Design and Implementation of a Thermal-Based Exploration Mobile Robot

Jay Robert B. Del Rosario,* Benjamin Emmanuel F. Tamonte, John Michael M. Ligan, Lyndon Vincent L. Ang, Darren Justin B. Cruz, and Chong We D. Tan

***Abstract* — Inaccurate control of the industrial thermal processes occurs when there is no operator involvement in monitoring temperature set points. This document will examine the specifics of a temperature controlled mobile robot (MoBot) with the use of PIC16F877A microcontroller and LM 35 as the temperature sensor for the input feed data. The project is primarily about acquiring the temperature measured by the sensor to determine the state and the speed of the mobile robot. The amount of temperature will dictate the state and the duty cycle of the mobile robot. Results show that the accuracy of the temperature sensor utilized in the project ended to 98.31% and the MoBot was able to work properly in different PWM values as triggered by the data from LM35.**

Keywords: **temperature, duty cycle, microcontroller, LM35 temperature sensor, mobile robot**

I. Introduction

A control system is basically a group of interconnected components that regulates and manages the actions or performance of a device or other systems. A control system was conceptualized to pave way for the increasing demand in efficiency, practicality, and convenience [1].

In the same manner, temperature-controlled devices were created for the efficiency, practicality, and convenience that they serve.

Applying the concept of a control system to our project led the group to the design and application of a temperature-controlled mobile robot (MoBot). Instead of the regular schemes wherein the power supplied to the MoBot is controlled by a simple off or on switch, the state and the duty cycle of the group's MoBot will be dependent and proportional to the input given by the LM35 temperature sensor.

The group's primary intent is essentially to design and create a temperature-controlled MoBot that would be able to vary in state and duty cycle depending on the temperature input provided by the sensor. Along with these objectives, the group would like to set upper and lower temperature bounds for the MoBot to work in.

The aim of the project is to work only in normal or room temperature conditions with variations of up to 5°C. This is to show the state and duty cycle of the MoBot in normal conditions and minimal temperature changes.

The MoBot's goal is to move away from places that have spiking temperature and anything that is connected to it. Most of the devices that are created require a certain temperature to operate and maintain its condition, though there are times that changing temperature is inevitable. One simple solution to this problem is to apply this MoBot or attach it to the devices. Once there is a spike in temperature, the MoBot is tasked to move away from that place and stop in a place that has its desirable temperature. Though the MoBot that we have created is just small with a direct current motor that is working only at 5 V, it could be attached to big devices and heavy components and be scaled up for heavier purposes.

Another application of the MoBot is for it to act like a heat sink. Instead of placing a wheel into the motors, it could be replaced with a fan that could dissipate heat. It could be placed in front or on top of the device that is overheating. This is an energy-conserving tool because it is not all the time that the device is overheating and needs to be cooled [2]. The PIC16F877A we have used in this project is programmed to operate only at a certain temperature.

If the desired temperature is met, it is programmed to stay idle and wait until the temperature changes so that the component could not operate anymore.

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II. Review of Related Literature

In an article entitled "Mobile Robot Temperature Sensing Application via Bluetooth," an LM 35 was also used in the acquisition of temperature data. According to the article, "ADC is used to convert the analog value from LM35z to 10 bits digital value." It also stated in the article that the acquired temperature value has a low error percentage [3]. Hence, the LM 35 is a very reliable temperature sensor.

A thesis paper from De La Salle University titled "Implementation of a Portable Automobile Exhaust Emission Analyzer" is about solving the problem of emission in our environment. The group who made the thesis aimed to create a device that would measure the emission of each vehicle so that the driver could gauge the emission of the car that he or she is using [4].

The group first connected the following things to create their device. The group members used the type T thermocouple of sensor that is connected to the analog-to-digital converter to monitor the oil temperature and whether the oil temperature is reaching 70°C. The temperature is proportional to the increase of the resistance in the sensor. The group connected it to a voltage divided and a comparator circuit using the LM741 operational amplifier.

The members of the group did many experiments that concluded that when the T thermocouple sensor detected that the oil temperature is 70°C, the corresponding resistance is 6.7 ohms.

So that the device could be used anytime and anywhere, the power supply connected to the device is the car battery. The device needs the car battery because the two devices need a lot of current that could easily drain the primary battery cell. The primary cell is connected to the PP3 9-V radio battery. The battery is used to satisfy the voltage required to power the voltage regulators [4].

The purpose of using an emission tester is to have data and to assess the acceptable values in the emission of the car; the car varies with two types of engine, namely, the gas engine and the diesel engine. Of course, the diesel engine has a higher tolerance for CO_2 emissions. There is also a classification on what year the engine's car is manufactured; older engines have a higher level of CO_2 emissions compared to those that are made in 1997 onwards. For gasoline engines, CO_2 emissions should be only 3.5% in volume for cars made in 1997 onwards and 4.5% in volume for cars made before that time. This paper is quite relevant to us as it also used a sensor and a programming component that determines the acceptable carbon dioxide emission of a vehicle and the device determines if the engine passed or not [4].

Another relevant paper is entitled "Robotic Arm Rehabilitation With Biofeedback for Filipino Stroke Patients." This paper states that the sensor used to take body temperature of patients is a thermistor, used to properly measure and compare variations of temperature measurements [5].

The thesis utilized a Z8-Encore microcontroller to control the motor with respect to the current state of the inputs as well as converting the measured analog temperature from the thermistor sensor to 10-bit binary number.

This thesis has similarities to our project because it also has a temperature-triggering device. The temperature determines the movement of the robotic arm. This group applied this concept in treating and aiding Filipino people who are suffering from stroke or whom we call stroke patients.

The difference of our project is instead of a moving robot that looks like a car, the thesis paper used a robotic arm that would move depending on the temperature recorded by the sensor. Another difference is this thesis has better devices that could help the society.

This thesis uses a robotic arm to conduct and motivate stroke patients to conduct different activities and to move around. The robotic arm also gathers information through the doctor's data and through real-time biofeedback. It also conducts its own evaluation on the patient's reaction and the patient's condition.

The paper "Global Fan Speed Control Considering Non-Ideal Temperature Measurements in Enterprise Servers" [6] describes that the function of a motor is somewhat similar to that of ours. It also shows a circuit that changes the speed of a fan, automatically and linearly, depending on the room temperature. The paper also states that the circuit shown has a high sensitivity and that the output RMS voltage can be changed from 120 V to 230 V. This entails a temperature range change from 22°C to 36°C. Therefore, this means a significant difference in speed is available. Another thing pointed out was that the change in speed varies linearly, not in steps.

Another article that we found related to the topic we proposed was entitled "Temperature Based DC Motor Speed" by Gary Royston George [7]. The article had the same idea as ours. It made use of an analog temperature sensor to determine the temperature that will control the speed of the motor. It was also said in the article that the microcontroller would create a pulsed width modulated (PWM) signal, which has changing duty cycles that are based on the temperature reading, and use that reading to change and vary the speed of the motor.

According to the article "Real Time Speed Control of a DC Motor by Temperature Variation Using LabVIEW and Arduino" [8], the use of DC fans has become widespread. These motors are used primarily in industries specifically for cooling in electronics, communication system, and other useful applications. Some DC fans allow for large

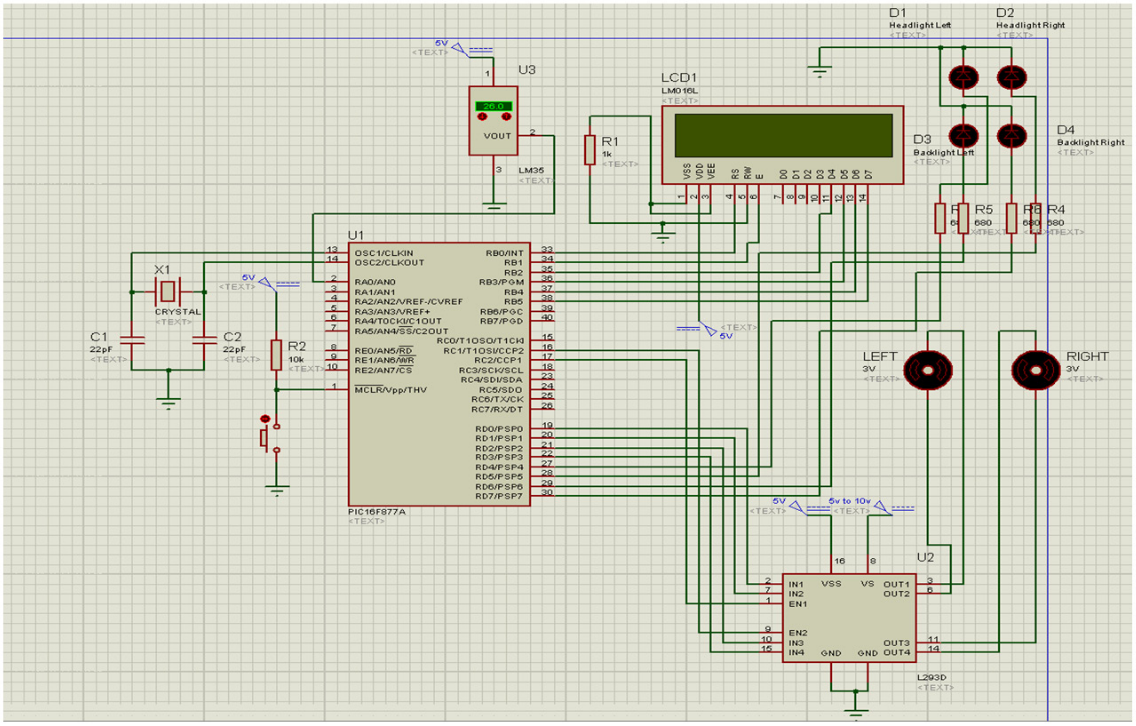

Fig. 1. Overall circuit diagram of the thermal-based exploration MoBot.

voltage-dependent speed variations, making them very popular where air moving noise or power consumption considerations are important.

According to the paper "A Novel Microcontroller-Based Sensor Less Brushless DC (BLDC) Motor Drive for Automotive Fuel Pumps" [9], PWM may be employed to vary the effective voltage in the armature of the motor. Pulse width modulation is simply controlled by short pulses of voltage or current. A pulse variation of pulses also varies the torque that a motor produces thus adjusting the speed or duty cycle of a motor.

III. Design and Application

To fundamentally implement the project, the group utilized a PIC16F877A as its main microcontroller. The group chose this microcontroller due to the number of I/O ports provided by this microcontroller that will suffice for the needed input and output components [10] and the ADC requirements of the project. Along with this microcontroller is a temperature sensor (LM35), 16 × 2 Alphanumeric LCD (LM016D), and H bridge motor drivers. The initial hardware implementation was done in a breadboard, and the final product, on a universal printed circuit board. Figure 1 shows the circuit diagram of the entire project.

A. LM 35—Precision Centigrade Temperature Sensors

The LM 35 is a precision centigrade temperature sensor that produces output voltages linearly proportional to the change in centigrade temperature. LM 35 can precisely sense temperature ranging from −55°C to 150°C. The LM 35 output voltage is approximately 10 mV per degree centigrade. As shown in Figure 2, the sensor should be supplied a minimum of 4 V and can potentially accept up to a maximum of 20 V [11].

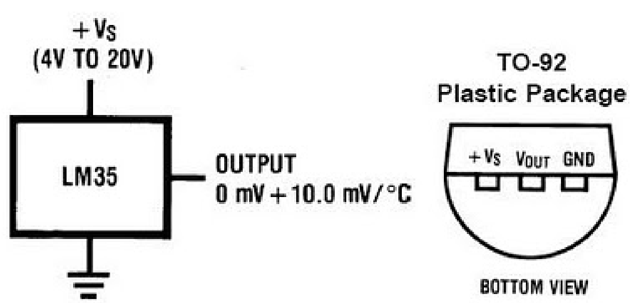

Fig. 2. Schematic diagram of temperature sensor [11].

The basic implementation of the LM 35 is to be placed across the body of the MoBot, preferably at a point where there is no interference with the sensor for accurate measurement of temperature [12][13]. The sensor is then fed or connected to RA0 of Port A for the built-in analog-to-digital converter of the microcontroller. The group essentially aims to limit or set the bounds of the temperature for the MoBot to work in. The group ideally aims to work only on room temperature conditions ranging from 25°C to 35°C.

The group will also make the MoBot very sensitive as possible to show the performance of the MoBot in minimal temperature changes.

The measured temperature shall then be displayed into an LCD along with its corresponding voltage.

B. LM016L—16 × 2 Alphanumeric LCD

To accurately discern the voltage produced by the LM35 and to properly display the state and duty cycle of the MoBot, an LCD will be used to display the temperature measured by the sensor. The group used a 16 × 2 Alphanumeric LCD to properly and accurately display the produced parameters [14].

C. L293D—H Bridge Motor Driver and Pulse Width Modulation

L293D is basically an integrated circuit used to drive components that have inductive loads such as DC and stepping motors. Relying on the output voltage produced by the microcontroller will not be sufficient to drive a DC motor [15]. The L293D will also use to implement the phase width modulation of the MoBot. Pulse width modulation is basically a modulation technique that varies the width of a pulse to control the power supplied to electrical devices, especially to devices with inertial loads such as motors.

To implement the PWM of the MoBot, the group declared certain ranges of temperatures with their corresponding ranges of voltage readings to a certain PWM value. Given a temperature range of 25°C to 30°C, the group can set these temperatures to their corresponding PWM values. Say, 25°C to 26°C has a PWM of 0 (stop), 27°C to 28°C has a PWM of 128 (mid speed), and lastly a 29°C to 30°C has a PWM reading of 255 (max speed). Therefore, it is very crucial to determine the bounds or the limits that the group's MoBot can work in.

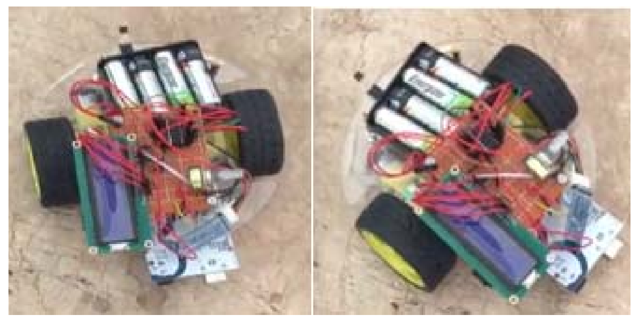

Fig. 3. Actual prototype of the MoBot.

IV. Results and Discussion

The actual temperature of the model environment was measured for 10 trials by the mercury-type thermometer and compared with the LM35 sensor to compute for the accuracy. The LCD specified the numerical value of the temperature. Varying temperature values were set at the set point temperature. Results are tabulated as shown in Table I.

TABLE I
Temperature Sensor Accuracy

Trial No.	Set Point (°C)	Mercury Thermometer	Digital Thermometer (LM 35)	Error	% Error
1	10	10	10.1	0.1	1.00
2	15	15	15.6	0.6	4.00
3	20	20	20.9	0.9	4.50
4	25	25	25.4	0.4	1.60
5	30	30	30.5	0.5	1.67
6	35	35	35.2	0.2	0.57
7	40	40	40.1	0.1	0.25
8	45	45	45.3	0.3	0.67
9	50	50	50.6	0.6	1.20
10	55	55	55.8	0.8	1.45

Hence, from the above configuration, the total percentage error is at 1.69% and the temperature sensor accuracy of the LM35 is at 98.31%. As seen in Figure 4, the result was satisfactory.

Testing methods should also be considered in the implementation of the project. The group used a hairdryer and a pack of ice to vary the temperature measured by the sensor for demonstration purposes. Relying on normal temperatures or outside temperature without means of controlling the measured temperature can or most likely exhibit errors.

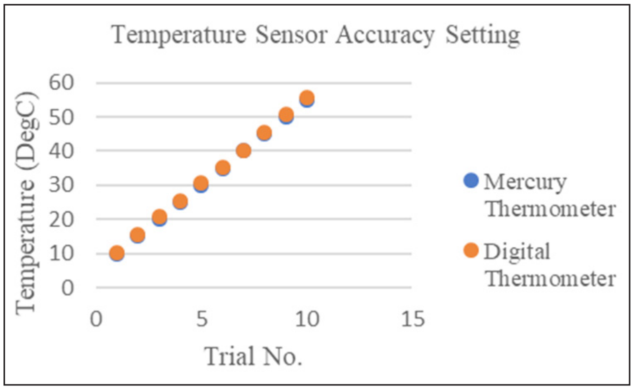

Fig. 4. Graph for temperature sensor accuracy test.

The temperature-based MoBot was able to work properly and was able to drive and vary the speed of the motor based on the temperature that it got from the sensor as seen in Table II. There are other ways to drive a motor based on temperature, one of which is using a thermistor, but we resorted to using a temperature sensor instead for we think it is accurate enough to give us the correct readings needed. The program used was self-made and is working properly.

TABLE II
Motor Speed Controller Through PWM Values

Trial No.	Set Point (°C)	LM 35	PWM	MOBOT Action
1	10	10.1	0	Stop
2	15	15.6	0	Stop
3	20	20.9	0	Stop
4	25	25.4	128	Clockwise
5	30	30.5	128	Clockwise
6	35	35.2	128	Counter-clockwise
7	40	40.1	255	Forward
8	45	45.3	255	Forward
9	50	50.6	255	Forward
10	55	55.8	255	Forward

TABLE III
MoBoT Decision Table

Temperature (°C)	Left Wheel	Right Wheel	Action
0–24.9	0	0	Stop
25.0–30.9	0	1	Turn clockwise
31.0–35.9	1	0	Turn counter-clockwise
36.0–above	1	1	Move forward

Based on the given MoBot decision table from Table III, Table II shows the corresponding PWM and sample movement of the MoBot.

Table III shows the sample movement of the MoBot and its corresponding temperature ranges. Sample MoBot action shows that the system can act depending on the temperature of the prescribed environment.

V. Conclusion

Students or simply enthusiasts of making MoBots should also consider making a temperature-controlled MoBot. In making this type of project, temperature sensitivity, testing methods, MoBot maneuvering, and chassis specifications should be carefully considered.

To accurately and coherently display the state of the MoBot, the temperature bounds must be accurately specified. Because of limited control over a certain range of temperature, the range of temperature that the MoBot can work in should also be limited.

The weight of the MoBot chassis must also be considered in the making of this project. Always consider if the motor can successfully drive the MoBot and display several values of its duty cycle.

In addition, the group knows that the MoBot is very limited in terms of its maneuvering capabilities. Further improvements can make the MoBot go left or right or even avoid obstacles to avoid being stuck in collision.

The MoBot was also able to move forward and backward and stayed stationary in varying speeds, depending on the temperature that the sensor gathered.

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