DEVELOPMENT OF SMART MUG WITH CHARGING COASTER USING A PELTIER MODULE AND RECHARGEABLE BATTERY

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DEVELOPMENT OF SMART MUG WITH CHARGING COASTER USING A PELTIER MODULE AND RECHARGEABLE BATTERY

MUHAMMAD HANIF IKHWAN BIN RAZALI

Thesis submitted in fulfilment of the requirements for the award of the degree of Bachelor of Engineering Technology in Electrical with Honours

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STATEMENT OF AWARD FOR DEGREE

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Thesis submitted in fulfilmentof the requirements for the award of the degree of Bachelor of Engineering Technology in Electrical with Honours.

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of degree of Bachelor of Engineering Technology in Electrical with Honours.

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ABSTRACT

Demanding of beverages is increase in statistic around the world. Company like Starbuck and Dunkin' Donut are among the company productivity affected by this phenomenon. The increase of intake of coffee, tea and other beverages increase the usage of cup either in the plastic, polystyrene or paper make a problem towards the environment. It will increase the number of dumping plastic or polysterene and also number of cutting down of tree. Besides, the usage of others mug such as ceramic mug did not become too efficient to overcome this problem since it cannot maintain the temperature and also be portable. Thus, a research is conduct to overcome the problem. This research is focused on inculcating all these characteristics and enables users to carry a multifunctional mug anywhere and everywhere. The Smart Mug with charging coaster as added values enables users to choose to prepare hot or cold water with onle need to press the button and it only takes around 45 minutes to be done the process. When the water or beverages reached the desired temperature, user will be able to consume the water directly from the Smart Mug. The Smart Mug is portable, reusable and affordable. Nowadays, people are looking for products which are cheap, efficient and long lasting. The goal of this project is to produce a controller circuit that can control the heating and cooling process of the Peltier Moudle and implying a proper rechargeable power supply for the system.

ABSTRAK

Permintaan minuman meningkat dalam statistik di seluruh dunia. Syarikat seperti Starbuck dan Dunkin 'Donut adalah antara syarikat produktiviti yang terkesan dengan fenomena ini. Peningkatan pengambilan kopi, teh dan minuman lain meningkatkan penggunaan cawan sama ada dalam plastik, polistirena atau kertas menimbulkan masalah terhadap alam sekitar. Ia akan meningkatkan bilangan pembuangan plastik atau polistirena dan juga bilangan pemotongan pokok. Selain itu, penggunaan cawan lain seperti cawan seramik tidak menjadi begitu cekap untuk mengatasi masalah ini kerana ia tidak dapat mengekalkan suhu dan juga mudah alih. Oleh itu, penyelidikan dijalankan bagi mengatasi masalah ini. Penyelidikan ini memberi fokus kepada menanamkan semua ciri-ciri ini dan membolehkan pengguna membawa cawan pelbagai fungsi di mana sahaja dan di mana-mana sahaja. Mug Pintar dengan pengecas koaster sebagai nilai tambahan membolehkan pengguna memilih untuk menyediakan air panas atau sejuk dengan hanya perlu menekan butang dan memerlukan masa sekitar 45 minit untuk dilakukan. Apabila air atau minuman mencapai suhu yang dikehendaki, pengguna akan dapat mengambil air terus dari Mug Pintar. Mug Pintar adalah mudah alih, boleh diguna semula dan berpatutan. Kini, orang mencari produk yang murah, cekap dan berpanjangan. Matlamat projek ini adalah untuk menghasilkan litar pengawal yang boleh mengawal pemanasan dan proses penyejukan Peltier Moudle dan menyiratkan bekalan kuasa yang boleh dicas semula untuk sistem.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$	Dollar
%	Percentages
A	Ampere
°F	Degree Ferenheit
H	Hours
I	Current
J	Joule
KB	Kilobyte
mA	Milli-Ampere
mAh	Milli-Ampere-hours
mg	Milligram
MHz	Megahertz
Min	Min
ml	Millilitre
mm	Millimeter
ºC	Degree Celcius
R	Resistor
s	Second
S	Seedback Coefficiet
T	Temperature
V	Voltage
Δt	Delta Time
Ω	Ohm

LIST OF ABBREVIATION

3D	Three-Dimensional
AREF	Analog Reference
CDC	Communications Device Class
COM	Communication
CRT	Cathode Ray Tube
DC	Direct Currect
ECU	Electrocnic Controlling Unit
EMF	Electromotive Force
GND	Ground
IC	Integrated Circuit
ICSP	In-Circuit Serial Programming
IDE	Integrated Development Enviroment
IoT	Internet of Things
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LIB	Lithium Ion Battery
Li-Ion	Lithium Ion
Li-Po	Lithium Polymer
MCU	Microcontroller Unit
NASDAQ	National Association of Securities Dealers Automated Quotations
PWM	Pulse Width Modulation
RGB	Red Green Blue
RX	Receive

SBUX	Starbucks
TEC	Thermoelectric Cooler
TEG	Thermoelecric Generator
TGWC	The Great Wall of China
TTL	Time-to-Live
TX	Transmit
UK	United Kingdom
USB	Universal Serial Bus

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In history of mug, ancient mugs were usually carved in wood or bone, or shaped of clay, while most modern ones are made of ceramic materials such as bone china, earthenware, porcelain, or stoneware. Some are made from strengthened glass, such as Pyrex. Other materials, including enameled metal, plastic, or steel are preferred, when reduced weight or resistance to breakage is at a premium, such as for camping. A travel mug is insulated and has a cover with a small sipping opening to prevent spills. Techniques such as silk screen printing or decals are used to apply decorations such as logos or images, which are fired onto the mug to ensure permanence.

Mug is a type of cup typically used for storing hot beverages, such as coffee, tea, hot chocolate or even soup. Hot beverages such as tea, hot chocolate, and coffee are frequently served at temperatures between 160 °F (71.1 ºC) and 185 °F (85 ºC). Mug commonly has handles and holds a larger amount of fluid than other types of cup.

As we know, people nowadays are likely to spend their life with mug of beverage either in hot or cold. Furthermore, caffeine consumption is on the rise. As coffee chains like Starbucks and Dunkin' Donuts offer larger sizes, Americans are consuming more of the stimulant than ever, according to a recent report by Bank of America (Lutz, 2015). The average daily intake of caffeine grew from 120 mg/day in 1999 to 165 mg per day in 2010, according to the report. Bank of America's analysts studied how much caffeine different age groups consume. People tend to consume more caffeine as they get older. In adults, total caffeine intake ranged from 122 to 143 mg/day. Coffee (49.5 mg/day) and tea (36.2 mg/day) were the greatest contributors of daily caffeine intake, followed by the in this study combined category of soft drinks and energy drinks (34.5 mg/day) (Vester and Koenig, 2017). After retirement, consumption drops again (Lutz, 2015). The result can be referring to the Figure 1.1. Therefore, it proved that the demand of the beverage upon a person is higher especially towards the adult who is working. Besides, the demand of beverages also can be referred to the Figure 1.2.

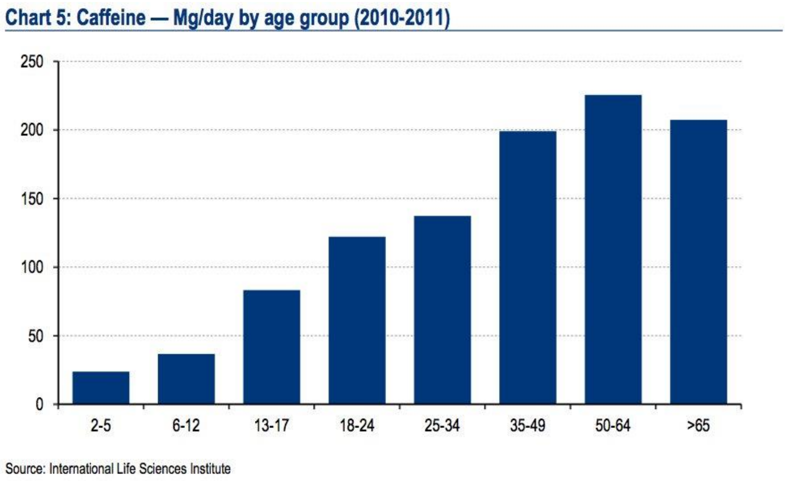

Figure 1.1: The demand of caffeine by age group in 2010-2011(Lutz, 2015).

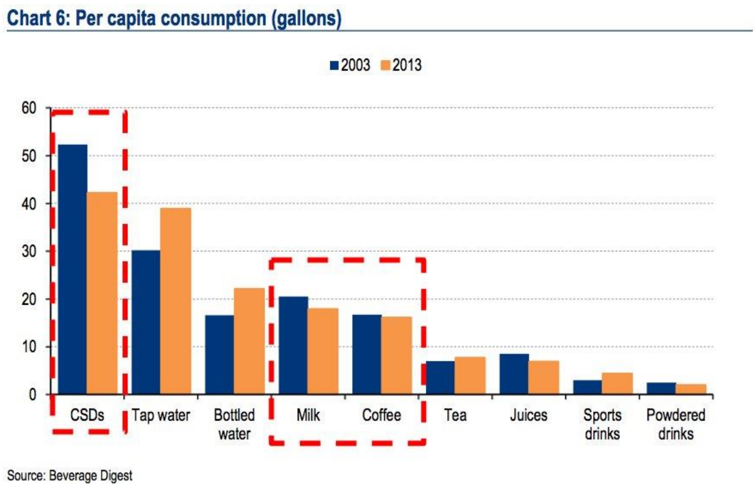

Figure 1.2: The type beverages demand per capita consumption (gallons) of 2003 and 2013(Lutz, 2015).

In a statistic from a well-known company named Starbucks, people around the world spent over $10 billion on beverages at Starbucks in 2014. In 2015, Starbucks Corporation (NASDAQ: SBUX) is up almost 40% and hit an all-time high (Khatri, 2015). In addition, the cups used are around 4 billion and it would be 35 times longer than the entire TGWC. Besides, on average 1.4 cups/day of coffee drink by American people while 28,985 cups/s of coffee people consume around the world (Susan, 2015).

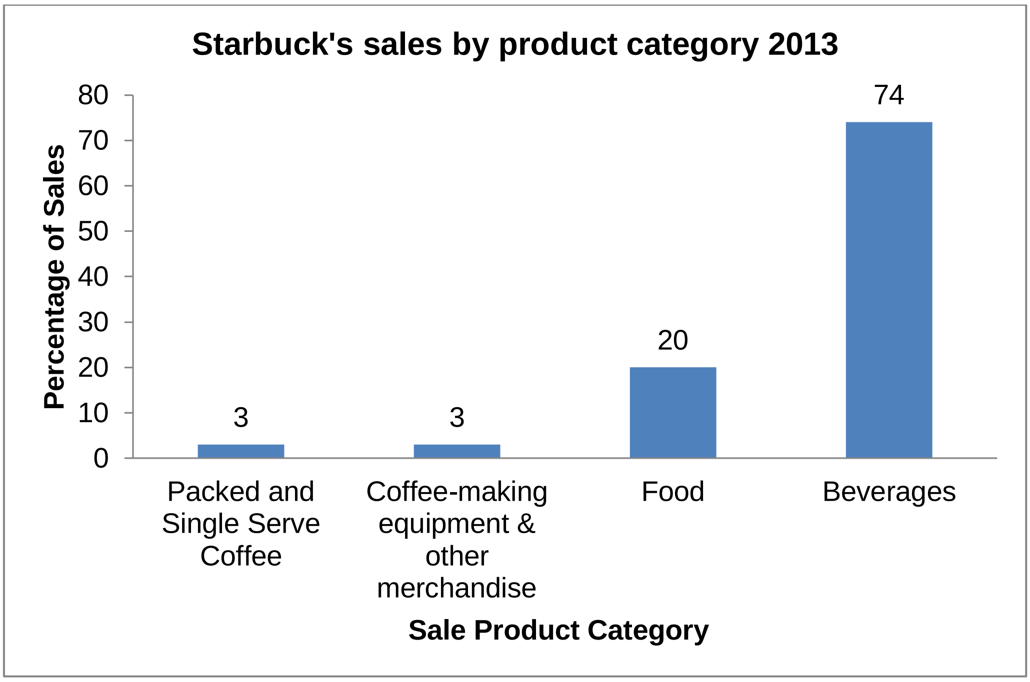

Figure 1.3: The Starbuck's sales by product category in 2013 (Richter, 2014).

The intake of beverage on our life like coffee or tea will increases the productivity of our daily activities. Since, the caffeine inside it can use to stay alert and focus. Besides, it also brightens your mood, helps fight depression and lowers risk of suicide. Caffeine stimulates the central nervous system and boosts production of neurotransmitters like serotonin, dopamine, and noradrenaline, which elevate your mood. Two cups of coffee a day prevents risk of suicide by 50%. However, the consumption of too much caffeine in life is not encouraged since it has the negative effect on the overdose of taking it. The bad beverage will be not good for our life and can become toxic in our body. Thus, to have ideal types of beverages is the way it will be served. A better temperature can increase the productivity of the daily life and increase the mood to do work progressively. Lastly, a suitable environment needs to be set up in order to achieve the target of the temperature of beverages.

1.2 PROBLEM STATEMENT

Most of people nowadays used mug in workplace to place their hot water or beverage in the mug while doing work. Basically, they love to put their hot water or beverage on the mug to increase their productivity in working. At the point when gone to the temperature, the issue will come. This is because the water or beverage becomes decrease in the temperature rapidly in air conditioner office thus making the water or beverage is less suitable to drink. Furthermore, water has become less energize to be given up when it is cold and can warm them in the cold condition. Then, the hot water or beverages is demanding by people as it gives nice warm condition to accompany them while doing their work that act as the catalyst or energize to them.

Beside, as we can see the consumption of cup become in high demand along with the demand of the beverages towards the people. When the situation comes, the pollution will be increased rapidly. This is due to the number of cups used will be rise up and most of the cups used are manufactured using plastics and polystyrene. But, only few of them are managing to serve the hot beverages commonly, using the paper types of cup that are more environmental and eco-friendly. The usage of polystyrene and plastic are not good for the health of our Earth. It can slowly destroy the stability and it is hard to be consumable with a short time of period. Thus, an invention of Smart Mug will be a solver to the problem that can create a user convienience and environmental care to save for more pollution occurs.

Besides, in order to overcome this problem, an invention of a smart mug with charging coaster is created. Therefore, people do not have to worry about the temperature of their water or beverage. This is because the smart mug can regulate the temperature of the water or beverage according to the temperature that ideal to us or we want and also a charging coaster for recharging the rechargeable battery that been installed inside it. Furthermore, the smart mug with a charging coaster is aiming to give the best temperature serve for user drinking water or beverage. In addition, it also portable which means no direct supply needed to make it functioning. The Smart Mug is installed with rechargeable batteries that act as the supply for it. On the other hand, the system of the smart mug is using Arduino Nano to control the process of the mug while the DS18B20 waterproof temperature sensor is used to sense the heat from the beverages. The controlling circuit consists of relays that will turn off the power supply to a fan attached to the Peltier Chip when either heating or cooling process is done. Lastly, with the smart mug is invented, the usage of non-consumables cup can be reduce due to people can use their on smart mug to store the beverages in their ideal temperature.

1.3 OBJECTIVES

This project has objectives as below:

1. To design low cost smart mug that can meet the user’s desires by heating up or cooling down a beverages.
2. To make the mug portable by designing a charging coasterwith a suffecient rechargeable battery.

1.4 PROJECT SCOPE

This project is focused in designing and fabricating the prototype of Smart Mug with charging coaster that can give an ideal temperature of water or beverages for the user since it able to do heating and cooling process. Thus, this prototype wills implementing a microcontroller ATmega328P which is Arduino Nano and use DS18B20 waterproof temperature sensor as the sensor while Peltier Module as the heating and cooling element. Besides that, this project also focuses on developing a Smart Mug that can heat up or cool down the water or beverages form 20°C up to 70°C. The reasons is 20°C is the optimum value of water that can give a little impact to the body and 70°C is the maximum normal human tongue can received a hot water before it burned and become reddish colour. Lastly, this project also designed with LCD to monitor the temperature and button for controlling the temperature.

CHAPTER 2

LITERATURE REVIEW

2.1 THERMOELECTRIC EFFECT

Thermoelectric effect has created a lot of impacts in human life. Since 1894, the developer developed so many ways of making use of thermoelectric for preserving food, cooling water, and heating. Nowadays, people are looking for products which are cheap, efficient and long lasting. The thermoelectric effect is the immediate change of temperature contrasts to electric voltage and the other way around. A thermoelectric device makes voltage when there is an alternate temperature on each side. Then again, when a voltage is connected to it, it makes a temperature distinction. At the nuclear scale, a connected temperature slope causes charge transporters in the material to diffuse from the hot side to the frosty side. This effect can be utilized to create power, measure temperature or change the temperature of objects. Since the heading of heating and cooling is dictated by the extremity of the connected voltage, thermoelectric device can be utilized as temperature controllers.

The expression "thermoelectric effect" includes three independently recognized effects which are the Seebeck effect, Peltier effect, and Thomson effect. Course books may allude to it as the Peltier–Seebeck effect. This division gets from the free revelations of French physicist Jean Charles Athanase Peltier and Baltic German physicist Thomas Johann Seebeck. Joule warming, the warmth that is created at whatever point a current is gone through a resistive material, is connected, however it is not for the most part named as thermoelectric effect. The Peltier–Seebeck and Thomson impacts are thermodynamically reversible, while Joule (J) warming is definitely not.

2.1.1 Seedback Effect

The Seebeck effect is the conversion of heat directly into electricity at the junction of different types of wire. It is named after the Baltic German physicist Thomas Johann Seebeck, who in 1821 discovered that a compass needle would be deflected by a closed loop formed by two different metals joined in two places, with a temperature difference between the joints. This was because the electron energy levels in each metal shifted differently and a voltage difference between the junctions created an electrical current and therefore a magnetic field around the wires. Seebeck did not recognize there was an electric current involved, so he called the phenomenon "thermomagnetic effect." Danish physicist Hans Christian Ørsted rectified the oversight and coined the term "thermoelectricity".

The Seebeck effect is a classic example of an electromotive force (emf) and leads to measurable currents or voltages in the same way as any other emf. Emf modify Ohm's law by generating currents even in the absence of voltage differences (or vice versa); the local current density is given by

$$\mathbf{J} = \sigma(-\boldsymbol{\nabla} V + \mathbf{E}_{\text{emf}})$$

where V is the local voltage and is the local conductivity. In general, the Seebeck effect is described locally by the creation of an electromotive field

$$\mathbf{E}_{\text{emf}} = -S\boldsymbol{\nabla} T$$

where S is the Seebeck coefficient (also known as thermopower), a property of the local material, and $\boldsymbol{\nabla} T$ is the gradient in temperature T.

A thermoelectric circuit composed of materials of different Seebeck coefficient (p-doped and n-doped semiconductors), configured as a thermoelectric generator. If the load resistor at the bottom is replaced with a voltmeter the circuit then functions as a temperature-sensing thermocouple.

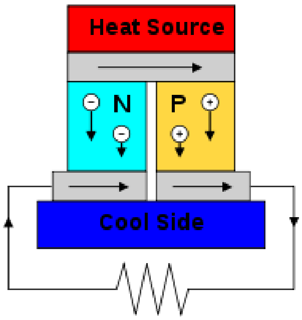

Figure 2.1: The Seedback Effect circuit configured as a thermoelectric heater.

2.1.2 Peltier Effect

The Peltier effect is the presence of heating or cooling at an electrified junction of two different conductors. The Peltier effect is named after Jean Charles Peltier (1785-1845) who first observed it in 1834. Peltier found that the junctions of dissimilar metals were heated or cooled, depending upon the direction in which an electrical current passed through them. The Peltier effect had no practical use for over 100 years until dissimilar metal devices were replaced with semiconductor Peltiers which could produce much larger thermal gradients.

When a current is made to flow through a junction between two conductors, A and B, heat may be generated or removed at the junction. The Peltier heat generated at the junction per unit time, $\dot{Q}$, is equal to

$$\dot{Q} = (\Pi_A - \Pi_B)\, I$$

Where Π_A (Π_B) = the Peltier coefficient of conductor A (B)

I = electric current from A to B

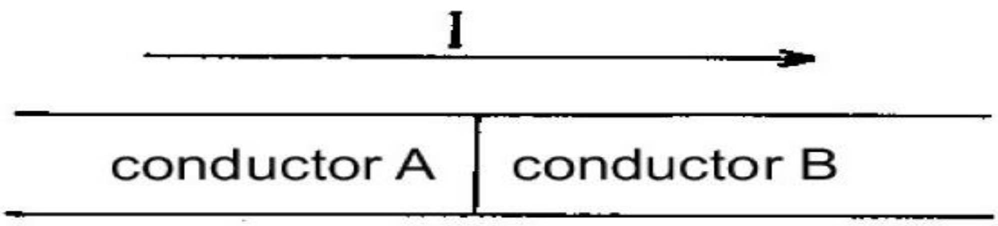

Figure 2.2: Setup of observing Peltier Effect

The sign of $\dot{Q}$ can be positive as well as negative. A negative sign means cooling of the junction. In contrast to Joule heating, the Peltier effect is reversible and depends on the direction of the current to decide the heating and cooling effects. In short, Peltier effect is more flexible compared to normal heating or cooling.

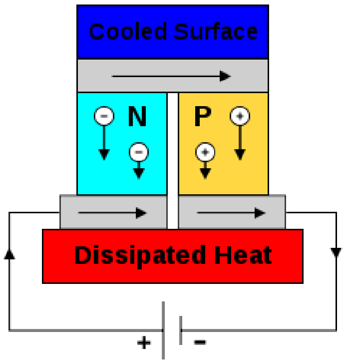

Figure 2.3: The Peltier Effect circuit configured as a thermoelectric cooler.

Solid state "Peltier" electrodes have been constructed for thermal stimulation of the cortex, subcortex, skin and other organs. They are simple to operate and permit a fine control of the rate and extent of warming and cooling within a limited temperature range (Stuatr et al., 1962).

2.2.3 Selected Technique of Thermoelectric Effect

Based on the review, we use Peltier effect for our technic of thermoelectric effect for our project. This is because our main review for this technique is to have an element of heating or cooling. By that, we can heat up or cool down the temperature of the beverages. Peltier effect is use the electrical to produce an environment of heat or cooling depends on how it will be connected. Beside, the Seedback effect is more to generating the electricity by converting the heat from surrounding into a voltage of volts. Therefore, we conclude that the Peltier effect is more suitable rather that Seedback effect into our project.

2.2 ELECTRONIC CONTROLLING UNITS

Historically, ECU hardware and software limitations have led designers to implement calibratable values using opaque binary blocks tied directly to ECU internal software data structures. Such coupling between calibration data files and ECU software limits traceability and reuse across different software versions and ECU variants. However, more and more automotive ECUs are featuring fast microprocessors, large memories, and preemptive, multi-tasking operating systems that open opportunities to object-oriented approaches (Rush, 2017). An electronic controlling unit is the most important things in this project. This is because we need a controller to control the system automatically to make it as auto machine and can reduce the energy need to use up by a person. Actually, a control unit is works by receiving input information that it converts into control signals, which are then sent to the central processor. The control unit system consists of the combination of elements which direct and control the operation and functions of the system (Browne et al., 1969). The function of the control unit of an electronic digital computer is to provide the sequences of pulses, which, when applied to the store, arithmetic unit and other units of the machine cause the orders of the programme to be executed (Wheeler et al., 1958). The functions that a control unit performs are dependent on the type of CPU, due to the variance of architecture between different manufacturers. The following Figure 2.4 illustrates is an example how instructions from a program are processed.

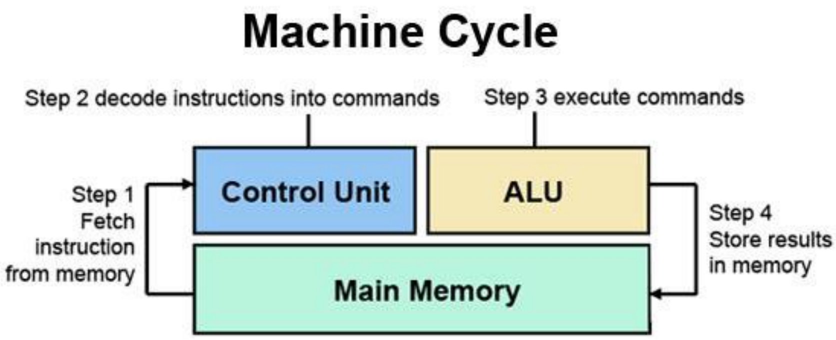

Figure 2.4: Illustration of instructions from a program is processed.

2.2.1 Types of MCU

These days, most of our projects include some sort of digital component such as a microprocessor. If you have even a minimal understanding of programming, there are websites, platforms and tools to help you develop your skills to the point where you actually create a hardware device with buttons, knobs and servos for a real physical world gadget.

There are so many great platforms for creating digitally enabled devices that it is gotten hard to figure out which one to use. For example, we are currently Smart Mug with charging coaster project and had to choose a controller to run the heating and cooling process, read the sensors and others. We were surprised at the number of choices that were available to us. Thus, we have taken three of the popular models and compared them so that you can choose the right tool for this project.

The three models are the Arduino, Raspberry Pi and BeagleBone. We chose these three because they are all readily available, affordable, about the same size and all can be used for creating systems for the project. Before we get to the comparison, here is a brief introduction to each one.

- The Arduino Uno

  The Arduino Uno is a staple for the maker community. Arduino's come in various sizes and flavors, but we chose the Arduino Uno as an example of the prototypical Arduino. It has an easy to use development environment, an avid user base and is designed to be easy to interface all sorts of hardware to.
- The Raspbery Pi

  The Raspberry Pi is the newcomer to the game. It is not really an embedded computer. It is actually a very inexpensive full-on desktop computer. It is barebones, but at $35 for a real computer, its worthy of note, and it is a great platform for lots of Maker projects.
- BeagleBone

  The BeagleBone is the perhaps the least known of these platforms, but an incredibly capable board worthy of consideration for many projects. It is a powerful Linux computer that fits inside an Altoid's mint container.

The three boards features are make them valuable to the project. Below in Figure 2.5 is put together outlining the features of the three for comparison. However, there are a few differences that make each of these MCUs shine in their own types of applications.

Name	Arduino Uno	Raspberry Pi	BeagleBone
Model Tested	R3	Model B	Rev A5
Price	$29.95	$35	$89
Size	2.95"x2.10"	3.37"x2.125"	3.4"x2.1"
Processor	ATMega 328	ARM11	ARM Cortex-A8
Clock Speed	16MHz	700MHz	700MHz
RAM	2KB	256MB	256MB
Flash	32KB	(SD Card)	4GB(microSD)
EEPROM	1KB		
Input Voltage	7-12v	5v	5v
Min Power	42mA (.3W)	700mA (3.5W)	170mA (.85W)
Digital GPIO	14	8	66
Analog Input	6 10-bit	N/A	7 12-bit
PWM	6		8
TWI/I2C	2	1	2
SPI	1	1	1
UART	1	1	5
Dev IDE	Arduino Tool	IDLE, Scratch, Squeak/Linux	Python, Scratch, Squeak, Cloud9/Linux
Ethernet	N/A	10/100	10/100
USB Master	N/A	2 USB 2.0	1 USB 2.0
Video Out	N/A	HDMI, Composite	N/A
Audio Output	N/A	HDMI, Analog	Analog

Figure 2.5: Comparing the three platforms of MCU (Roger, 2015)

2.2.2 Comparison of MCU

First, the Arduino and Raspberry Pi are very inexpensive at under $40. The BeagleBone comes in at nearly the cost of three Arduino Unos. Also worthy of note is that the clock speed on the Arduino is about 40 times slower than the other two and it has 128,000 times less RAM. Therefore, we can see the differences starting to come out. The Arduino and Raspberry Pi are inexpensive and the Raspberry Pi and BeagleBone are much more powerful.

Seems like the Raspberry Pi is looking really good at this point, however, it is never that simple. First, its price is not quite as good as it seems because to run the Raspberry Pi you need to supply your own SD Card which will run you another $5-10 in cost.

Also, despite the clock speed similarities, in our tests the BeagleBone ran about twice as fast as the Raspberry Pi. And perhaps most counterintuitive, the Arduino was right in the mix as far as performance goes as well, at least for a beginner. The reason for this is that the Raspberry Pi and BeagleBone both run the Linux operating system. This fancy software makes these systems into tiny computers which are capable of running multiple programs at the same time and being programmed in many different languages. The Arduino is very simple in design. It can run one program at a time and it programmed in low level C++.

For the beginner, the Arduino is recommending. It has the largest community of users, the most tutorials and sample projects and is simplest to interface to external hardware. There are more ways to learn about Arduino for beginners than you can shake a soldering iron at. The boards are designed to easily interface with a wide variety of sensors and effectors without and external circuitry and do not need to know much about electronics at all to get started.

For applications minimizing size the Arduino is also recommended. All three devices are similar in size, although the Raspberry Pi has SD Memory card sticks out a bit making it slightly larger overall. There are so many different flavors of Arduinos it is the best. Basically, Arduino is a particular microprocessor and a little bit of software. It uses a very small, inexpensive, embedded system on a chip microprocessor from a company named Atmel. For advanced projects that need to be really small, it can be bought these chips for a dollar or two and put the Arduino bootloader (a program that makes the Arduino give the Arduino its basic functions) on the chip and viola.

For applications that connect to the internet the BeagleBone or Raspberry Pi are recommending. Both these devices are real linux computers. They both include Ethernet interfaces and USB that can connect them to the network relatively painlessly. Via USB, it can connect to wireless modules then connect to the internet without wires. Also, the Linux operating system has many components built-in that provide rather advanced networking capabilities.A very small USB WiFi adapter plugs right in to the BeagleBone or Raspberry Pi, and the Linux operating system can support these types of devices. A very small USB WiFi adapter plugs right in to the BeagleBone or Raspberry Pi, and the Linux operating system can support these types of devices. The Arduino supports plug-in peripherals called “shields” that include the ability to connect to Ethernet, but the access to the networking functions is fairly limited. Plus the Ethernet shield might as well just get one of the more advanced boards.

For applications that interface to external sensors we recommend the Arduino and the BeagleBone. The Arduino makes it the easiest of any of the boards to interface to external sensors. There are different versions of the board that operate at different voltages (3.3v vs 5v) to make it easier to connect to external devices. The BeagleBone only operates with 3.3v devices and will require a resistor or other external circuitry to interface to some devices. Both the Arduino and BeagleBone have analog to digital interfaces that easily connect components that output varying voltages. The BeagleBone has slightly higher resolution analog to digital converters which can be useful for more demanding applications.

For battery powered applications, the Arduino is recomending. The Arduino uses the least power of the bunch, although, in terms of computer power per watt, the BeagleBone is the clear winner. However, the Arduino has an edge here since it can work with a wide range of input voltages. This allows it to run from a variety of different types of batteries and keep working as the battery loses juice. The Arduino uses the least power of the bunch, although, in terms of computer power per watt, the BeagleBone is the clear winner. However, the Arduino has an edge here since it can work with a wide range of input voltages. This allows it to run from a variety of different types of batteries and keep working as the battery loses juice.

2.2.3 Selected MCU

The Arduino is a flexible platform with great ability to interface to most anything. It is a great platform to learn first and perfect for many smaller projects. The Raspberry Pi is good for projects that require a display or network connectivity. It has incredible price/performance capabilities.The BeagleBone is a great combination of some of the interfacing flexibility of the Arduino with the fast processor and full Linux environment of the Raspberry Pi.

Besides, in order to complete our project, we choose Arduino as our MCU. As the review, the Arduino have a lot of advantages such as a better battery powered, interface to external sensors, minimizing size and a beginner user like us. It will be a great contribution to our project since it is much easier to conduct and also find resources to be as references.

2.3 ARDUINO

Arduino is one of the common electronic control unit that been using world wide to be a controller for a certain project. Aduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message and turn it into an output such as activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing.

There are various ATMEGA microcontroller used for many applications. In this paper, we are going to use ATMEGA 328 arduino microcontroller. ATMEGA 328 microcontroller has different numbers of analog and digital inputs. A specially provided USB cable which acts as an interface between the micro controller and the computer. From the USB cable, we upload the program to the microcontroller (Harisudhan et al., 2017). Arduino is an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the Arduino board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for IoT applications, wearable, 3D printing, and embedded environments. All Arduino boards are completely open-source, empowering users to build them independently and eventually adapt them to their particular needs. The software, too, is open-source, and it is growing through the contributions of users worldwide.

The benefits of utilizing diverse Arduino board are: Arduino Uno-effectively replaceable, Arduino Leonardo eliminates the need of optional processor and Arduino Dueused in convoluted venture. Arduino small scale –enables quicker prototyping, Lily cushion Arduino – wearable's and e-materials, Arduino Esplora-has joysticks, amplifier, and sensors on info side and ringer on yield side, Arduino yun-bolster cloud based administrations, Arduino Robot-bolster our own particular customed equipment parts. This review gives a wide portrayal about Arduino processor; it will be useful for some automated specialists (Rajan et al., 2015). In this way, the Arduino ATMEGA 328 microcontroller can be utilized for different applications, for example, modern and research facility applications.

These Arduino ATMEGA 328 microcontrollers are the most appropriate microcontroller for the mechanical applications. These Arduino ATMEGA 328 microcontrollers can be broadly utilized as a part of robotization process businesses (Harisudhan et al., 2015).

2.3.1 Arduino Nano

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x). It has more or less the same functionality of the Arduino Duemilanove, but in a different package. It lacks only a DC power jack, and works with a Mini-B USB cable instead of a standard one (Arduino, 2017). The technical specification for Arduino Nano is as Table 2.1 below.

Table 2.1: The technical specification of Aduino Nano (Arduino, 2017).

Microcontroller	ATmega328
Architecture	AVR
Operating Voltage	5 V
Flash Memory	32 KB of which 2 KB used by bootloader
SRAM	2 KB
Clock Speed	16 MHz
Analog I/O Pins	8
EEPROM	1 KB
Input Voltage	7-12 V
Digital I/O Pins	22
PWM Output	6
Power Consumption	19 mA
PCB Size	18 x 45 mm
Weight	7 g

2.3.2 Arduino Uno

Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. You can tinker with your UNO without worring too much about doing something wrong, worst case scenario you can replace the chip for a few dollars and start over again (Arduino, 2017).

"Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform; for an extensive list of current, past or outdated boards see the Arduino index of boards. The specification for the Arduino Uno is as in Table 2.2 below.

Table 2.2: The technical specification of Aduino Uno (Arduino, 2017).

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328P)

EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
Length	68.6 mm
Width	53.4 mm
Weight	25 g

2.3.3 Arduino Mini

The Arduino Mini is a small microcontroller board originally based on the ATmega168, but now supplied with the 328, intended for use on breadboards and when space is at a premium. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 8 analog inputs, and a 16 MHz crystal oscillator. It can be programmed with the USB Serial adapter or other USB or RS232 to TTL serial adapter (Arduino, 2017). The specification for Arduino Mini is as in Table 2.3 below.

Table 2.3: The technical specification of Arduino Mini (Arduino, 2017).

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage	7-9 V
Digital I/O Pins	14 (of which 6 provide PWM output)
DC Current per I/O Pin	40 mA
Flash Memory	32 KB (of which 2 KB used by bootloader)
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz
Length x Width	30 mm x 18mm

2.3.4 Arduino Micro

The Micro is a microcontroller board based on the ATmega32U4 , developed in conjunction with Adafruit. It has 20 digital input/output pins (of which 7 can be used as PWM outputs and 12 as analog inputs), a 16 MHz crystal oscillator, a micro USB connection, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a micro USB cable to get started. It has a form factor that enables it to be easily placed on a breadboard (Arduino, 2017).

The Micro board is similar to the Arduino Leonardo in that the ATmega32U4 has built-in USB communication, eliminating the need for a secondary processor. This allows the Micro to appear to a connected computer as a mouse and keyboard, in addition to a virtual (CDC) serial / COM port. It also has other implications for the behavior of the board; these are detailed on the getting started page. The technical specification is as in Table 2.4 below.

Table 2.4: The technical specification of Arduino Micro (Arduino, 2017).

Microcontroller	ATmega32U4
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Digital I/O Pins	20
PWM Channels	7
Analog Input Channels	12
Flash Memory	32 KB (ATmega32U4) of which 4 KB used by bootloader
SRAM	2.5 KB (ATmega32U4)
EEPROM	1 KB (ATmega32U4)
Clock Speed	16 MHz

Length x Width	48 mm x 18mm
Weight	13 g

2.3.5 Selected Arduino

Based on the review we had made, we can conclude that we choose the Arduino Nano. Since, the technical specifications that can be seen in Table 2.1 show the ideal controller that can be used in our project. The Arduino Nano gives the input and output for Analog and Digital estimated 30 pins are enough for installing the sensor, Peltier chip and others related component. Moreover, the size is compatible with the design of our mug which is 18 mm x 45 mm. Besides, the Arduino Nano are commonly use in the project and also user friendly along with Arduino Uno. But, Arduino Uno is much bigger and heavier that Arduino Nano. Lastly, a USB port is included that make it much suitable to our project component implementation rather than Arduino Mini and Arduino Micro.

2.4 RECHARGEBLE BATERRY

In this project, heating and cooling process consumes a lot of power from the power supply. Thus, the battery selected must be able to discharge current for a long period of time in order to sustain the functionality of the tumbler. Since the battery will be working in a hot environment, high safety features is an important aspect of the battery as we do not want a battery that will reduce its life span or explode when exposed to a lot of heat energy. Every battery is made of chemicals and metals such as nickel, mercury and lead acid. Each cell of a battery stores electrical energy as chemical energy in two electrodes, a reductant (anode) and an oxidant (cathode), separated by an electrolyte that transfers the ionic component of the chemical reaction inside the cell and forces the electronic component outside the battery. The output on discharge is an external electronic current I at a voltage V for a time Δt (John and Park, 2013).

A rechargeable battery is an energy storage device that can be charged again after being discharged by applying DC current to its terminals. Rechargeable batteries allow for multiple usages from a cell, reducing waste and generally providing a better long-term investment in terms of dollars spent for usable device time. The chemical reaction of a rechargeable battery must be reversible on the application of a charging I and V. Critical parameters of a rechargeable battery are safety, density of energy that can be stored at a specific power input and retrieved at a specific power output, cycle and shelf life, storage efficiency, and cost of fabrication. Conventional ambient-temperature rechargeable batteries have solid electrodes and a liquid electrolyte (John and Park, 2013)

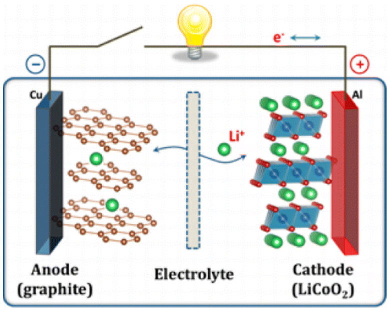

Figure 2.6: An ilustration of the rechrageable battery (John and Park, 2013).

2.4.1 Types of Rechargeble Baterry

Rechargeable batteries are produced in many different shapes and sizes, ranging from button cells to megawatt systems connected to stabilize an electrical distribution network. Several different combinations of electrode materials and electrolytes are used to create different types of rechargeable battery. For instant, types of rechargeable battery are lead–acid, lithium-ion (Li-ion), and lithium polymer (Li-Po).

2.4.1.1 Lead Acid Rechageable Battery

Lead Acid rechargeable battery is made of lead and lead dioxide, the active materials on the battery's plates, react with sulfuric acid in the electrolyte to form lead sulfate. The lead sulfate first forms in a finely divided, amorphous state, and easily reverts to lead, lead dioxide and sulfuric acid when the battery recharges. In a normal lead acid battery approximate voltage is 2 V/cell; so a total voltage on a battery is 12 V usually, 6 cells (Dinis et al., 2014).

Lead acid is heavy and is less durable than nickel- and lithium-based systems when deep cycled. A full discharge causes strain and each discharge/charge cycle permanently robs the battery of a small amount of capacity. This loss is small while the battery is in good operating condition, but the fading increases once the performance drops to half the nominal capacity. This wear-down characteristic applies to all batteries in various degrees.

Depending on the depth of discharge, lead acid for deep-cycle applications provides 200 to 300 discharge/charge cycles. The primary reasons for its relatively short cycle life are grid corrosion on the positive electrode, depletion of the active material and expansion of the positive plates. This aging phenomenon is accelerated at elevated operating temperatures and when drawing high discharge currents. At the charging of the battery 12 V, 9 Ah, the voltage increases slightly, and the current is maintained constant for a long period of time. Upon completion of charging the battery, the voltage has maximum value and the current is limited at almost 0.1 A. At discharging the battery through a lamp, the voltage on the lamp decreases faster than the current. Voltage and current suddenly decrease, after a period of time (Dinis et al., 2014).

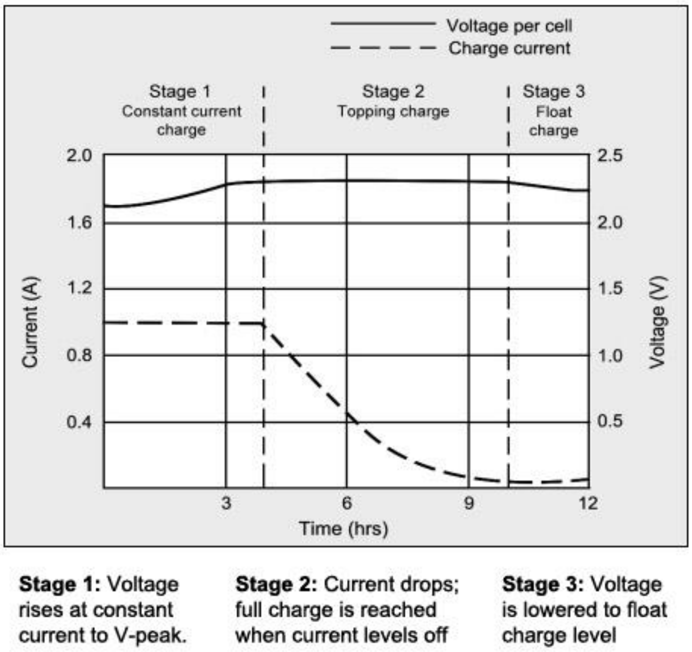

Figure 2.7: Charge stages of a lead acid battery (Battery University, 2017).

Lead acid does not lend itself to fast charging and with most types, a full charge takes 14–16 hours. The battery must always be stored at full state-of-charge. Low charge causes sulfation, a condition that robs the battery of performance. Adding carbon on the negative electrode reduces this problem but this lowers the specific energy.

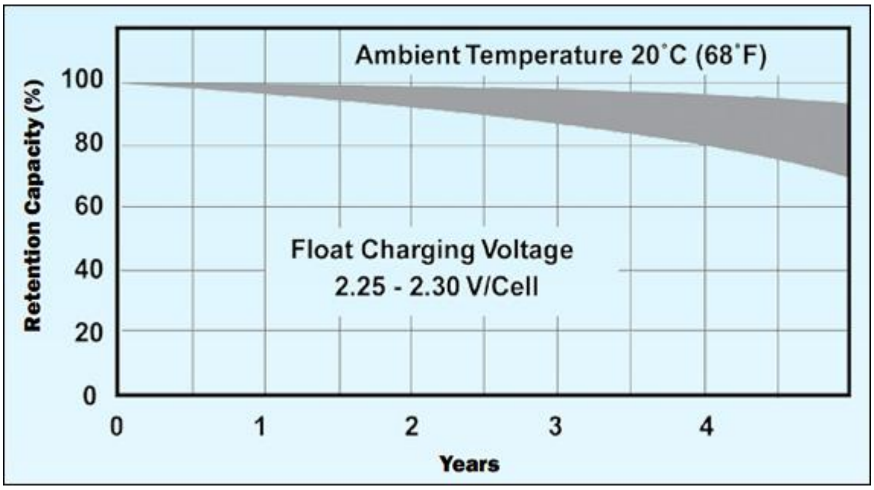

Figure 2.8: Capacity loss on standby (Battery University, 2017).

Lead acid has a moderate life span, but it is not subject to memory as nickel-based systems are, and the charge retention is best among rechargeable batteries. While NiCd loses approximately 40% of their stored energy in three months, lead acid self-discharges the same amount in one year. The lead acid battery works well at cold temperatures and is superior to lithium-ion when operating in subzero conditions. The greatest enemies of lead acid batteries are over-charging and over-heating. For charging of lead acid batteries it can use three methods of charging: at constant current, constant voltage, or mixed (Dinis et al., 2017)

Figure 2.9: An example of Lead Acid Battery

Usually in market, Lead Acid commonly known as a high capacity battery that can supply enough power to done a certain activities based on its power rating. A long cycle life with a safe a high reliability with high operating temperature make it well known among user. Since we need a power sources that can supply atleast 12V and 2A, Table 2.5 will show the technical specification for the choosing Lead Acid battery.

Table 2.5: Technical Specification for Lead Acid Battery

Dimension	65mm(L) x 150mm(W) x 100mm(H)
Output Voltage	DC12V
Output Power	7.0AH
Weight	1.98kg

2.4.1.2 Lithium Polymer Rechageable Battery

A lithium polymer battery, or more correctly lithium-ion polymer battery (abbreviated as LiPo, LIP, Li-poly, lithium-poly and others), is a rechargeable battery of lithium-ion technology using a polymer electrolyte instead of a liquid one. High conductivity semisolid (gel) polymers form this electrolyte. These batteries provide a higher specific energy than other lithium-battery types and are being used in applications where weight is a critical feature - like tablet computers, cellular telephone handsets or radio-controlled aircraft.

Figure 2.10: An example of Lipo Battery

Just as with other lithium-ion cells, LiPos work on the principle of intercalation and de-intercalation of lithium ions from a positive electrode material and a negative electrode material, with the liquid electrolyte providing a conductive medium. To prevent the electrodes from touching each other directly, a microporous separator is in between which allows only the ions and not the electrode particles to migrate from one side to the other.

Besides the battery chemistry, this also depends on the battery packaging and design, as well as the operating point (Dell, 2001). The Specific Energy of LiPo's varies between 100-300Wh/kg (Abdilla et al., 2015), with a value of ~150Wh/kg being typically adopted, as in (Beckman, 2010) and (Lawrence and Kamran, 2005). Based on experimental results with Commercial Off-The-Shelf (COTS) LiPo's, (Gur and Aviv, 2009) adopt a quadratic model for energy density and perform a battery sensitivity study with linear model of variations about a nominal value of 180Wh/kg.

Next, the thermal performance of the lithium ion polymer (Li-ion polymer/ LiPo) batteries is discussed. The cell has been tested at 10˚C, 25 ˚C and 35 ˚C, with charging currents of 0.5C and 1C, and discharging currents of 0.5C, 1C, 5C, 10C and 20C. (The charge and discharge current of a battery is measured in C-rate. This means that a 1.5 Ah battery would provide 1.5 A for one hour if discharged at I C rate.) During the 10 ˚C tests, discharging and charging processes are paused for 10 min, instead of 5 min, as all the time constants increase at low temperature (Baronti et al., 2010).

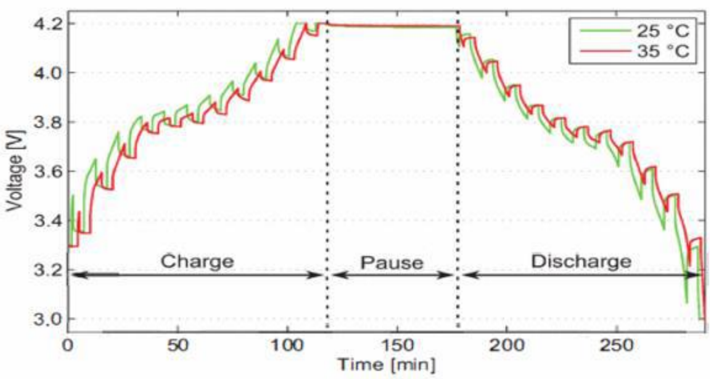

Figure 2.11: Test Curve at Different T, 1C current

As to complete the project, we need a rechargeable battery that can supply 12V and 2A of power sources to power up the system. Thus, Table 2.6 is the technical specification for the choosing LiPo battery.

Table 2.6: Technical Specification for Lipo Battery

Nominal output	11V
Cell	3
Discharged Rate	25C
Capacity	3000mAh
Size	140mm(L) x50mm(W) x20mm(H) (+-3mm)
Weight	300g (+-5g)

2.4.1.3 Lithium Ion Recahgeable Battery

A lithium-ion battery or Li-ion battery (abbreviated as LIB) is a type of rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. Batteries are store and releases energy by moving electrons from one “end” of the battery to the other. Then we can use the energy from those moving electrons to do work for us, like power a drill. These two batteries “ends” are known as electrodes. One is called the anode and the other is called the cathode. Generally, the anode is made from carbon and the cathode from a chemical compound known as a metal oxide (cobalt oxide, for example). The final battery ingredient is known as the electrolyte, and it sits in between the two electrodes. In the case of lithium-ion batteries, the electrolyte is a salt solution that contains lithium ions—hence the name.When you place the battery in a device, the positively charged lithium ions are attracted to and move towards the cathode. Once it is bombarded with these ions, the cathode becomes more positively charged than the anode, and this attracts negatively charged electrons (Troiano, 2013).

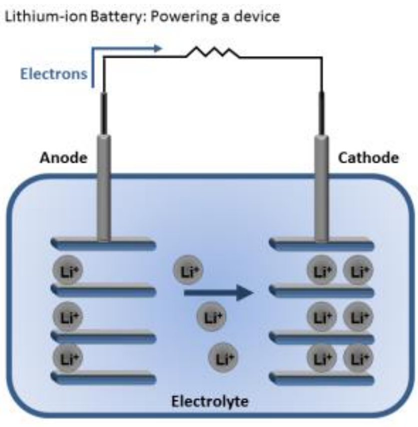

Figure 2.12: How a lithium-ion battery produces electricity (Troiano, 2013)

As the electrons start moving toward the cathode, we force them to go through our device and use the energy of the electrons "flowing" toward the cathode to generate power. You can think of this kind of like a water wheel, except instead of water flowing, electrons are flowing. Lithium-ion batteries are great because they are rechargeable. When the battery is connected to a charger, the lithium ions move in the opposite direction as before. As they move from the cathode to the anode, the battery is restored for another use.

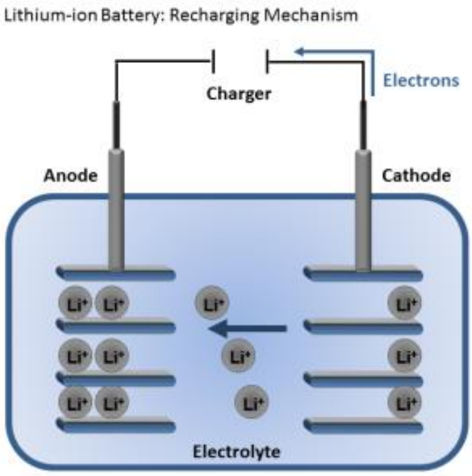

Figure 2.13: Recharging a lithium-ion battery (Troiano, 2013)

The recharge ability of the Li-ion battery, the present-day LIB is fabricated in a discharged state. It uses reversible Li extraction from an oxide host as the rechargeable cathode and into carbon or buffered spongy silicon or tin as the anode host. The capacity of an oxide host is limited to the reversible solid−solution range of Li in the cathode host structure operating on the redox energy of a single transition metal cation; and where a passivating layer forms on the anode during the first charge, the capacity is further reduced by an irreversible loss of Li from the cathode in the Li+-permeable SEI layer formed on the anode. Nevertheless, rechargeable batteries capable of over 30 000 safe charge/discharge cycles at an acceptable rate, equivalent to a 10 year operational life, have been achieved (John and Park, 2013).

Temperature is one of the parameters of a battery that has to be controlled carefully, as the optimum working region is normally limited between 20°C and 65°C. Furthermore, the working temperature of the battery has a big influence on efficiency, cell degradation and life time. Battery cells generate heat during charge and discharge process. The heat generation in the battery can increase sharply leading to overheating under certain conditions such as high discharge rate and high ambient temperature and also over-charged or over-discharged during cycling. This is the major contribution to premature failure in the battery packs in form of thermal runaway or accelerating capacity fading. For the lithium ion (Li-ion) battery, the temperature increases sharply if the SOC is too small (less than 20%). Higher discharge rate contributes to higher temperature increase and bigger maximum and minimum temperature difference. Higher cooling air velocity helps to decrease the overall temperature and create better cell surface temperature distribution (Zul Hilmi et al., 2014)

The thermal behavior of the sample Li-ion battery during discharge processes is studied using the proposed analytical approach. As the capacity of the sample battery is 180Ah, the empirical data for (0.25C, 0.5C, 1C) discharge rates conditions, as shown in Fig 2, correspond to 45 A, 90 A, and 180A, discharge currents, during 4 hours, 2 hour, 1hour, respectively. With the different value of discharge, homogeneous heat generation rates q are obtained by fitting high-order polynomials to the data points Figure 2.13.

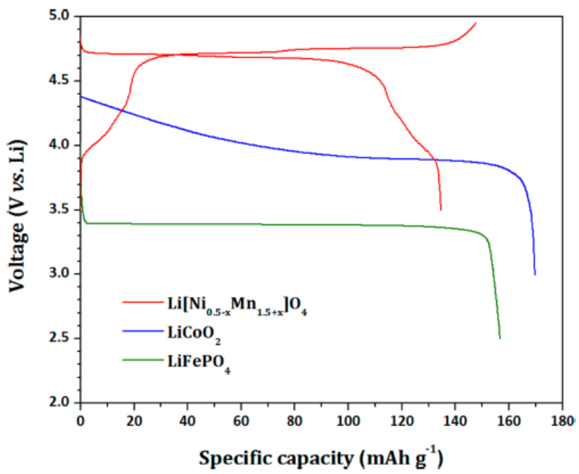

Figure 2.14: Comparison graph of charge/discharge voltage curves

Thus, Table 2.7 will shows the LIB chosen for completing the 12V and 2A power sources of a battery to power up the sysem.

Table 2.7: Technical Specification for the LIB

Output Voltage	12 V
Output Power	2.2Ah
Dimension	90mm(L) x 20mm(W) x 100mm(H)
Weight	0.15Kg

2.4.2 Selection of Rechageable Battery

Based on the review, we can clearly see that Lead Acid Battery is the best for the capacity and the discharged rate and cycle for the battery. But, we decided to focus mainly on Lithium based batteries because Lithium rechargeable batteries are very attractive power sources for portable electronic devices and several new and emerging medical devices. Lithium batteries have high energy and power density and good cycle life compared to those of nickel metal hydride and nickel cadmium batteries (Venkatasetty and Jeong, 2002). Thus, as we compare for both LiPo battery and LIB the rate of the discharged and cycle is nearly the same. But, the LiPo battery has much advantages rather than LIB. But, the battery avaibility market right knows and also the size consideration, the LIB is the most suitable one. This is because with the capacity and rating needed still achieved the targeted for making the systems work. Besides, for satety purposes, LIB system is safe, providing certain precautions are met when charging and discharging. Today, lithium-ion is one of the most successful and safe battery chemistries available. Two billion cells are produced every year. While, when LiPo is mishandling, it can lead to fire, explosions and toxic smoke inhalation. In the rest of this guide we will cover safety guidelines of charging and handling Lipo battery packs. Some may seem pretty obvious, but it is often the obvious things that are the most dangerous when ignored. Charging Lithium Polymer or LiPo batteries have very specific charging requirements and must only be changed by specific chargers designed to charge lithium polymer batteries and recommend only balance charging your lipo batteries. Lastly, we can conclude that LIB is the suitable rechargeable battery for the project based on review.

2.5 MECHANISM OF SMART MUG WITH CHARGING COASTER

The smart mug is innovative mug in order to conserve the energy while giving the perfect temperature for the user. In order to maintain the temperature and save the energy, thermoelectric effect mechanism is used. In thermoelectric effect, we focus on the Seeback effect and Peltier effect that enable the conversion of heat for heating and cooling by the junction of wire. Besides, we use the Thermoelectrical chip that also known as Peltier chip as the conductor that change the conversion of heating and cooling in the system of the smartmug. In addition, we are choosing arduino nano as our controller to control and give the process of our system according to the needed of the smartmug. Lastly, we use an rechargeable battery to support the smartmug to be portable and can be carried away to any place to use it. There are a lot of type of rechargeable battery can be use to become as a power source of it.

CHAPTER 3

THEORY & METHODOLOGY

3.1 THEORY

One important factor is to construct a safe and efficient system. The circuit encloses different important componenets.

3.1.1 Peltier Module

Peltier module known as Thermoelectric Cooler (TEC) is able to reduce the temperature at upper side and increase the temperature at lower side of the component. This is occurring when the Peltier module is connected according to its polarities. But, the ability can be turn oppositely when the connection of the component is reverse.

The Peltier Module has a characteristic of switching its heating and cooling sides if the polarity of the power supply is reversed. Due to the confining space of the tumbler, a mechanical method of reversing the Peltier Module or the power supply is unpractical. Therefore we want to design a circuit is able to electronically reverse the polarity of the power supply when needed.

Peltier Module draws at least 12V and 2A to work at ideal cooling and heating procedure. At the point when the temperature distinction between the cool side and hot side is 70˚C, the Peltier draws a greatest of 16V and 6.1A. (Keong, 2016).

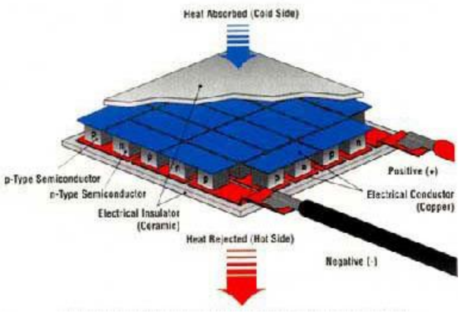

Figure 3.1: The illustration of mechanism for the Peltier Module

Thus, we can use the Peltier module as our component to done the mechanism of heating and cooling process. As we can conclude at the above review, the switching polarities of the Peltier module will be a huge element to our project prospect heating and cooling the beverages.

3.1.1.1 Cooling Process

In cooling process, after the user enters the temperature need, the Arduino Nano will collect the data and transfer it to the Peltier module. Next, the Peltier module will be the component to absorb the heat from the upper side and reject it in the other side. Then, the Peltier module that contacting with the container of water will be cooling up. Thus, the temperature is transfer through the contacting surface and also cools up the water inside the container. In order to increase the efficiency, the DC fan will be operate and help in the process of cooling while the heatsink will allowing regulation of the Peltier module's temperature at optimal levels. Later, when the temperature require is reached, the DS18B20 waterproof temperature sensor will detect it and send the data back to Arduino Nano and end the process of cooling by the Peltier module.

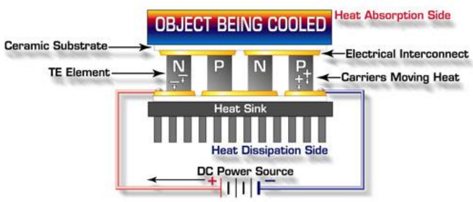

Figure 3.2: Illustration process of Cooling

3.1.1.2 Heating Process

For the heating process, the user must enter the temperature more than room temperature. The Arduino Nano will receive the data and send it to the Peltier module to start heating. The heat rejected will be transferred to contacting container and automatically will be heated up the water in it. After the water reached the require temperature, the DS18B20 waterproof temperature sensor will detect and send the data to the Arduino Nano. Then, the Arduino Nano will be cut the process of heating that has been done by the Peltier module.

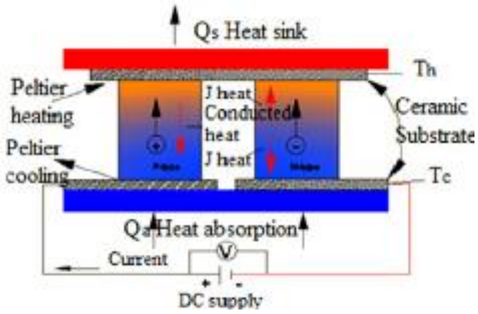

Figure 3.3: Illustration process of Heating

3.1.2 Transistor as a Switch in the circuit.

Below is an example circuit with a NPN transistor that work as a switch for turning an LED on or off is used. Futher explaination will be stated later through the next paragraph.

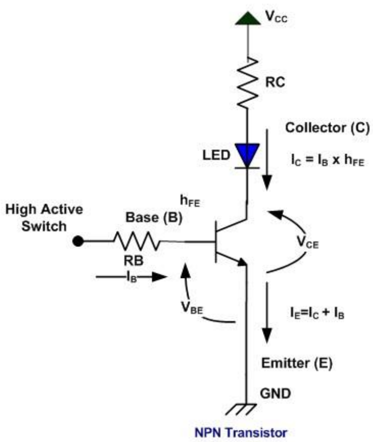

Figure 3.4: A sample of connection of a transistor as a switch

A resistor is added to help limit the amount of current flowing into the transistor to prevent overload. From Figure 3.1, R_1 is a 330 Ω resistor that limits the current through the LED to prevent the LED from burning out. Using Ohm's Law, amount of current that the resistor will allow to flow is calculated.

Resistor R_2 is a 1kΩ resistor which limits the current flowing into the base of the transistor. Using Ohm's Law again, we can calculate the base current. Base-emitter junction drop, Vb = 0.7 V.

The transistor allows us to use a small current to control a much larger current, which is a useful component as the Arduino Nano's output is very small compare to the power source. In an ideal switch, the transistor should be in only one of two states which are off or on. The transistor is off when there's no bias voltage or when the bias voltage is less than 0.7 V. The switch is on when the base is saturated so that collector current can flow without restriction. Besides, using the transistor control the relay used in the circuit thus the circuit will has an automatic switch that functioning when needed and give an extra protection to the circuit.

3.1.3 Battery Connection

For this project, we required at least 9V and 1.5A to operate Peltier module and this issue has to be solved by manually connecting the battery cells. 4 battery cells are first connect as a pack in series. As we connecting batteries in series, it will add up the voltage output of every battery cell as total voltage output. Since, adding cells in a string increases the voltage and the capacity remains the same.

Figure 3.5: Illustration of Series connection for battery

This battery pack we can obtain 14.4V and 1.5A of output voltage and current respectively since ampere value remains the same throughout the battery cells if they are connected in series. However, a single battery packs with only 3400mAh unable to maintain the ability of Peltier module operation for a long time. The amount of time taken by the Peltier module to exhaust the battery fully is calculated:

Thus, we require more extended battery life, which can be obtained by increasing the ampere hour of the battery. This can be achieved by connecting the battery cells in parallel. Connecting battery cells in parallel will maintain the voltage output but increases the total ampere hour of the battery.

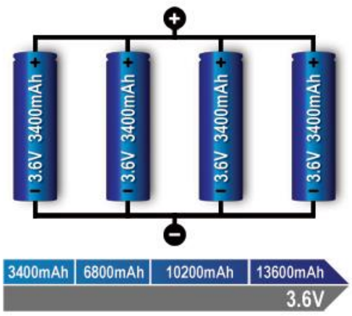

Figure 3.6: Illustration of parallel connection for battery

Therefore, series-parallel connection is applied in order to gain increase voltage and ampere hour the batteries are connected in. As mentioned earlier, 4 cells are connected in series as a pack and two packs are now connected in parallel, giving it an effective ampere hour of around 6800mAh.

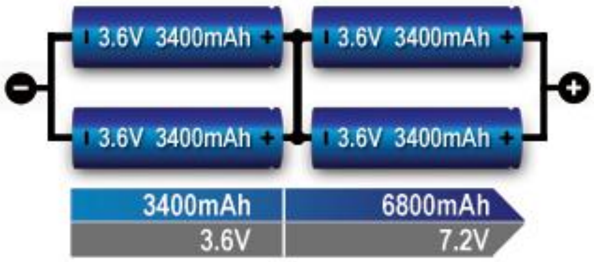

Figure 3.7: Illustration of series-parallel connection for battery

Therefore, in this project we connect the battery in series-parallel connection to increase the current and voltage for drawing enough power to the system. The series-parallel connection gives us better connection rather than other. This is because the compactibility of itself will be a great added value to the Smart Mug project.

3.2 METHODOLOGY

3.2.1 Working Principle

In order to create and develop a controller circuit that will control the process of cooling or heating. We also need to set our temperature range for the smart mug technical specification. Thus, we set the water is cooled till reached 20 ºC or heated till reached 70ºC. The reason to set the water for 20 ºC and 70ºC is for giving the best condition for the beverages to be not too cold or too hot that can harm or effect the body.

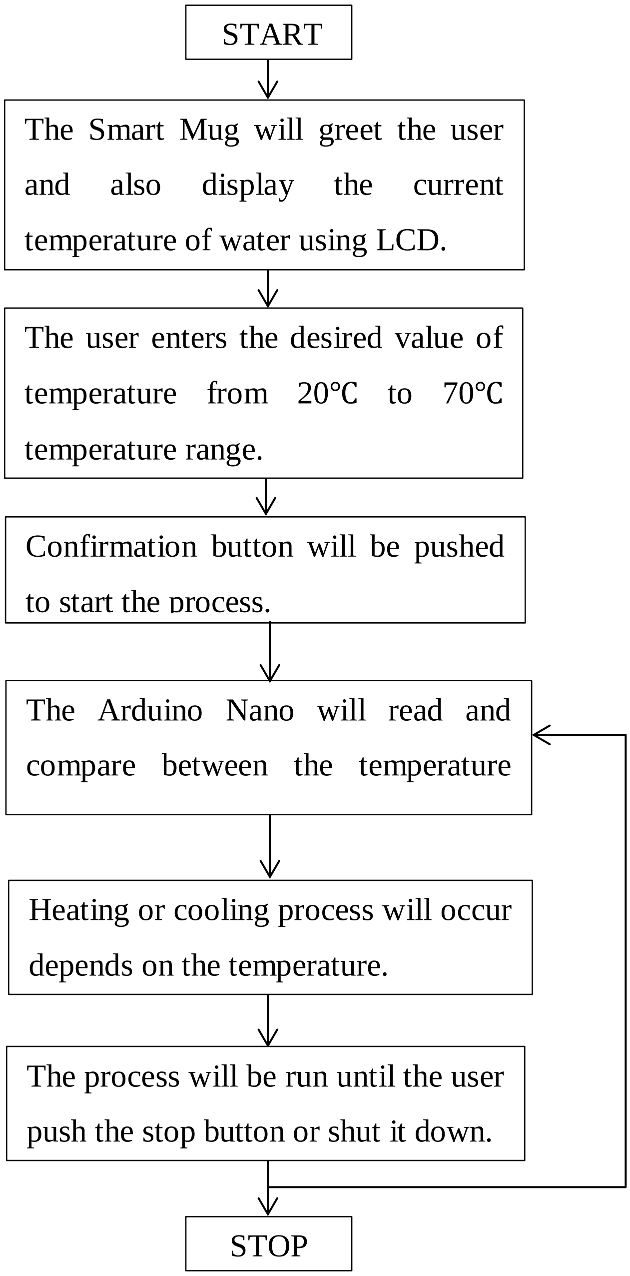

Figure 3.8: A sequence of the working principle for the Smart Mug

3.2.2 Flowchart

Moreover, a flowchart is the main things to be developed as one of the first step for easier the understanding of the conditions and actions that should be taken.

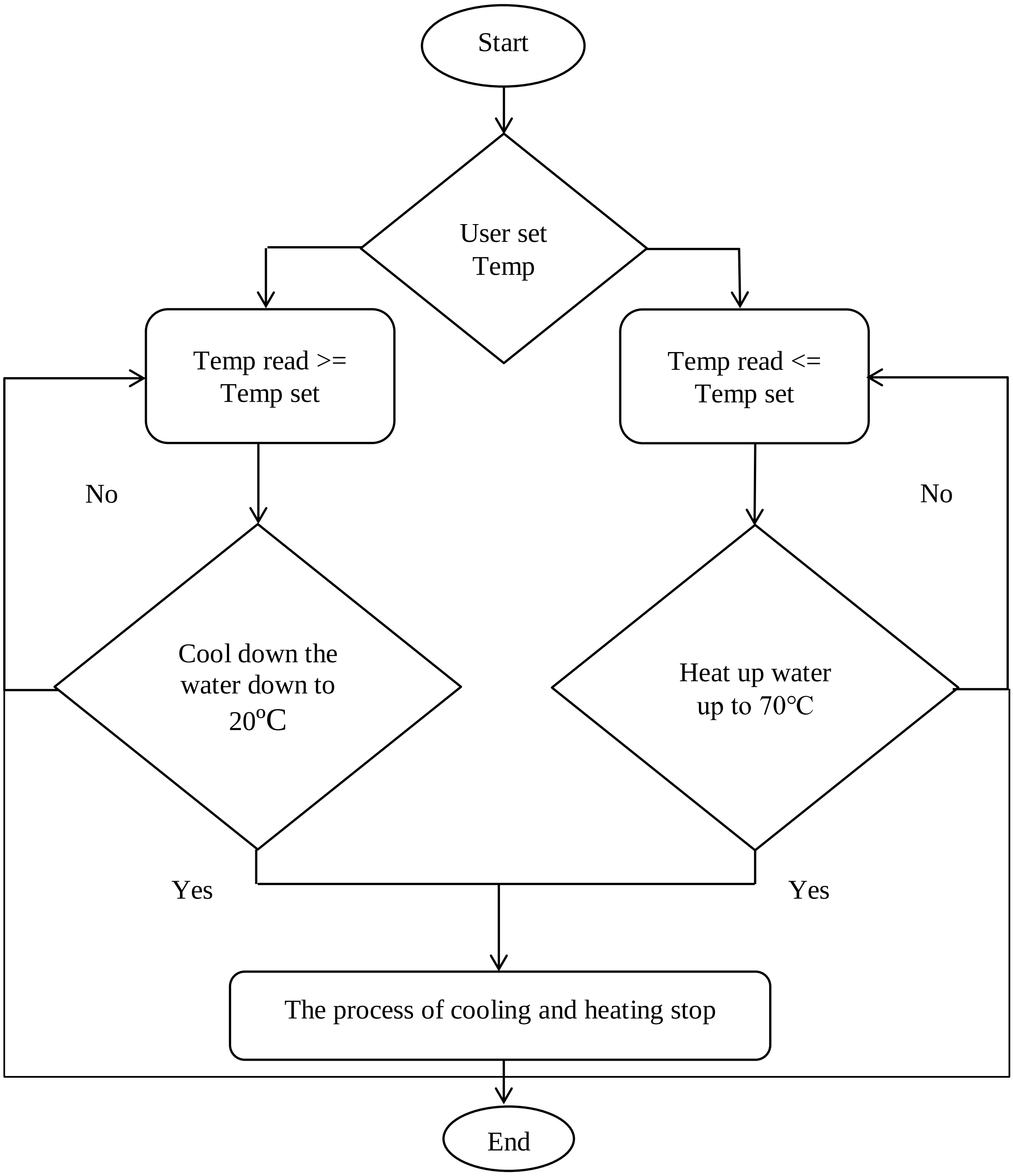

Figure 3.9: The process of the system in the Arduino Nano

3.3 PROJECT IMPLEMENTATION

3.3.1 Arduino Nano

Based on the design, we decided to choose Arduino Nano for our controller or the main part of the system. The Arduino Nano is a surface mount breadboard embedded version with integrated USB. It is a smallest, complete, and breadboard friendly. It has everything that Diecimila/Duemilanove has (electrically) with more analog input pins and onboard +5V AREF jumper. Physically, it is missing power jack. The Nano is automatically sense and switch to the higher potential source of power, there is no need for the power select jumper.

Nano's got the breadboard-ability of the Boarduino and the Mini+USB with smaller footprint than either, so users have more breadboard space. It is got a pin layout that works well with the Mini or the Basic Stamp (TX, RX, ATN, GND on one top, power and ground on the other). This new version 3.0 comes with ATMEGA328 which offer more programming and data memory space. It is two layers. That make it easier to hack and more affordable.

Figure 3.10: Arduino Nano

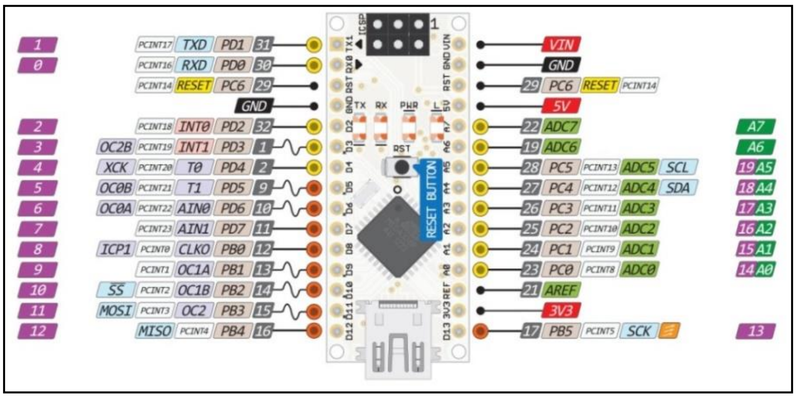

Figure 3.11: Pinout Diagram of Arduino Nano

3.3.2 Single Pole Double Throw (SPDT) Relay

The Single Pole Double Throw (SPDT) relay is quite useful in certain applications because of its internal configuration. It has one common terminal and 2 contacts in 2 different configurations which is Normally Closed and the other one is opened. The other one is Normally Open and the other one closed. There for we can see the SPDT relay as a way of switching between 2 circuits. First, the situation when there is no voltage applied to the coil one circuit “receives” current, the other one does not happen. On the other hand, the situation when the coil gets energised the opposite is happening. For these reasons, they are extensively used in products needing some type of electric or electronic regulation. Relays and contactors can be found, e.g., in cars, home appliances, communications systems or industrial machines.

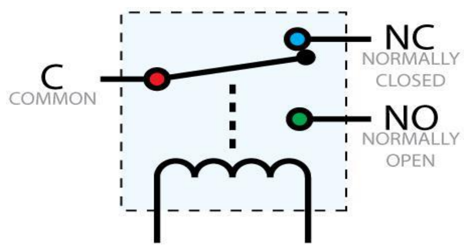

Figure 3.12: Pinout Diagram of SPDT Relay

3.3.3 DS18B20 Waterproof Temperature Sensor

DS18B20 Waterproof Temperature Sensor is a precision intergrated-circuit (IC) temperature sensor with its output proportional to the temperature (in ºC). It is use a unique 64 bit ID burned into chip. It also uses 1-Wire interface- requires only one digital pin for communication. The sensor circuitry is sealed. Therefore it is not subjected to oxidation and other processes. Using DS18B20 Waterproof Temperature Sensor, the temperature can be measured more accurately rather than with a thermistor and DS18B20 waterproof temperature sensor. It also possess low self heating and does not cause more than 0.1 ºC temperature rise in still air. The operating temperature range is from -55 to 125°C. The operation voltage is usable with 3.0V to 5.5V power/data. By the specification of the DS18B20 waterproof temperature sensor, we decided to use it because it is suitable and match with our project criteria.

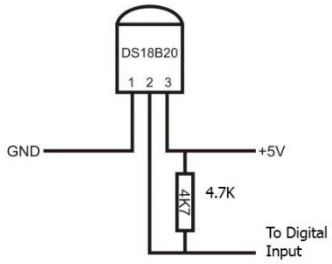

Figure 3.13: Pinout Diagram of DS18B20 waterproof temperature sensor

3.3.4 Peltier Module

Peltier module is an amazing device whereas one side of these Peltier modules can become absolutely freezing cold and the other very hot when power is applied. Thus, make a miniature refrigerator with no moving parts and also no compressor.

The mechanism of the Peltier module is a DC voltage need to be applied to this semiconductor device, one side gets cold while the opposite side gets hot. They are so efficient that they will self destruct if measures are not taken to draw the heat off the hot side using a heat sink and/or fan. Properly utilized, these like other semiconductors will enjoy a very long and dependable life. The possible applications for these go far beyond the simple heating or cooling of coffee and tea and controlling the temperature of chemical reactions, heating or cooling of small engines, dissipating heat from critical components, and others.

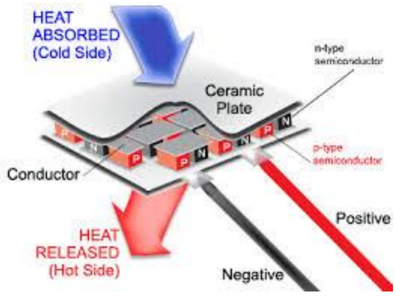

Figure 3.14: An illustration of Peltier module and its part

3.3.5 Lithium Ion Battery

Lithium ion (Li-Ion) battery is one of the types of rechargeable battery that exist. Lithium ion battery or most commonly know as Li- ion battery have the mechanism of Li-ion move from the negative electrode to the positive electrode during discharge and back when charging. Therefore, it makes itself rechageable and can be cycle in use for a few times until the lifespan limit reached. But, if the voltage of a lithium-ion cell drops below a certain level, it will be ruined the Li- ion batteries age. They only last two to three years, even if they are sitting on a shelf unused.

Futhermore, although it is slightly lower in energy density, the lithium-ion system is safe to be used for any purpose. Besides, Lithium ion battery is providing certain precautions that are met the safety when charging and discharging. Today, lithium-ion is one of the most successful and safe battery chemistries available. It has been implementing in a lot of devices such as mobile phone, laptop, camera or even car battery. Therefore, we are sure that Li- ion battery is the most suitable battery to be used in our project.

3.3.6 Single Pole Single Throw (SPST) Switch

A single pole singlethrow (SPST) switch is as simple as it gets. It is got one output and one input. The switch will either be closed or completely disconnected. SPST switch is perfect for on-off switching. Thus, it is needed in this project as it will be controlling the on-off of the Smart Mug and and being a cut off source from the battery to the Arduino Nano to make it functioning. They are also a very common form of momentary switches. SPST switches should only require two terminals.

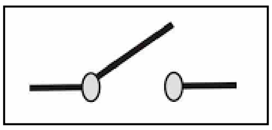

Figure 3.15: SPST Switch Symbol

3.3.7 RGB Light Emitting Diode (LED)

The RGB LED means red, blue and green LEDs. RGB LED is a product of combination three colors to produce over 16 million hues of light. But not all colors are possible to be emitted. Some colors are “outside” the triangle formed by the RGB LEDs and the pigment colors such as brown or pink also are difficult, or impossible, to achieve. Therefore, in our project we use the RGB LED to indicate the status of the smart mug such as green for the system function is on, red for heating, blue for cooling and yellow for the temperature achieve the ideal user temperature.

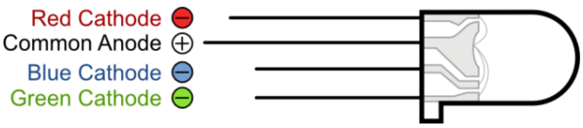

Figure 3.16: RGB LED pinout diagram

3.3.8 Liquid Crystal Display (LCD)

LCD (liquid crystal display) is the technology used for displays in notebook and other smaller computers. Like light-emitting diode (LED) and gas-plasma technologies, LCDs allow displays to be much thinner than cathode ray tube (CRT) technology.The pixels are controlled in completely different ways in plasma and LCD screens.

In a plasma screen, each pixel is a tiny fluorescent lamp switched on or off electronically. In an LCD television, the pixels are switched on or off electronically using liquid crystals to rotate polarized light. Therefore, it is match with our project criteria to display our temperature of water contain in the Smart Mug and easy the user because it is readeable.

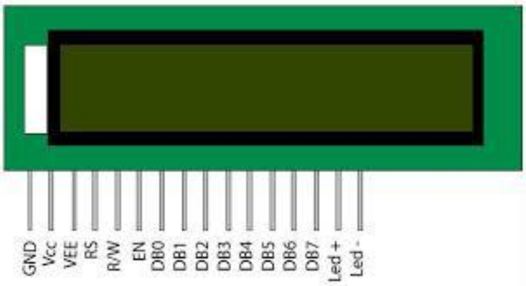

Figure 3.17: LCD pinout diagram

3.3.9 DC Fan and Heatsink

A heat sink and DC fan is an active cooling solution used to cool down a system. Heat sink, a fin-like structure, is an electronic device that incorporates either a fan or a peltier device to keep a hot component such as a processor cool. There are two heat sink types which are active and passive. Active heat sinks utilize the power supply and are usually a fan type or some other peltier cooling device. While, the DC fan is attached to this heat sink and improves the transfer of hot air by pulling the hot air from the electrical heat generated by the components and pushing in cooler air between the aluminum fins, thus keeping the processor cool. The Peltier Module also dissipates a large amount of heat when performing the cooling process. Proper heat dissipation through heat sink and air circulation is crucial to allow the Peltier Module to function under maximum efficiency. Therefore, we need to design a circuit that allows the fan that serves as air circulation to operate when needed and stop as we switch off the power supply (Keong, 2016).

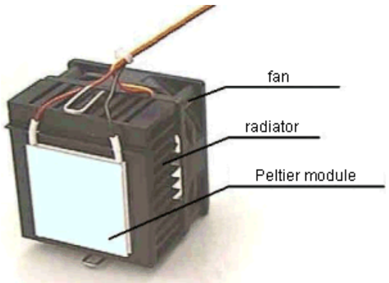

Figure 3.18: An example of DC Fan and Heat sink

3.3.10 Circuit Design

As the working principle for the Smart Mug, the flowchart for the process of heating and cooling are already been constructed according to the behaviour of the original idea for the Smart Mug to be operating. Thus, the suggested component as stated above will come out with a electrical circuit design as below to make it fuctioning as a competent Smart Mug.

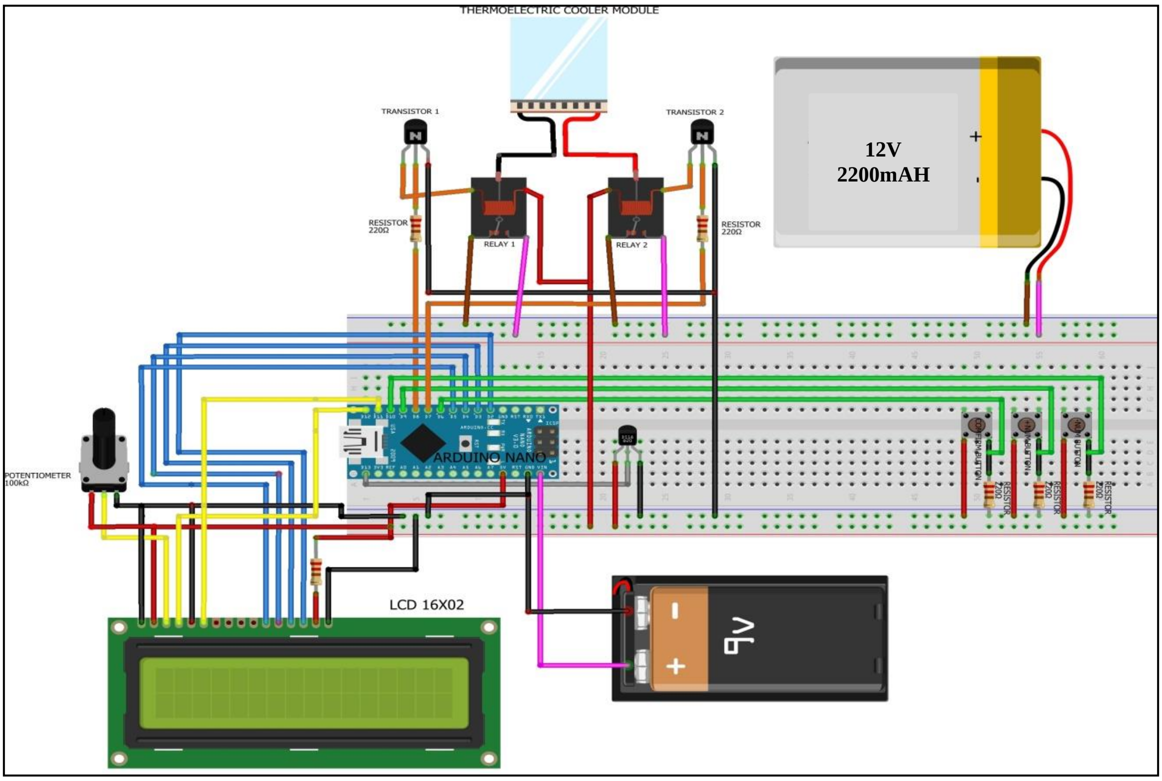

Figure 3.19: Circuit design for the Smart Mug with Charging Coaster

CHAPTER 4

RESULT AND DISCUSSION

4.1 PROBLEM FACED IN CIRCUIT DESIGN

In the beginning of designing the circuit, there is no problem encounter when designing a temperature control using LED and LM35 temperature sensor. The flow of designing is working well. The problem starts when the Peltier module is implementing in the circuit designing. The demand of voltage and current are causing a lot of trouble and cause the circuit to burn probability is higher. The Arduino Nano also can burn since the voltage and current capacity is too high for it. Once we connected it in wrong way, we need to replace the burn Arduino Nano. Besides, we cannot add any voltage regulator to the circuit connected to the Peltier Module. This is due to the specification of the Peltier Module itself. The rate for working is at least the voltage and current supply is 9V and 1.5A. Thus, if we add a voltage regulator will be caused the lower the current since voltage regulator only allowed 1A to pass through it and make the Peltier Module malfunction. On the other hand, at first the temperature sensor used is LM 35 which is analog types of sensor. But the problem encounter is the sensor cannot read the value correctly. This is because of the voltage demand on the Arduino Nano to the push-button, LCD and LED disturb the signal of the analog sensor. As a replace for solving the problem, a DS18B20 waterproof temperature sensor is used. The benefits of using the sensor are the reading became more accurate than before and the waterproof properties make it easy to measure the water temperature accurately. For the sources, the system needs two different sources which are for the Arduino Nano and the system. This is because when the supply of Li-Ion rechargeable battery cannot be connected directly to the Arduino Nano. A voltage regulator is added to regulate the voltages. When a 7805 voltage regulator is used, the voltage regulator became too hot to be touched same goes to 7809 when it is replaced. The problem is the Li-Ion rechargeable battery capacity is too high and cannot be supported by voltage regulator. A 9V battery is attached differently to the

Arduino Nano to power it up. As the problems have been detected and solved, a complete circuit design managed to be designed and makes the Smart Mug functioning as it behavior that suggested.

4.2 PERFORMANCE OF PELTIER MODULE IN THE SMART MUG

As stated before, the Smart Mug is used a Peltier module as an element for the cooling and heating process in the Smart Mug along with 12V DC Fan and heatsink to increase the efficiency of the Smart Mug. For the testing of Peltier module, experiment was carried out in two phase. For the first phase, we run a heating cycle with a full load of 350ml of water. The initial temperature for the test is 25℃ and targeted temperature is 50℃. As we run the experiment, we managed to record the time taken for the Smart Mug to achieve the target is 45 minutes. The result is as show in Table 4.1 and for a graph is in the Figure 4.1.

Table 4.1: Time Taken for Water Heating Process up to 50℃

Time (Min)	Temperature (°C)
0	25
3	29
6	31
9	34
12	37
15	38
18	40
21	41
24	43
27	44
30	45
33	47
36	48
39	49
42	49
45	50

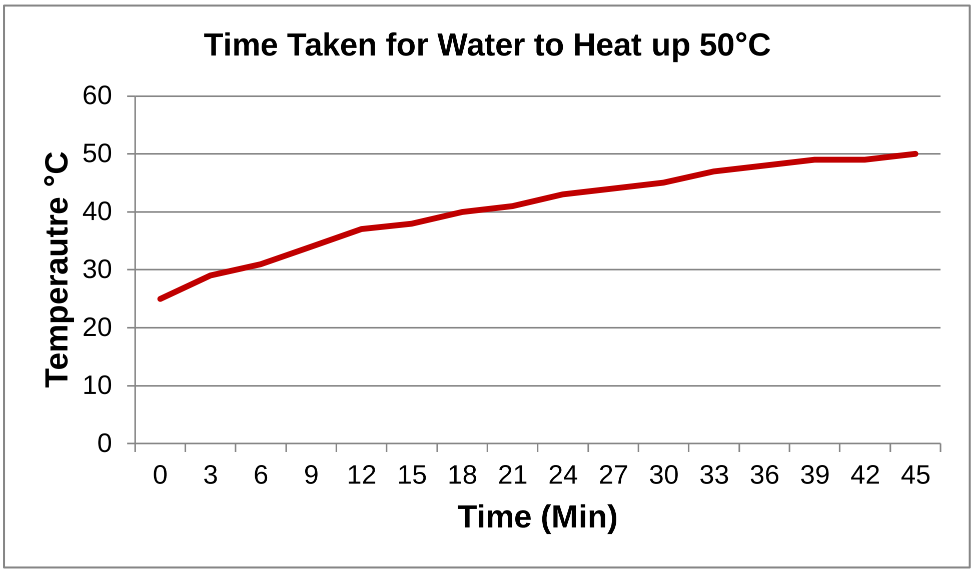

Figure 4.1: Time vs Temperature Graph for Water Heating Process

For second phase, we run a cooling cycle with a full load of 350ml of water. The temperature testing is initial temperature is 30°C and the target temperature is 20°C. After the experiment, the recorded time taken for achieved the targeted temperature is also 45 minutes. The result recorded as been stated in the Table 4.2 and graph in Figure 4.2.

Table 4.2: Time Taken for Water Cooling Process up to 20°C

Time(Min)	Temperature (°C)
0	30
3	30
6	30
9	29
12	28
15	27
18	27
21	26
24	26
27	25
30	24
33	23
36	22
39	22
42	21
45	20

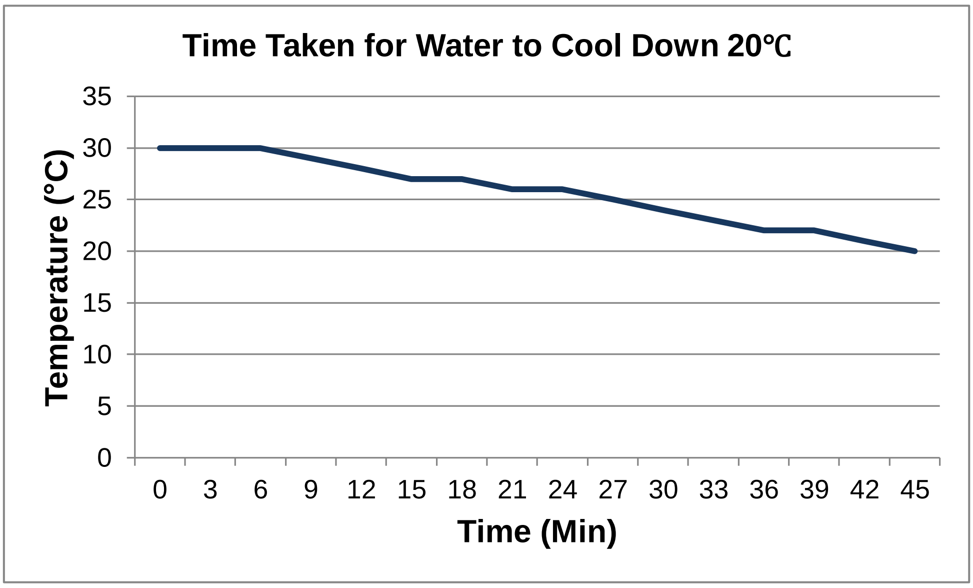

Figure 4.2: Time vs Temperature Graph for Water Heating Process

The tests carried out on Smart Mug with Charging Coaster show that it can function as the way it was designed. It can do the process for heating and cooling of the liquids. The time taken for heating and cooling was about 45 minutes. This result is actually a bit slower than we expected.

4.3 BATTERY LIFESPAN FOR SMART MUG

The main component to make the Smart Mug portable is the battery. The battery acted as the source for the Smart Mug to make it keep functioning although there is no direct supply from the plug. Thus, a rechargeable battery is used as it is can reduces the usage of battery since it can be recharge again. Meanwhile, the battery capacity specification for the Smart Mug is a Li-ion battery with 12V and 2200mAh capacity. Below is the ability of the battery to support the Smart Mug. The result is shown in Table 4.3 below.

Table 4.3: The usage of the Li-Ion rechargeable battery for the Smart Mug

Detail	Result
Time Taken for Battery can be operated without load	2 Hours
Time Taken for the Battery can be operated with Load	1 Hours
Time Taken for one cycle of process	45 Mins
Time Taken for the remaining maintaining process	15 Mins
Time Taken need to be recharged	4 Hours

As we can refer to Table 4.3, the battery only can be used for only one cycle of the heating or cooling process. In addition, after the cycle it only can maintain the water temperature for around 15 minutes before the battery going to be run out of energy. This is because the usage of voltage and current demand is high because of the specification of the thermoelectric module itself needed at least 7V and 1.5A to make it working, and 12V and 2A to make it works efficiently. Besides, the DC 12V fan used for a better flow of air ventilation in the Smart Mug also makes a great impact for the battery drain. Thus, the high demand of power in the Smart Mug is the main cause that the battery cannot perform and support the needs of the Smart Mug. A bigger capacity of power needed to overcome the problems and make the Smart Mug more efficient.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In a nutshell, the planning in term of designing, installing, and choosing electrical parts of the device, we hope that we will successfully designing an ideal Smart Mug that can be useful for people. The Smart Mug, a product that can heat up and cool down the beverages to an ideal temperature according to the user desired. It is also portable for bringing it anywhere the user want because it is attached with rechargeable battery. On the other hand, the coaster that being design to the Smart Mug is for the charging purpose. In addition, this product will be very useful to people especially traveler. It can safe time, energy and also effort on doing things that can make us slowing time the productivity of the daily activity. Besides, when it is developed to the final stage of the product, it will a good way to reduce the usage of the cup for the café or stall since it is more efficient and will not effects a lot to the environment. Moreover, the number of cup that can be reduce will be a high impact to the nature since it can save a lot of tree to be cut and also for polystyrene cup, it will reduce the dumping and destroying the environment. Unfortunate, this current product also has some defects and weaknesses. The Smart Mug cannot conduct a temperature heating and cooling in a better time taken. That means the beverages only can heat up or cool down to the desired temperature in a slow reaction of time. Besides, it also uses a not compatible material and part in fabrication of the Smart Mug. Thus, our recommendations, it is more to increase the efficiency and bring more benefits to the user when the Smart Mug can be developed towards the complete nature of it beginning idea.

5.2 RECOMMENDATIONS FOR THE FUTURE RESEARCH

There are few ways to increase the competency of the Smart Mug to make it compatible in the industrial market. First is to increase the capacity of the battery. We need to find a suitable size and capacity that can cover the usage of the thermoelectric module, DC Fan and also the Arduino Nano. The current power source is not competent enough to run the system of the Smart Mug. Next, we can use a solar panel to generate the sources or Thermoelectric Generator (TEG) to generate the voltage to recharge the battery from the heat source from the thermoelectric module. It can be energy save since we generates electrical for the heat of the nature and no effect the environment and destroy it. Besides that, the current 304 food grade stainless steel is not fast enough to spread the heat towards itself make the reaction and time taken for completing the process becoming slow. Thus, we can use the food grade stainless steel with higher heat transfer to make the heating and cooling to be more effective and reduce the time taken to achieve the targeted temperature. In addition, we also can create a controlling device using a Bluetooth for monitoring the temperature from the smart phone and change it according to the desired temperature. This function will make the user easy to monitor the water temperature and also control it without need to push the button and reduce the time for operating. Lastly, we can change the function of the Smart Mug function from heating or cooling to become as a maintainer of the temperature itself.

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APPENDIX A

CODING FOR SMART MUG WITH CHARGING COASTER

```
#include <OneWire.h>
#include <DallasTemperature.h>
#include<LiquidCrystal.h>
LiquidCrystal lcd(13, 12, 6, 5, 4, 3);
#define ONE_WIRE_BUS 2 // Data wire is plugged into pin 2 on the Arduino
OneWire oneWire(ONE_WIRE_BUS); // Setup a oneWire instance to communicate with any
OneWire devices  // (not just Maxim/Dallas temperature ICs)
DallasTemperature sensors(&oneWire); // Pass our oneWire reference to Dallas Temperature.
int tempc;  //variable to store temperature in degree Celsius
float tempf;  //variable to store temperature in Fahreinheit
float vout;  //temporary variable to hold sensor reading
int count = 20;
int value;
int state = LOW;      // the current state of the output pin
int reading;          // the current reading from the input pin
int previous = HIGH;    // the previous reading from the input pin
void counter();
void systems();
void senseread();

void setup()
{
  pinMode(9, INPUT);
  pinMode(10, INPUT);
  pinMode(11, INPUT);
  pinMode(7, OUTPUT);
  pinMode(8, OUTPUT);
  sensors.begin();
  Serial.begin(9600);
  lcd.begin(16, 2);
  delay(500);
  lcd.setCursor(7, 0);
  lcd.print("Hi");
  lcd.setCursor(3, 1);
  lcd.print("ANEP  IWAN");
  delay(5000);
  lcd.clear();
  delay(500);
  lcd.setCursor(0, 0);
  lcd.print ("Have a Nice day");
  lcd.setCursor(3, 1);
  lcd.print ("with smile :)");
  delay(5000);
  lcd.clear();
  delay(500);
}
```

```
void loop()
{
  senseread();
  delay (100);
  counter();
  reading = digitalRead(9);

  // if the input just went from LOW and HIGH and we've waited long enough
  // to ignore any noise on the circuit, toggle the output pin and remember
  // the time
  if (reading == HIGH && previous == LOW)
  {
    if (state == HIGH)
    {
      state = LOW;
    }
    else
    {
      state = HIGH;
    }
  }
  previous = reading;
  systems();
}

void senseread()
{
  // call sensors.requestTemperatures() to issue a global temperature
  // request to all devices on the bus
  Serial.print(" Requesting temperatures...");
  sensors.requestTemperatures(); // Send the command to get temperatures
  Serial.println("DONE");
  Serial.print("Temperature is: ");
  Serial.print(sensors.getTempCByIndex(0)); // Why "byIndex"?
  // You can have more than one IC on the same bus.
  // 0 refers to the first IC on the wire
  lcd.setCursor(0, 0);
  lcd.print("Temp(degreeC) ");
  lcd.print(sensors.getTempCByIndex(0));
  delay(100); //Delay of 1 second for ease of viewing in serial monitor
}

void counter()
{
  lcd.setCursor(7, 1);
  lcd.print(count);
  delay(200);
  value = counter;
```

```
  if (digitalRead(10) == HIGH)
  {
    value = ++count;
    lcd.setCursor(7, 1);
    lcd.print(value);
    delay(100);
    while (digitalRead(10) == HIGH);
  }
  else if (digitalRead(11) == HIGH)
  {
    value = --count;
    lcd.setCursor(7, 1);
    lcd.print(value);
    delay(100);
    while (digitalRead (11) == HIGH);
  }
  else
  {
    value = count;
  }

  if (count < 20)
  {
    count = 70;
    value = count;
  }

  else if (count > 70)
  {
    count = 20;
    value = count;
  }
}

void systems()
{
  if (state)
    if (value < sensors.getTempCByIndex(0))
    {
      digitalWrite(7, HIGH);
      digitalWrite(8, LOW);
    }
    else if (value > sensors.getTempCByIndex(0))
    {
      digitalWrite(7, LOW);
      digitalWrite(8, HIGH);

    }
    else
    {
```

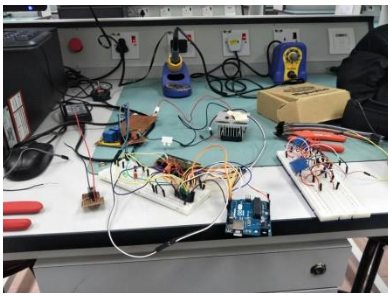
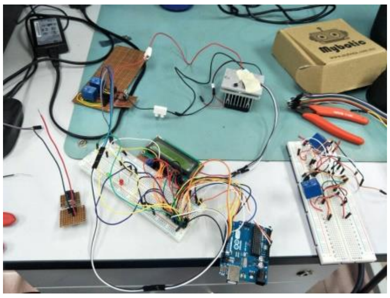
```
      digitalWrite(7, LOW);
      digitalWrite(8, LOW);
    }
  else
  {
    digitalWrite(7, LOW);
    digitalWrite(8, LOW);
  }
}
```

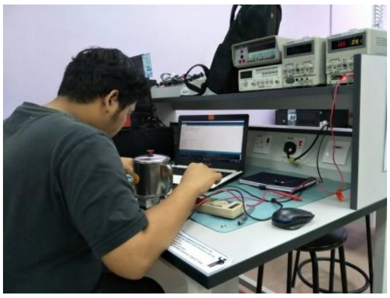
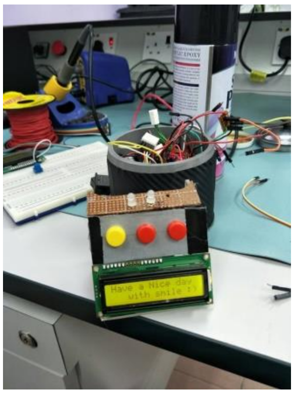
APPENDIX B
COST ANALYSIS

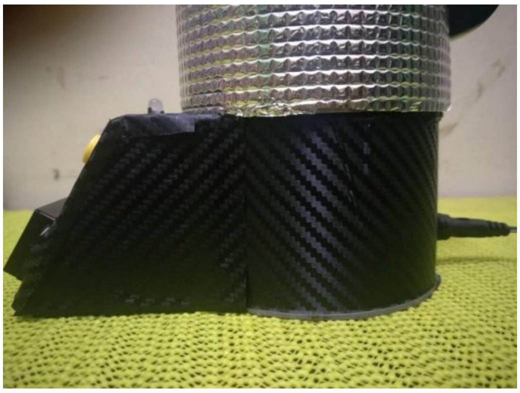
Bil	Name	No. of Unit	Cost per Unit (RM)	Total cost (RM)
1.	Arduino Nano 3.0	1	40.00	40.00
2.	Li-ion Battery	2	70.00	140.00
3.	DPDT switch	1	4.40	4.40
4.	Relay	2	2.20	4.40
5.	Temperature Sensor	1	2.05	2.05
6.	Transistor	2	0.05	0.10
7.	Resistor	10	0.05	0.50
8.	Potentiometer	1	0.90	0.90
9.	Voltage Regulator	1	0.30	0.30
10.	RGB LED	2	0.35	0.70
11.	LCD	1	12.00	12.00
12.	Peltier Chip	1	80.00	80.00
13.	AC to DC converter	1	28.00	28.00
Total Cost for Electrical Part				313.35

Electrical and Electronic Component Cost

APPENDIX C
CIRCUIT AND PROJECT PRODUCTION

APPENDIX D

DS18B20 WATERPROOF TEMPERATURE SENSOR DATASHEET

Waterproof DS18B20 Digital Temperature Sensor (SKU:DFR0198)

Contents

Introduction

This is a waterproofed version of the **DS18B20 Arduino Temperature sensor**. Handy for when you need to measure something far away, or in wet conditions. While the sensor is good up to 125℃ the cable is jacketed in PVC so we suggest keeping it under 100℃. Because they are digital, you don't get any signal degradation even over long distances! The DS18B20 provides 9 to 12-bit (configurable) temperature readings over a 1-Wire interface, so that only one wire (and ground) needs to be connected from a central microprocessor.Usable with 3.0-5.5V systems.
Because each DS18B20 contains a unique silicon serial number, multiple DS18B20s can exist on the same 1-Wire bus. This allows for placing temperature sensors in many different places. Applications where this feature is useful include HVAC environmental controls, sensing temperatures inside buildings,equipment or machinery, and process monitoring and control.

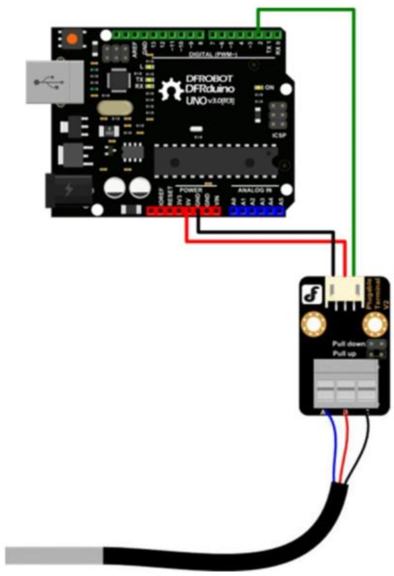
Specification

- Usable with 3.0V to 5.5V power/data
- ±0.5℃ Accuracy from -10℃ to +85℃
- Usable temperature range: -55 to 125℃ (-67°F to +257°F)
- 9 to 12 bit selectable resolution
- Uses 1-Wire interface- requires only one digital pin for communication
- Unique 64 bit ID burned into chip
- Multiple sensors can share one pin
- Temperature-limit alarm system
- Query time is less than 750ms
- 3 wires interface:
  Red wire - VCC
  Black wire - GND
  Yellow wire - DATA

- Stainless steel tube 6mm diameter by 35mm long
- Cable diameter: 4mm
- Length: 90cm

Sensor Connection

This sensor requires a 4.7K Ohm resistor between the voltage and Signal pin. as seen in the picture below. Optionally you can use a Plugable Terminal sensor adapter to help in making this connection secure.



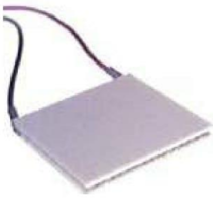
APPENDIX E
TEC12706 DATASHEET

Thermoelectric Cooler

TEC1-12706

Performance Specifications

Hot Side Temperature (º C)	25º C	50º C
Qmax (Watts)	50	57
Delta Tmax (º C)	66	75
Imax (Amps)	6.4	6.4
Vmax (Volts)	14.4	16.4
Module Resistance (Ohms)	1.98	2.30



Performance curves on page 2

 Rev 2.03

TEC1-12706