system based on microcontroller Arduino that can facilitate the users to control the gel temperature during the treatment. Below are the objectives of this project:

1. to design a cooling therapy using the thermoelectric module for cryotherapy treatment,
2. to design a therapy device control system that can control temperatures to meet the specification of the treatment,
3. to develop a prototype that can control the desired temperature of the gel using Arduino microcontroller.

Sections 2 and 3 in this paper provide introduction and literature review. The methodology will be explained in details in Section 4. Lastly, relevant results, discussion, and conclusion will be discussed in Sections 5 and 6 respectively.

LITERATURE REVIEW

CRYOTHERAPY

Cryotherapy, also known as cold application is the easiest way in treating injury since the 1800's (Snyder et al. 2011). The effect of cryotherapy depends on the application, period of time, temperature of ice and the depth of subcutaneous fat.

Swenson et al. stated that, there are various methods for this treatment such gel pack, ice pack, ice massage, cooling gas and others (Swenson et al. 1996). According to McDowell et al., there are experiments that show silica gel packs being capable of cooling off the tissues affectively like the application of ice (McDowell et al. 1994).

The cryotherapy can be seen to have various advantages that have been accepted by medical professionals such as safe to use and able to reduce pain and inflammation. However, there is animal study which shows the potential of tissue damage caused by cold with prolonged exposure and very low temperature. There is a case report of some cases of burns, nervous injuries and frostbite from the usage of cold therapy (Deal et al. 2002; Dolan et al. 1997; O'Toole & Rayatt 1999).

In Hocutt et al. study, the requirement of application of ice is between 40°F to 50°F for 12 to 20 minutes, one to three times a day (Hocutt et al. 1982). There is also proof that suggests the application of ice for 10 minutes is effective to reduce the tissues temperature of optimal therapy (Bleakley et al. 2006; Swenson et al. 1996).

Thus, the application of cold treatment for more than 30 minutes should be avoided and the skin condition should be monitored during treatment.

THERMOELECTRIC MODULE

Generally, the thermoelectric module is divided into two types namely thermoelectric-cooler (TEC) and thermoelectric-generator (TEG). The thermoelectric module is one of the popular energy exchangers which has the ability for thermal conversion to electricity and vice versa. A TEC module will convert the electrical energy shown as the flow of current to temperature difference on both sides of the TEC while the TEG module will convert heat energy to electricity (Elarusi et al. 2017).

The thermoelectric cooling module consists of p-type and n-type of semiconductor elements that connect electricity in series and thermal in parallel and flanked together between two ceramic plates as in Figure 2 (Cai et al. 2019; Peltier et al. 1960). The TEC module operates with Peltier effect (Figure 3) which is the flow of electricity through two different conductors will produce cooling and heating effects at the interchange (Sagar D. Patil 2011; Sulaiman et al. 2018).

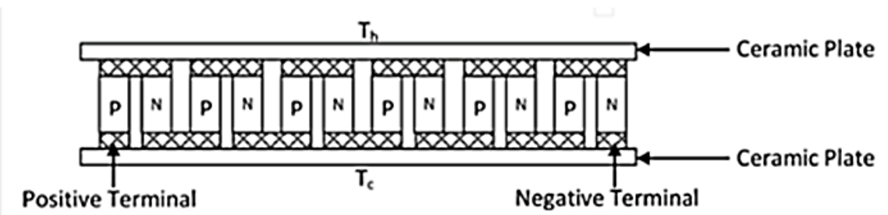

FIGURE 2. Internal structure of thermoelectric
Source: Drahansky et al. (2016)

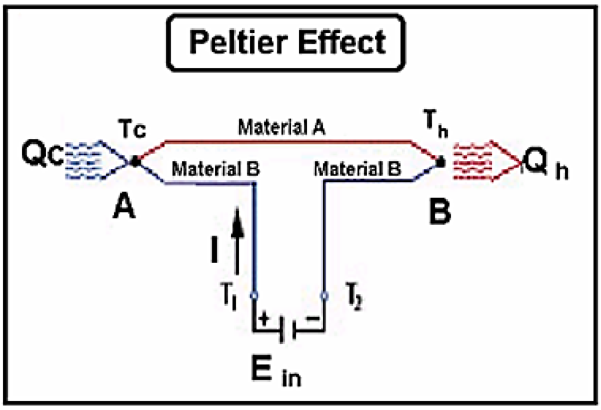

FIGURE 3. Peltier effect
Source: Peltier et al. (1960)

The TEC module acts as a cooling system and has been used in various applications such as medical instrument, air conditioning, refrigerators, electronic devices etc. (Sagar D. Patil 2011). In a study conducted by Sulaiman et al., it is stated the application of thermoelectric cooling module is used in reducing electricity consumption for cooling system (Sulaiman et al. 2018).

In a study done by Abbas Rahmani, a prototype of a smart mobile therapy system was developed using thermoelectric cooling module for medical application. The system involves electronic devices that has been integrated with conventional ice packs. The prototype used 12 V and maximum 6A current, temperature sensor and fan as heat exchanger for the cooling part. The ATMEGA32 processor is used and to control the microcontroller, AVR Vision software was used for processor programming and controlling the cryotherapy treatment (Abbas Rahmani, Reza Hassanzadeh Pack Rezaee 2018).

PID CONTROLLER

PID (Proportional, Integral and Derivative) controller was first introduced in 1930's and the application of this controller is still famous nowadays. Element-P (Kp) or known as "during error" will generate an offset correction due to interference where it can stabilize the first (1st order) process. Element-I (Ki) or "past error" was intended to remove offset and make an error to zero where the Ki will increase the process speed toward its set value. While element-D (Kd) or "future error" relates to the rate of change of error or to improve the stability of a system (Araki M. 2014; Thakor et al. 2015).

PID controller (Figure 4) uses feedback loops to control system parameters so that the measured value measured by the sensor is matched to the setpoint. In a system, the PID controller will use the error which is the difference between the measured value and the desired value (setpoint).

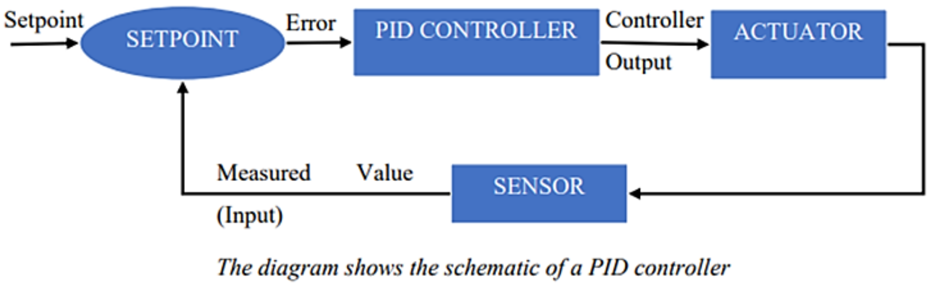

FIGURE 4. The PID controller

According to a study done by Sundayani et al., an experiment was carried out to differentiate periods of TEC cooling by using PID controller. The study showed that, without PID controller, TEC module took about 6538 seconds to be cooled until 11°c, while only 2060 seconds when PID controller is used. This study proved that PID controller is able to accelerate the cooling process of a TEC module by three-fold (Sundayani et al. 2017).

METHODOLOGY

This section will explain the development of a controller for thermoelectric therapy device using gel as a medium. Here, temperature is used as a parameter that will be controlled by integrating the suitable components, microcontroller and actuator in order to monitor and control the performance of the gel during the treatment.

The block diagram of the hardware is shown in Figure 5. This figure shows how the system of the thermoelectric cooling works. The system contains a microcontroller, power supply, MOSFET (Metal Oxide Semi-Conductor Field Effect transistors) switch, TEC Module, temperature sensor as an actuator and heat sink. This system requires 12V and minimum 6A power supply to function properly.

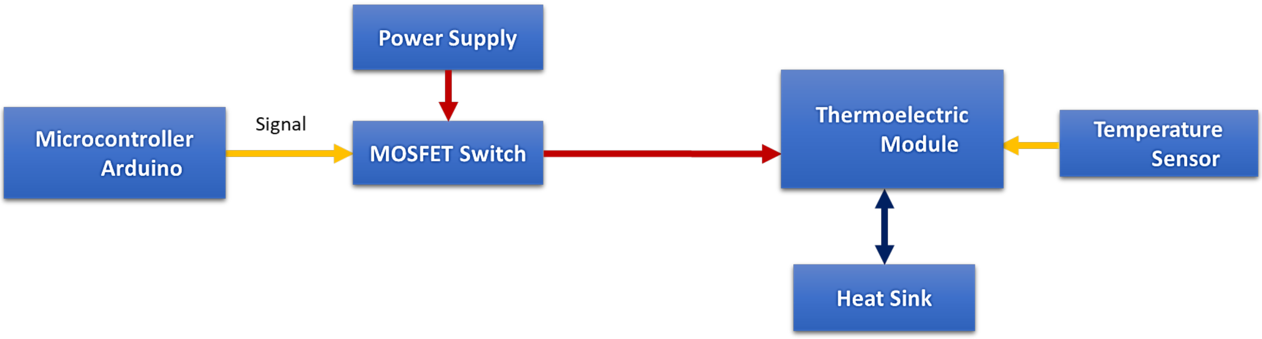

FIGURE 5. Block diagram of the prototype

DATA ACQUISITION SYSTEM

For data acquisition system, the microcontroller Arduino (Figure 6) will act as an overall manager of data acquisition system of this therapy device. An Arduino UNO is chosen in this project because of its advantages such as low in cost and the programming language is convenient to use.

The Arduino UNO is used to take the temperature readings of the gel from the temperature sensor and the PID (Proportional, Integral and Derivative) controller is used to calculate the error between the temperature value set in the Arduino with the measured gel temperature by the temperature sensor. This will give the output reading of gel temperature.

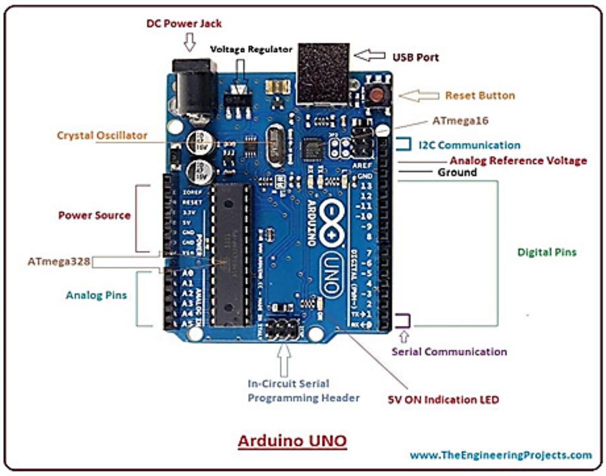

FIGURE 6. Arduino UNO
Source: Adnan Aqeel (2018a)

INTEGRATION OF OPTICAL-COUPLER WITH ARDUINO

In this project, an optical-coupler model 4N35 is used to isolate between power control circuits and load. Figure 7 shows the internal structure of the opto-coupler. On the left side (pin 1 and pin 2) will be connected to the power control circuit while on the right side (pin 3 and pin 4) will be connected to the output circuit.

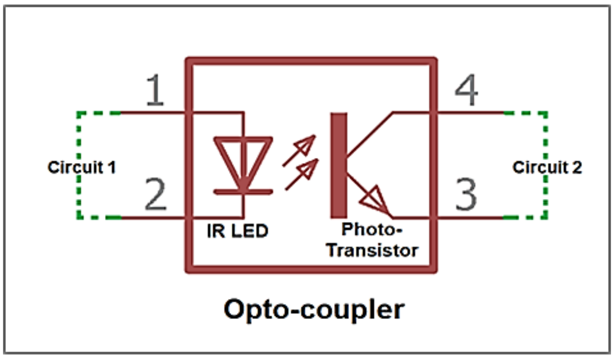

FIGURE 7. Internal structure of opto-coupler
Source: Gupta (2018)

POWER CONTROL BLOCK
(OPTICAL-COUPLER AND MOSFET PNP)

Figure 8 shows the power control block of the optical-coupler and MOSFET PNP which acts as a pulse-width-modulation (PWM) amplifier. The model of the PNP MOSFET used is IR4905 (Figure 9). This circuit is suitable for isolated ground but can be made common, and high-power load (low if common ground). It is used to control the high side of the isolated ground load and it enables the use of PWM for high power load. A relay is not suitable to use as it is a mechanical component and cannot react quickly with high frequency switching. This setup is used for switching the thermoelectric cooling (TEC) module. The diagram is simulated from Falstad online circuit simulator.

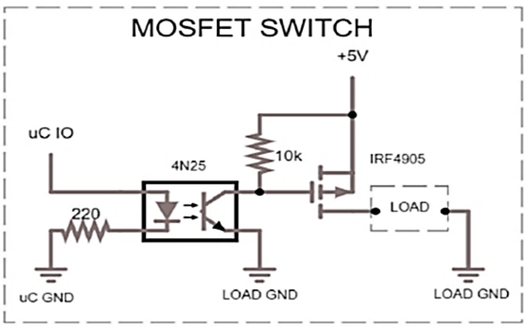

FIGURE 8. Power control block
(opto-coupler & MOSFET PNP)

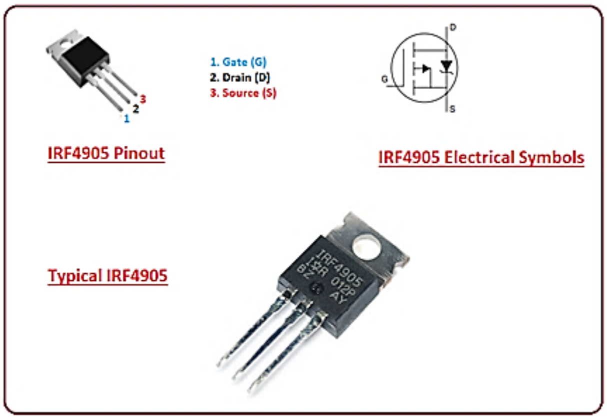

FIGURE 9. MOSFET PNP model IRF4905
Source: Adnan Aqeel (2018b)

TEMPERATURE SENSOR

Based on the required parameters, the selection of appropriate and suitable sensor that can integrated with Arduino UNO has been done. In this project, a waterproof temperature sensor DS18B20 model (Figure 10) is chosen to measure the gel temperature. This temperature sensor has three wires which are red (voltage), black (ground) and yellow (data) and can measure from -55°c to + 125°c with the accuracy of ± 0.5°c.

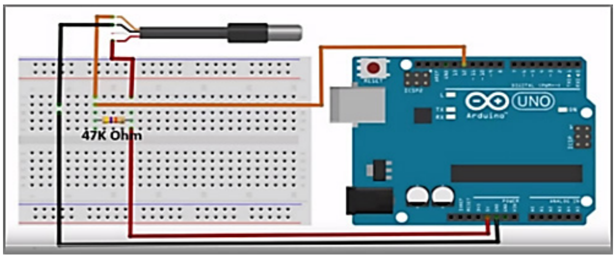

FIGURE 10. Temperature sensor model DS18B20
Source: Messy Electronics (2017)

RESULT AND DISCUSSION

This section will discuss the results and discussion regarding the development of the thermoelectric therapy device. To achieve the objectives, a prototype of thermoelectric therapy device and the integration between temperature sensor and microcontroller has been implemented. Figure 11 and Figure 12 show the prototype that has been developed.

Figure 11 shows the circuit for integration between the power control block of the MOSFET with the Arduino UNO. The brightness of white light emitting diode (LED) at the power control block indicates the duty cycle of the signal of PWM that is given from pin 10 of Arduino UNO. Figure 12 shows the 12V power supply and the integration between the TEC, heat sink, gel and temperature sensor.

The PID controller is used to control and maintain the temperature of the gel by calculating the error difference between the temperature that has been set with the measured temperature by temperature sensor. The fan and heat sink are used to transfer the heat that is generated from the hot side of the TEC. The heat sink is important in order to keep the TEC and the gel at a stable temperature. The insulation above the gel is also important in order to minimize the heat transferred to the surrounding, thus the temperature of the gel can be maintained.

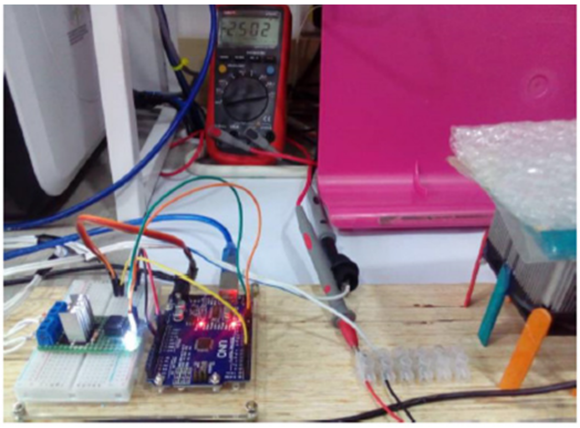

FIGURE 11. Integration between power control block (MOSFET switch) and Arduino

FIGURE 12. Power supply (12V) & thermoelectric module with heat sink

Figure 13 shows the plotted graph for the prototype of thermoelectric therapy device. Data is obtained from the serial monitor of the Arduino UNO and then transferred into Microsoft Excel. In order to get the result as shown in Figure 13, the set point of the temperature is set to 8°C for the duration of one hour and thirty minutes. The average temperature of the gel is 8.668°C.

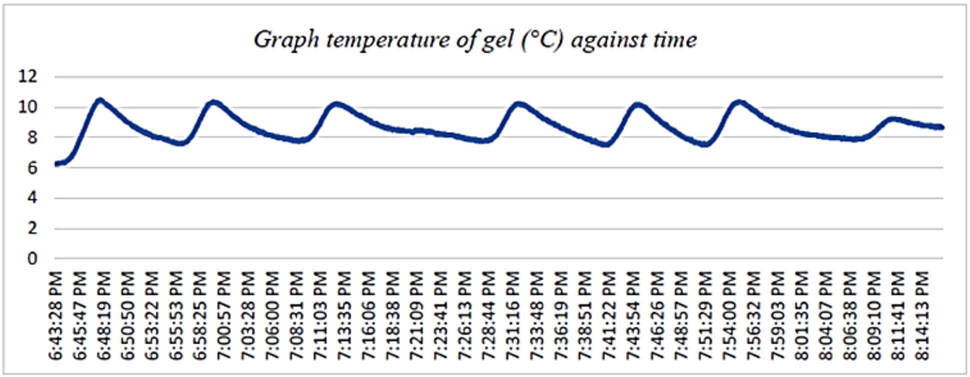

FIGURE 13. Temperature of gel against time

From the results, it can be concluded that the gel temperature for thermoelectric therapy device can be controlled using microcontroller Arduino UNO. The PID controller has been implemented in the Arduino coding to calculate the error difference between the gel temperature readings from the temperature sensor and the temperature set in the Arduino. The temperature output from this prototype is readable in the Arduino serial monitor and the result shows that the PID controller is able to produce a consistent output temperature. Then the output of this serial monitor is translated in the form of a graph to facilitate learning and analysis process. Thus, this section shows that the objectives have been achieved.

CONCLUSION

In conclusion, this project has been successfully implemented based on the targeted objectives. A cooling therapy using thermoelectric module for cryotherapy has been designed. In addition, a therapy device control system that can control the temperature to meet the specification of the treatment has been designed. A prototype of a thermoelectric therapy device that can control the desired gel temperature using microcontroller Arduino and PID controller has been developed and the parameter to control the temperature of the gel cooling based on the set temperature in the coding is successfully controlled. The results showed that the PID controller in the Arduino can control the gel temperature consistently when the gel temperature was set in the Arduino coding.

This study can be improved for research and learning purposes. Some of the improvement that can be done is by modifying the fan and heat sink into a water cooled heat sink as water cooling system is more comfortable and safer to the users. Other improvement is by adding the other important parameter for the treatment such as the duration of the cooling gel. This improvement can allow the therapy device to control both important parameters which are the cooling gel temperature and the duration on the gel cooling according to the treatment specifications. Finally, another improvement that can be done is by developing a thermoelectric therapy device that can be integrated using smart phone application so that the users can control and monitor the important parameters more efficiently.

ACKNOWLEDGEMENT

This research is supported by the Ministry of Higher Education Malaysia and Universiti Kebangsaan Malaysia under grant no. LRGS/2018/UNITEN-UKM/EWS/04.

DECLARATION OF COMPETING INTEREST

None

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