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Efficient Temperature Regulation: An Arduino-PID Approach to Peltier Water Cooling

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***Abstract*— This paper elaborates on the implementation of a water cooling system that utilizes a control system, central to which is an Arduino device. The cooling mechanism is facilitated by a Peltier module, which is a critical component in many temperature control devices. The control system implemented is a Proportional, Integral and Derivative (PID) control system. This control system has been selected as it provides easy change in the variables of the device used as the Peltier module can be a little sensitive. Furthermore, our experimental design incorporates a Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET), which serves as the control device. The MOSFET is responsible for monitoring the voltage differential across the Peltier module's pins, thereby contributing to the system's overall efficiency. The results derived from our study highlight the significance of the Peltier module in the field of temperature control. They also shed light on the promising potential of integrating multiple Peltier modules for more advanced applications. As such, our study serves as a stepping stone for future research aimed at enhancing the effectiveness and efficiency of temperature control systems.**

***Index Terms*— Control System, Peltier Module, MOSFET, Power-Integral-Derivative (PID) Control System.**

I. INTRODUCTION

The application of Peltier devices, commonly referred to as Thermoelectric Coolers (TECs) [1], has become a viable and affordable method in the search for environmentally sustainable and effective refrigeration solutions [2]. These solid-state heat pumps have a variety of benefits such as lack of hazardous refrigerants, compact size and low vibration. This makes them ideal for a variety of uses like industrial processes, wine coolers, and CPU cooling. However, obtaining accurate cooling control might be difficult. This is because Peltier devices are nonlinear in nature and hence the control might vary.

The task at hand is to overcome these difficulties. The main solution used according to open literature is to use a control system that can properly supervise the working of the Peltier device [3]. There have been different control systems used to tackle this problem. Even Deep Learning and ANN techniques have been used [4]. The PID control system is one of the techniques considered the best in this regard. Various literature have innovated the PID control system using techniques such as self-tuning ability [5], fuzzy PID [6], two degrees of freedom [7], etc. However, almost all of these require expensive equipment that will increase the cost of the product. The problem now is to provide a cost-effective PID water temperature control system using the Peltier module.

This paper elaborates on the PID control system and the water cooling process in complete detail.

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This is done, as mentioned, using an Arduino microcontroller. The Peltier module is put inside a heat sink along with a fan in this particular experimental setup. The Arduino microcontroller functions as the primary command center, coordinating the many parts of the system. Arduino is used here because of its user-friendliness, light-weight and relative cheapness as compared to other microcontrollers in the market [8]. Precise and reliable regulation of temperature is made possible by the PID controller's meticulous tuning of the Peltier device in tandem with temperature control optimization. Thorough performance assessments demonstrate how well the system keeps the water at the desired temperature, with under-expected response times and low energy consumption. Most importantly, the PID controller parameters are fine-tuned to achieve a precise balance between responsiveness and system stability, which greatly enhances the cooling system's overall efficacy.

The study highlights the resilience of the suggested approach, establishing it as a useful instrument for uses requiring accurate and energy-saving water temperature regulation. PID control in conjunction with Arduino ensures accuracy and offers a flexible, scalable platform that can be tailored to meet a variety of temperature control needs. The system's usefulness is improved by real-time temperature monitoring, using the Arduino monitor’s serial window. This allows users to effortlessly set and monitor desired water temperatures. The output produced shows the current temperature and the PWM output. In conclusion, our study contributes to the development of Peltier-based cooling systems by addressing a key demand for accurate and energy-conscious temperature management. Promising applications across a range of industrial processes and research and development contexts, the proposed integration of Arduino with PID control opens doors for varied and effective temperature regulation.

II. System Components: A Comprehensive Overview

A. Experimental Setup

The experimental setup used in this project has the following main key components:

- Arduino UNO: The microcontroller that will be used in this project to implement the PID control system.
- TEC1-12706 Peltier module: The other most important aspect of this project that will be used to cool.
- MOSFET: A MOSFET will be used to be the controller device.
- DS18B20 temperature sensor: This is the device that will be used to detect the temperature value. It is a temperature sensor that uses the OneWire and Dallas libraries in Arduino.

B. Design

The PID control system and the Peltier module are the two primary parts of the Peltier-based cooling system. A device called the Peltier module uses the thermoelectric effect to move heat from one side of the system to the other. The apparatus is composed of two plates, one linked to a power supply and the other to a heat sink. The Peltier module's heat is absorbed by the heat sink, and the power supply provides the energy required to control the heat transfer rate. The control system is in charge of keeping an eye on the system's temperature and modifying the Peltier module's power supply as necessary. A power source, a feedback loop, and a temperature sensor make up the control system. The temperature sensor communicates data to the power source about the system's temperature.

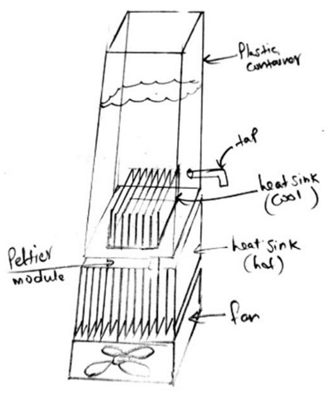

Figure 1. Design of System Used

The Peltier module's power is then modulated by the power supply to maintain the required temperature. This apparatus is a simplistic one that has been constructed just to demonstrate the working of the project.

C. Advantages

The Peltier-based cooling system has several advantages over other cooling systems. Firstly, it is extremely efficient and can transfer heat quickly and efficiently. Secondly, it is relatively inexpensive to build and maintain. Finally, it is also relatively easy to control, as it utilizes a simple feedback loop to regulate the temperature.

D. Limitations

There are other restrictions with the Peltier-based cooling system. First of all, it is constrained by the power supply to the Peltier module. Secondly, because the Peltier module is not able to transfer a lot of heat, it is not appropriate for applications that call for extremely low temperatures. Lastly, depending on the room temperature it can take different times for the cooling process to occur.

III. PID CONTROLLER

The PID control system has a wide range of uses. This control system can also be utilized in temperature applications, despite it being typically used in motor-related applications. We can convert this motor-related application into temperature related.
The block diagram for the PID controller is shown below. Three parameters, Kp, Ki, and Kd, are displayed. The integral and derivative gain parameters are called Ki and Kd, respectively, and the proportional gain parameter is called Kp.

IV. EXPERIMENTAL OBSERVATIONS

The set point (required) temperature for the observation was 22 degrees Celsius. Taking observations would be simpler at this temperature, given the humidity and the high temperature of the room where the experiment was conducted. Kd = 1, Ki = 0.5, and Kp = 1 values.
To prevent drastic shifts, they were kept modest. The PWM range of 0-255 was assigned to the output value. The actual observations taken are shown in table 1. Once the value of temperature hit 22 degree Celsius, the value of PWM started decreasing significantly until it reached a value of 0. After this happened, the temperature started rising as there was no voltage difference being provided to the Peltier device.
Once the temperature rose up to 22.5 degree Celsius, the value of PWM already had risen up to 255 again and the cooling process had already started once again.

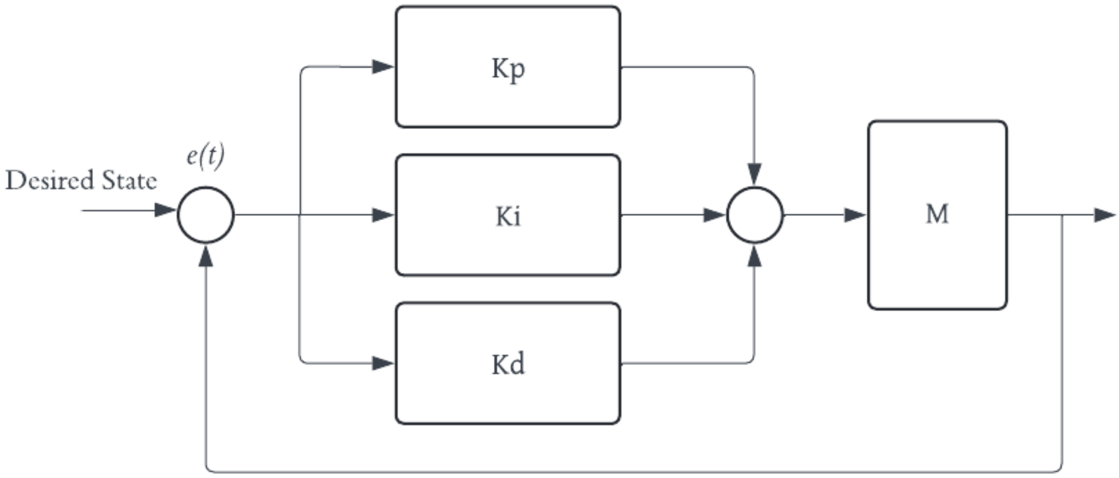

Figure 2. PID Control Block diagram

The results from the above table show how PWM value is affected by the temperature. The threshold temperature was 22 degree Celsius. Until the temperature dropped to that, the value of PWM stayed constant. This is consistent with expectations.
Once the temperature hit the threshold value, however, the PWM value suddenly drops, turning the power supply off to the Peltier module. This in turn causes the cooling to stop and the temperature starts to rise again. As it rises, we can see the PWM value also starts rising, in order to restart the cooling process.

TABLE I. OBSERVATIONS

No.	Temperature	PWM Value
1.	27	255
2.	24	255
3.	23	255
4.	22.50	255
5.	22	255
6.	22	174
7.	22	15
8.	22	0
9.	22.5	3
10.	23	2551

V. CONCLUSION

PID control was employed in this Peltier-based cooling system. Even while the control system can be regarded as being somewhat slow, it is incredibly accurate and quite simple to deploy. Implementing a fuzzy system could be challenging given the project's financial and schedule limitations. This cooling system, which uses a Peltier module, is not only affordable but also environmentally benign and sustainable. It consumes very little power, and it momentarily shuts down when the system achieves the necessary temperature, using even less energy. Hence, this system can be considered a really power efficient as well as a cost-efficient solution to the problem of cooling water. One future prospect of this project is that it can be modified so as to make the cooling process more efficient by using better materials instead. Not only that, the system can also benefit from an overhaul in the shape/structure of the system to make it more portable and usable.

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