Thermal Regulation in Active Temperature Sensor (July 9, 2021)

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***Abstract*—The active temperature sensor we plan to create will be able to do thermal regulation by using PID control which will adjust the power output applied to the system based on the temperature change the heater experiences to maintain a constant desired temperature. This adjustment to keep a constant temperature in a way that makes the current or voltage the same before and after is called the 'Null Mechanism'. The measurement of temperature can therefore be done by measuring the change in current or voltage.**

***Index Terms*—Active Temperature Sensor, PID control, Thermal Regulation**

I. Introduction

Active Temperature Sensor is a circuit system where the sensor learns to maintain its temperature from its environment that can cause temperature changes through thermal regulation. It learns to do so by automatically adjusting its current value based on the temperature change. If a current or voltage change is detected through the circuit, that means a thermal difference on the heater has occurred. This adjustment of the current to keep a constant temperature in a way that makes the current or voltage the same before and after is called the 'Null Mechanism'. The change in current or voltage can then be used to measure the temperature.

The circuit we plan to create will use a PID (Proportional Integral Derivative) controller which uses a control loop feedback mechanism to regulate the process variables. It is also known to be the most precise and stable controller.

The PID controller will gather the feedback of the real temperature measurement of the system and a setpoint will be set on the arduino for our desired temperature. If there is a temperature difference between the desired temperature and feedback from the output, the system will detect it and that's when we use PID control to change the output according to the feedback. The PID control will regulate the power applied to the system based on the temperature difference the heater experiences, if the temperature feedback is higher than our desired temperature the power input will be decreased and vice versa, if the temperature feedback is less, the power input will be increased.

II. Equipments Used

A. MOSFET IRLZ44N

MOSFET has four terminals (source, gate, drain, body) and it is commonly used for switching or amplifying electric signals in electronic devices. It adjusts the current flow between the source and drain terminals to produce the designated power by varying the width of the channel that the electrons flow through. The width of the channel is controlled by the voltage on an electrode between the source and drain terminals.

IRLZ44N is a type of mosfet that has a low gate voltage of 5V, this makes the mosfet can be turned on with only 5V in its gate pin. As it has a low gate voltage, it can be turned on directly with a microcontroller like Arduino without additional driver circuit.[1]

B. Nichrome Wire

Electrical devices commonly use a safety fuse to limit the electric current that flows through it to make it more durable. The fuse wire that is used is a conductor as it can easily conduct electric current. Some common materials used for fuse wire are copper and nichrome wire. However, studies show that nichrome wire has a better quality in sense of resistivity and melting point. Where the nichrome wire has a resistivity of $100\ 10^{-8}\ \Omega m$and a melting point of$1672°C$, and as for copper, it has a resistivity of $1.68\ 10^{-8}\Omega m$and a melting point of $1083°C$.[2] This shows that nichrome wire is a better material as it has a higher resistivity and it will not break at a higher temperature.

C. Current Sensor (ACS712)

Current sensors are devices that use magnetic fields to measure current and generate a proportional output. The current that flows through a conductor will create a proportional magnetic field around it. This magnetic field will be used to measure the current flow.

ACS712 is a hall effect-based linear current sensor with 2.1kVRMS voltage isolation and an integrated low-resistance current conductor. It uses its conductor to calculate and measure the amount of current applied. When current flows through the hall sensor in its IC, the hall effect sensor will detect the current through its magnetic field generation. After that, the sensor will generate voltage that is proportional to its magnetic field which will be used to measure the amount of current.[3]

D. K-Type Thermocouple

K-Type Thermocouples have a Chromel positive leg and an Alumel negative leg and are used to measure the temperature of its surroundings. It can be used as a surface sensor, immersion sensor, wire or other types of sensors or cables.

Type K wires commonly have two color-codes. Yellow connectors and occasionally red connectors as well per ANSI/ASTM E230 or green connectors and occasionally white connectors as well per IEC 60584.[4]

E. MAX6675

The MAX6675 carries out cold-junction compensation and converts signals from K-type thermocouples. It resolves temperatures to 0.25°C and can read temperatures as high as +1024°C. It displays thermocouple accuracy of 8 LSBs for temperatures ranging from 0°C to +700°C.[5]

III. Flow Diagrams

A. Algorithm Flow Diagram

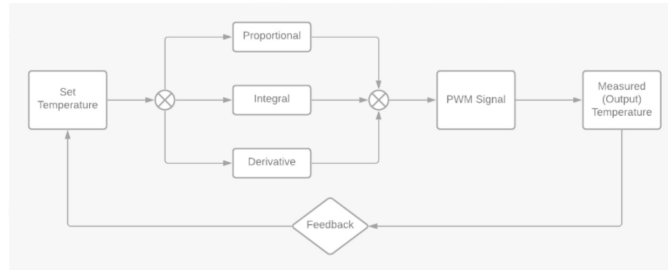

Figure 3.1 PID Control Algorithm Flow Diagram

PID Control, or Proportional -Integral-Derivative Control is one of the most widely used control algorithms in many process industries. This is due to the fact that it is a highly effective control algorithm, despite having simple mechanisms and ease of implementation by manufacturers.[6]

In a control system, a sensor would measure the process variable, or the parameter to be controlled, like temperature or pressure, which in the case of this project, would be a heater to detect a change in process variable, the temperature. Furthermore, a set value is usually determined in a control system and the set value will be the basis of comparison, where the difference or the error between the process variable and set value is calculated continuously by the control system to provide an output close or equal to the set value.[7] For example, if the heater was set to a constant temperature of 30oC, and an external heat is applied to the heater, like touching the heater with a person's hands, the initial response of the system would be to increase the temperature due to the heat from the hands. However, due to the PID control, there would be feedback through the difference between the output process value and the set value and it would adjust itself through controlling the current or voltage so that the output value would be made close to the set value. This regulation of current and voltage is particularly important as the changes in current or voltage can be used to measure the temperature of the object, under the principle of the Null Mechanism.

The three smaller controls that make up the larger PID control are the Proportional, Integral and Derivative controls, each having different mechanisms, and when combined, can produce an output value that is equivalent to the set value. The Proportional control is dependent only on the error or the difference between the process variable and the set value. It is determined by the proportional constant, Kc. The higher the constant, the larger the oscillation of the output value, thus making the system unstable. The Integral control sums the error calculated over a period of time, therefore, the smaller the error, the more gentle the slopes of the graph approaching steady-state, leading to a more desired output. The Integral Time Constant, Ti, controls the sum of error over time. The Derivative control influences the output based on the rate at which the process variable changes. The Derivative Time Constant, Td, helps in determining this rate.[8]

Due to the different constants, a part of the project's main goal is to determine the suitable constants. This can be done through trial and error, which can be done by setting Ti and Td to 0, and slowly increase Kc until the output oscillates. Once it oscillates, the Ti can be increased to reduce the oscillation and thus reduce the steady state error. The Td can then be increased to increase the rate at which the output becomes equivalent to the set value.[9]

B. Circuit Flow Diagram

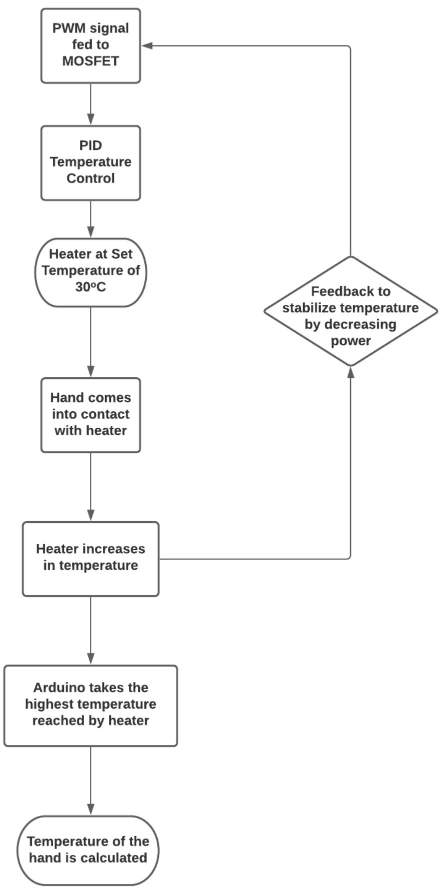

Figure 3.2 Circuit Flow Diagram

The circuit is mainly controlled through the PID control, where it will maintain the temperature of the heater at 30ºC. Initially, through PID control, the heater's temperature was increased up to 30ºC from room temperature. The detection of this temperature was done using the K-Type Thermocouple. When an object is placed onto the heater, which in the case of this project would be the hand touching the nichrome wire, the heater's temperature would increase because the temperature of the heater was set in a way that it would be colder than the hand's temperature. This temperature is constantly being read from the K-Type Thermocouple. The highest temperature that could be reached by the heater due to the hand's warmth recorded by the thermocouple would be subtracted from the setpoint value. This value would then be put into a linearized equation which will be further explained and discussed in the results and discussion section, and the value calculated would be the approximate temperature of the hand, and thus the temperature. Once the hand is released, the PID control will function in a way that it feedbacks to the PWM signal in order to decrease the PWM value, thus the power supplied to the heater, which therefore decreases it back to 30ºC, thus performing thermal regulation.

IV. Codes and Circuit Diagram

A. Codes

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27,20,4);

//thermocouple
#include <max6675.h>

int MAX6675_CS = 10;
int MAX6675_SO = 12;
int MAX6675_SCK = 13;

MAX6675 ktc(MAX6675_SCK, MAX6675_CS, MAX6675_SO);

//pid
#include <PID_v1.h>

//Pins
int PWM_pin = 3;

//Variables
#define SAMPLETIME 500
double Setpoint, currentTemp, Output, Voltage, Current, bodyTemp, rangeTemp, largest;
const unsigned int numReadings = 10;
double tempVal[numReadings];

PID myPID(&currentTemp, &Output, &Setpoint, 230, 0.9, 0 , DIRECT);

 void setup() {
   Serial.begin(9600);
   pinMode(PWM_pin,OUTPUT);
   currentTemp = ktc.readCelsius();
   Setpoint = 30;
   myPID.SetMode(AUTOMATIC);
   myPID.SetSampleTime(SAMPLETIME);
   lcd.init();
   lcd.backlight();
 }
```

```
void loop() {
  //Temperature Reading
  currentTemp = ktc.readCelsius();
  //Convert PWM to Current Reading
  Voltage = (Output/255)*10;
  Current = (Voltage/13)*1000;

  //Active Temperature Sensing
  if (currentTemp > (Setpoint+0.25))
  {
    for (int i = 0; i <= (numReadings-1); i++)
    {
      tempVal[i] = ktc.readCelsius();
      delay(500);
      if (tempVal[i] > largest)
      {
        largest = tempVal[i];
      }
      rangeTemp = largest - Setpoint;
      bodyTemp = (rangeTemp*1.12) + 34.2;
    }
  }
  //

  myPID.Compute();
  analogWrite(PWM_pin, Output);
  Serial.println(currentTemp);
  delay(SAMPLETIME);

  lcd.setCursor(0, 0);
  lcd.print("S:");
  lcd.setCursor(2, 0);
  lcd.print(Setpoint);

  lcd.setCursor(9, 0);
  lcd.print("C:");
  lcd.setCursor(11, 0);
  lcd.print(Current);

  lcd.setCursor(0, 1);
  lcd.print("T:");
  lcd.setCursor(2, 1);
  lcd.print(currentTemp);

  lcd.setCursor(9, 1);
  lcd.print("B:");
  lcd.setCursor(11, 1);
  lcd.print(bodyTemp);
}
```

B. Circuit Diagram

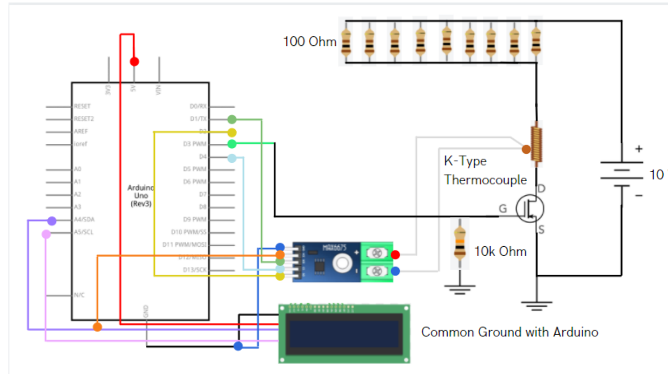

Figure 4.1 Project Circuit Diagram

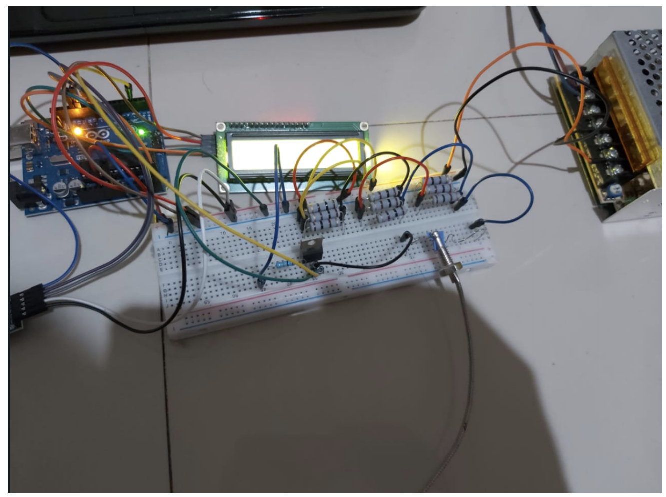

Figure 4.2 Circuit on Breadboard

V. Results and Discussion

V.1 Thermal Regulation through PID Control

Thermal regulation was able to be successfully performed through PID control. However, because the system does not involve a rapidly changing environment, the derivative control would not be of much use for this particular implementation. Therefore, the project is solely focused on PI control. The proportional gain was set to 230 and the integral gain was set to 0.9. The proportional gain was set to a high value due to the fact that the system requires the PWM signal to be set to a high value initially to increase the temperature of the heater, thus a lower proportional gain would increase the time taken to increase the temperature. The integral gain does not necessarily need to be set to a high value as it only calculates the summation of all previous errors. With the PI values set, it was found that the offset was only 0.25, where it fluctuates between 29.75ºC to 30ºC, which is very satisfactory.

V.2 Active Temperature Sensing

First and foremost, it was found that nichrome is not a suitable active temperature sensing device. By definition of active temperature sensing, it requires a very noticeable change in current or voltage when heat is applied to it. If, for example, the current increases, the system has to decrease the voltage, so that the current goes back to normal. How much the voltage is decreased can then be used to calculate the temperature that heats the heater. The problem with the nichrome wire is that it was found through testing that it has a very small and negligible change in resistance, thus a very little to no change in current when temperature is increased or decreased. This is very disadvantageous for measuring the body temperature and thus, the basic understanding of active temperature sensing cannot be fully implemented in the project. Therefore, another method is proposed to counter the problem.

Firstly, because there is virtually no change in resistance or current from the nichrome wire due to the temperature change, therefore, the temperature change itself can be depended on. The algorithm proposed is that once the temperature of the heater recorded by the thermocouple increases above 30.25 (due to the offset being between 29.75 to 30.25) when the hand is placed, an array would be made which consists of all the readings of the thermocouple. Within this array, the Arduino will constantly look for the highest temperature recorded, and once it is found, it will calculate the range, which is the highest temperature subtracted with the setpoint temperature. This value is then put into a linearized equation. It may take up to around 2 minutes to obtain an accurate temperature.

The linearized equation was achieved by first measuring the hand (body) temperature using a thermometer then, after the nichrome wire has reached a stable temperature (30°C), the hand was placed on to the wire for 2 minutes and the largest change (range) in nichrome wire temperature was recorded. After that, these processes were repeated 10 times and a linearised graph was made, shown in Figure 5.1.

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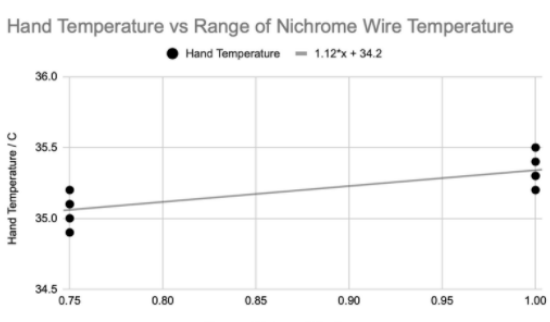

Equation for the relationship between range of nichrome wire temperature and hand temperature:

$$T = 1.12x + 34.2$$

Figure 5.1 Hand Temperature vs Range of Nichrome Wire Temperature

The equation will then be achieved by using a scattered line function to make the most accurate equation. After the equation was made, the temperature was able to be calculated through a linearised equation between real hand temperature and the range of the nichrome wire temperature when the hand is placed.

V.3 Precision and Range of the Reading

The following table shows the different temperatures tested done using a body thermometer to obtain the graph shown in Figure 5.1, along with the highest change in temperature of the nichrome wire and the equivalent temperature reading calculated with the linearized equation

Table 5.1 Different Temperatures Measured and the Calculated Equivalent

Hand Temperature (Body Thermometer Reading) / °C	Highest Change / °C	Hand Temperature (Calculated Reading) / °C
34.9	0.75	35.04
35	0.75	35.04
35.1	0.75	35.04
35.1	0.75	35.04
35.2	1	35.32
35.2	0.75	35.04
35.3	1	35.32
35.3	1	35.32
35.4	1	35.32
35.5	1	35.32

As for now, due to the lack of suitable temperature measuring equipment, only the body temperature range can be tested. Cases of hypothermia (33-34°C) and hyperthermia (39-41°C) still cannot be accurately conducted unless a more suitable equipment of measurement is used. As for the range of body temperature, the device has a range of 0.28°C, and a precision of 35.18°C ± 0.28°C.

VI. Suggestions

After the final milestone, it was found that PID was successfully implemented to thermally regulate the nichrome wire temperature at 30°C, with an offset of 0.25°C, where it tends to fluctuate between 29.75°C to

30.25ºC. The temperature sensing was found to have a precision of 35.18ºC ± 0.28ºC, which is only in the range of normal body temperature. Due to limited suitable and accurate measuring instruments, ranges from hypothermia up to hyperthermia was still not able to be implemented. It was also found that nichrome wire is not a suitable heater to be used for active temperature sensing. Therefore, another more suitable heater must be used. Once this heater is found, the K-Type Thermocouple may be disregarded as the current reading can now be read using a current sensor and can be used to calculate the temperature.

VII. References

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