Automated Temperature Regulation Delivery Box, Utilizing PID Control for Cooling and Heating

Buan, Danilo Jr. G. | de Leon, Bryan Paul A. | Dupaya, Jomarie A | Guevarra, Hans Angelo
Bachelor of Science in Computer Engineering
Technological Institute of the Philippines
Quezon City, Philippines
qdgbuan@tip.edu.ph, qbpadeleon@tip.edu.ph , qjadupaya@tip.edu.ph, qhacguevarra@tip.edu.ph

Abstract - The food delivery industry thrives on convenience, but maintaining food quality during transport remains a challenge. This paper presents the design and development of an Automated Temperature Regulation Delivery Box utilizing Proportional-Integral-Derivative (PID) control for precise cooling and heating. The Automated Temperature Regulation Delivery Box addresses the limitations of traditional insulated boxes by employing active temperature regulation. It leverages thermoelectric peltier modules and DHT22 sensors to achieve dynamic temperature control within a desired range. A user-friendly interface allows seamless user interaction through mobile phones. Testing confirms the Automated Temperature Regulation Delivery Box's effectiveness in maintaining target temperatures for loaded and unloaded compartments. The PID control system ensures accurate temperature regulation, surpassing conventional methods. The project demonstrates the potential of sensor-driven technology to revolutionize food delivery, enhancing food quality, safety, and customer satisfaction.

Keywords: Food Delivery, Temperature Regulation, PID Control, Thermoelectric Peltier Modules, Sensors

I. Introduction

In this document, it focuses on the creation of a project named Automated Temperature Regulated Delivery Box, Using PID Control for Cooling and Heating. The documentation will follow all of the procedures of the format and step by step descriptions and analysis of the project.

a. Problem Statement

The food delivery or modern logistic services is one of the useful services when it comes to convenience, quality and integrity of products. Using temperature regulated delivery boxes will solve a problem in the old insulation boxes that exist today. Technology can help ensure that food stays at a safe temperature throughout its journey from the kitchen to the customer's door. Smart thermometers and sensors are sophisticated devices that measure the temperature of food while it is being delivered, allowing restaurants to monitor its condition in real time. Delivering hot food is essential for guaranteeing customer satisfaction and safety [1]. In this article it is important that temperature regulation in food product delivery will ensure great food quality and integrity. In addition the materials involved within the insulation boxes are also known to be hazardous and dangerous materials that can seriously harm the environment, where the products contain polystyrene and chlorofluorocarbons, these two are well-known plastic polymers and greenhouse gasses. Improper handling of foam boxes can also result in the release of harmful chemicals into water sources, which can then contaminate food and drink during transportation [2]. To address these problems a solution must be created, where we aim to design and develop an Automated Temperature Regulation Delivery Box, that is equipped with a PID (Proportional-Integral-Derivative) control system for precise and dynamic temperature regulation.

b. Project Overview

The project seeks to design and develop a sensor-driven temperature regulation system that aims to revolutionize the food and logistics delivery industry by addressing the critical issue of maintaining the food and product quality during transit. The project endeavors to develop a solution that can surpass the conventional insulated box by implementing active heating and cooling, through the use of a thermoelectric peltier system in conjunction with two DHT22 sensors. Furthermore, a user-friendly interface will be developed in order for the user to seamlessly integrate with the device through their phones, which will be connected to their phones.

c. Objectives

The primary objective of this project is to develop a robust system that automatically regulates the food temperature at optimal levels. In line with this, the projects particular objectives are as follows:

- Designing and implementing a sensor-driven regulation system using PID control for both cooling and heating.
- Integrating thermoelectric peltier modules as the active heating and cooling element.
- Filtering the sensor to produce a standardized accuracy.
- Developing a user-friendly interface for the system.

II. Methodology

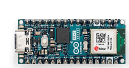
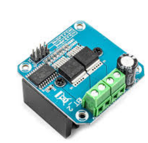
This section of the document covers the Hardware and Software Design aspects of the project. The methodology is designed to create and deploy a robust system.

a. Hardware Design

The hardware design of this document aims to show all of the components, purpose and its functionality in the system.

i. Electronics Systems

Electronic Systems are components that address the various components and subsystems that are necessary for the functioning of the electronic system.

Required Component	Actual Component	Picture
Microcontroller	Arduino Nano ESP32	
Motor Driver	BTS7960 Motor Driver	

Power Supply	male car cigarette lighter socket plug	
Power Supply	LifePo4 32700 Battery	
Sensor	DHT22	

Table 1: Electronics System Components

1. Arduino Nano Controls all the systems of the project it is also the brain of the system. It reads the data from the sensors and controls all of the systems that are connected to the system.
2. The BTS7960 Motor Driver controls the fans of the system where it splits the control between the cooler air and heated air, in addition the motor driver is used to control the fan speeds that are being commanded by the Arduino Nano.
3. Power Supplies, the male car plug and the LifePo4 battery are designed to power the system providing stable and reliable power to all components of the electronic system.
4. Sensors are used to integrate and interface all of its connections which will enable data acquisition and control functionalities.

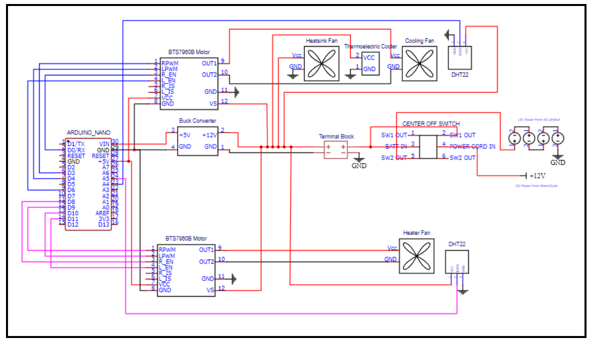


Figure 1: Schematic Diagram of Electronic System

ii. Physical Systems

The physical system are the tangible components and structures that comprise the electronic system, where all the components interact with each other.

Required Component	Actual Component	Picture
Heatsinks	Thermoelectric Peltier Cooling System Heatsink Kit	
DC Fan	12V Brushless DC Fan	
Heater and Cooling Element	Thermoelectric Peltier Module	
Data transfer Wire	Type C cable	

Jumper Wires	Female Jumping Wires	
Printed Circuit Board	Universal PCB (Prototyping Board)	

Table 2: Physical System Components

1. Heatsinks are to dissipate heat generated from the Peltier module as it transfers all of its heat to the surface of the heatsink providing decrease in temperature.
2. DC fans are used to dissipate heat and used for blowing cold air into the compartment of the device, it is generally used to serve as both our cooler and heater fans of the devices.
3. Heater and Cooling Element, Peltier module is used for the heater and cooler of the device that are used for both compartments to heat and cool the contents of the box.
4. Data transfer Wire, type C cable is used to upload and transfer the data, from the IDE to the microcontroller of the device, with the inclusion of the power cable from the regulator to the nano to power the device.
5. Jumper Wires are used to connect the pins of sensors, motor drivers and electrical systems, according to the schematic diagram.
6. Printed Circuit Board, used to expand the pins of the arduino nano, to fit all of the electronic components of the system, from its data pins, power and ground.

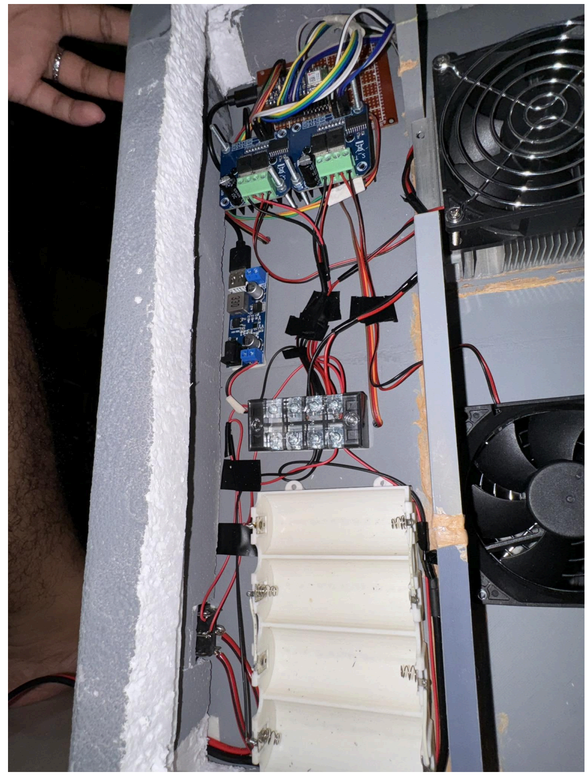


Figure 2: Actual Electronics, Physical and Power system

iii. Power Management

Required Component	Actual Component	Picture
Switch	Center Off Switch	
Voltage Regulator	24V/12V To 5V USB Mobile Phone DC-DC Step-Down Module 5.0 HW-688	

Table 3:Power Management Components

1. Switch is a requirement for the components to switch on and off the device, in addition it

is also used to split the power supply between the power cord and the battery.

2. Voltage Regulator maintains a stable output voltage in case of fluctuations in the input voltage and load conditions, for which it is essential for providing consistent power to sensitive electronic components.

b. Software Design

The software design of the document shows how the system works internally through codes and software, which gives control to the system without the need of control from the electronics.

i. Embedded Software

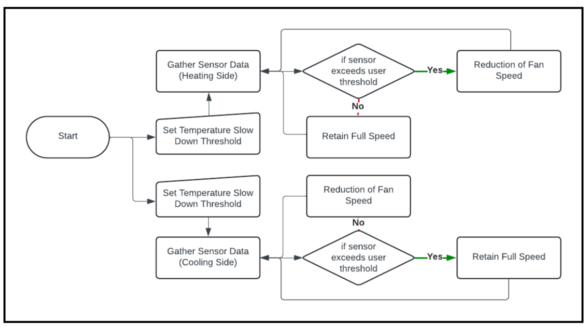


Figure 3: Software Flowchart

Code Snippet	Function
DHT dht_sensor_heat(DHT_SENSOR_PIN_heat, DHT_SENSOR_TYPE); **DHT dht_sensor_cold**(DHT_SENSOR_PIN_cold, DHT_SENSOR_TYPE);	Initializes the DHT22 sensors
input_heat = dht_sensor_heat.readTemperature() **input_cold** = dht_sensor_cold.readTemperature()	Reads temperature data from DHT22 Sensors using a library
temp_heat = input_heat; **temp_cold** = input_cold;	Assigns the sensor data to the dashboard cloud variable
#include <PID_v1.h>	Initializes the PID library
double Kp_heat = 0.5, **Ki_heat** = 0.5, **Kd_heat** = 0.05; **double Kp_cold** = 0, **Ki_cold** = 0.1, **Kd_cold** = 0.005;	PID Constants
PID pid_cold(&input_cold, &output_cold, &setpoint_cold, Kp_cold, Ki_cold, Kd_cold, DIRECT); **PID pid_heat**(&input_heat, &output_heat, &setpoint_heat, Kp_heat, Ki_heat, Kd_heat, DIRECT);	PID function that takes the temperature values, setpoint and the PID constants as input and outputs the result to output_cold and heat.

void onUserInputColdChange()
{
if (input_cold >= user_input_cold){
analogWrite(RPWM_COLD, 255);
//user_value_cold = user_input_cold;
} else {
analogWrite(RPWM_COLD, 255 - (motorSpeedcold_decrement+50));
}
 	
}
	Function wherein the fans will only start to decrease speed once the sensor input is above the user threshold

Table 4: Embedded Software Code

ii. Application Software

The project employs an Arduino Nano ESP32 as its microcontroller platform, requiring the use of the C++ programming language for coding due to its compatibility with Arduino development environments. Additionally, Arduino Cloud will be used as the IoT platform.

c. Data Engineering

The Data engineering section will describe how we will get the data, and use that data to implement in the system to make it learn and control the device automatically.

i. Data Description

The data collected via sensors and PID output determine the desired values and error values of the controller system, altering the behavior of the DC Fans based on PID values and raw temperature data. This ensures that the algorithm operates in line with our goal of creating a closed-loop system for the device.

ii. Algorithms Used

Algorithm	**Function**
PID pid_heat(&input_heat, &output_heat, &setpoint_heat, Kp_heat, Ki_heat, Kd_heat, REVERSE);	The REVERSE PID Function dictates that if the differences between the setpoint and sensor data are high, then the PID output will be higher as well. We can use this number to decrease the motor speed.
#define DHT_SENSOR_TYPE DHT22	The library of the DHT22 Sensor, includes built in calibration routines to ensure accuracy as opposed to using just analogRead.

Table 5: Algorithm Used

III. Testing Procedures and Results

This section of the document will show the process of testing procedures, and results of the project in determining the robustness, reliability, and accuracy of the project.

a. Testing Configuration / Setup

The testing configuration and setup, percentage accuracy tests are used to determine sensor accuracy, acceptability, consistency, and differential diagnostic results by considering several criteria.

1. The cooler compartment must maintain a temperature between 20°C and 27°C for the entire 1 hour test duration.
2. The heater compartment must maintain a temperature between 30°C and 45°C for the entire 1 hour test duration.
3. The Thermo Cooler box must demonstrate the ability to quickly recover to the target temperature ranges after door openings.
4. There should be no significant temperature fluctuations or deviations outside the target ranges during the test.

The percentage accuracy was calculated to determine the project system performance for the test cases. To determine the percentage accuracy, the ISO 5725-1: 2020 - Accuracy of Measurement Methods and Results are referenced. It states that the margin of error should be only 5%. Therefore, the result is considered accurate if the percentage accuracy is greater than or equal to 95%

$$Accuracy\% = \frac{No. of\ match\ trials}{Total\ No. of\ trials} x100$$

b. Testing Results

Trial Number	Temperature Range	Test Duration	Test Load	Remarks
1	25°C-29°C	5mins	Honey Lemon Tea	31°C(Within Range)
2	25°C-29°C	10mins	Honey Lemon Tea	29°C(Within Range)
3	25°C-29°C	15mins	Honey Lemon Tea	28.59°C(Within Range)
4	25°C-29°C	20mins	Honey Lemon Tea	27.79°C(Within Range)
5	25°C-29°C	30mins	Honey Lemon Tea	28.59°C(Within Range)
Total Average Percentage Accuracy				100%

Table 6: Cooler Compartment with load

Trial Number	Temperature Range	Test Duration	Test Load	Remarks
1	20°C-27°C	5mins	Non	31.45C (Out of Range)
2	20°C-27°C	10mins	Non	30.52C (Out of Range)
3	20°C-27°C	15mins	Non	30.49C (Out of Range)
4	20°C-27°C	20mins	Non	30.30C (Out of Range)
5	20°C-27°C	30mins	Non	30.12C (Out of Range)
Total Average Percentage Accuracy				0%

Table 7: Cooler Compartment with no load

Trial Number	Temperature Range	Test Duration	Test Load	Remarks
1	30°C - 45°C	5mins	Peach Mango Pie	37.9C (Within Range)
2	30°C - 45°C	10mins	Peach Mango Pie	39.5C (Within Range)
3	30°C - 45°C	15mins	Peach Mango Pie	41.9C (Within Range
4	30°C - 45°C	20mins	Peach Mango Pie	43.2C (Within Range)
5	30°C - 45°C	30mins	Peach Mango Pie	42.2C (Within Range)
Total Average Percentage Accuracy				100%

Table 8: Heater Compartment with load

Trial Number	Temperature Range	Test Duration	Test Load	Remarks

1	30°C - 45°C	5mins	Non	36.5°C (Within Range)
2	30°C - 45°C	10mins	Non	38.4°C (Within Range)
3	30°C - 45°C	15mins	Non	41.2°C (Within Range)
4	30°C - 45°C	20mins	Non	42.09°C(Within Range)
5	30°C - 45°C	30mins	Non	41.7°C (Within Range)
Total Average Percentage Accuracy				100%

Table 9: Heater Compartment with no load

IV. Analysis of Testing Results

Based on the results of the test, the overall performance shows that the system are within range of the desired temperature, it showed outputs are 100% accurate in reaching the desired temperature ranges for cooling and heating, however readings does tend to still change with loads inside the compartments shows that environmental factors can affect the readings of the temperature, where a load may already cold of hot inside. Furthermore, the test confirms the worthiness of the device.

V. Conclusions

In conclusion, the development of the Automated Temperature Regulation Delivery Box utilizing PID control for cooling and heating represents a significant advancement in addressing the challenges faced by the food delivery industry [3]. By integrating sensor-driven temperature regulation with active heating and cooling elements, this project aims to enhance food quality and integrity during transit, ultimately ensuring customer satisfaction and safety [4].

Through the implementation of a PID control system, precise and dynamic temperature regulation is achieved, also maintaining optimal temperature levels throughout the delivery process . The use of thermoelectric peltier modules and DHT22 sensors provide a reliable and efficient means of controlling temperature variations, surpassing conventional insulated boxes in terms of effectiveness and environmental impact .

Furthermore, the development of a user-friendly interface enables seamless integration with the device, enhancing accessibility and usability for both businesses and consumers [5].

Overall, this project underscores the potential of technology to revolutionize the food and logistics delivery industry, offering innovative solutions to improve service quality, sustainability, and customer experience . Further refinement and testing are necessary to optimize performance and ensure scalability, but the foundation laid by this project sets a promising trajectory for future developments in this field.

VI. References

[1]N. Fevrin, “How to keep food hot for delivery,” WorkWave, Mar. 22, 2023. https://insights.workwave.com/industry/home-delivery/how-to-keep-food-hot-for-delivery/

[2]N. D. T. Thuy, “Case study: Olivo insulated box for food delivery - Specco2,” Specco2, Feb. 20, 2023. https://specco2.com/olivo-for-food-delivery/

[3]A. Kherkhar et al., “Thermal investigation of a thermoelectric cooler based on Arduino and PID control approach,” ScienceDirect, Aug. 2022. https://www.sciencedirect.com/science/article/pii/S2214157X22004956

[4]”Why is temperature control important in food safety?, “ GreenCooling, https://www.greencooling.co.uk/why-is-temperature-control-important-in-food-safety/ (accessed May 09, 2024)

[5]R. Ramesh et al., “An empirical study of online food delivery services from applications perspective,” ScienceDirect, 2023, https://www.sciencedirect.com/science/article/abs/pii/S221478532104102X.