SENIOR DESIGN PROJECT REPORT
EE/CpE 4097 – Spring 2024

Project Title: Precision Controlled Bytes (PCB) Smoker

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1. INTRODUCTION

1.1. EXECUTIVE SUMMARY

This project introduces an advanced automated smoker, conceptualized and developed by engineers Trenton Cathcart, Parker Widmeyer, and Gabriel Boicu. The primary goal is to enhance the culinary experience by incorporating sophisticated electrical and control systems into traditional smoking methods.

Our automated smoker stands out with its unique features:

1. **Automated Temperature Control:** Utilizing high-precision sensors and a servo-controlled vent system, it maintains an optimal smoking environment with unparalleled accuracy.

2. **Remote Monitoring and Control:** A user-friendly web interface allows users to track and adjust the smoking process from any location, adding a layer of convenience and flexibility.

The distinctiveness of our project lies in its combination of automation, user customization, and remote accessibility. Unlike existing products, our smoker offers a fully integrated system with an open-source design, encouraging community involvement and continuous improvement. It represents a significant step forward in culinary technology, aiming not only to simplify and refine the smoking process but also to make it more accessible and enjoyable for both beginners and seasoned enthusiasts.

1.2. BACKGROUND AND PROBLEM STATEMENT

The motivation behind this project stems from the desire to revolutionize the traditional smoking process by integrating modern technology for enhanced control and convenience. Current smoking methods, while effective, often require constant manual monitoring and adjustments, making them time-consuming and less accessible for beginners. Our project is driven by the need to simplify this process, making it more user-friendly and precise.

1.2.1. EXISTING WORKS

Current market offerings in the realm of smokers include a range of products from simple charcoal-based units to more sophisticated electric and gas smokers. These products, such as those reviewed on Squirrel Cookoff, offer varying degrees of control and customization. However, they generally lack the integration of advanced control systems that allow for real-time monitoring and adjustment remotely.

Our automated smoker represents an evolution in this field. It differentiates itself through:

- **Advanced Automation and Control:** Unlike many existing smokers that offer limited control presets, our design incorporates automated temperature control with real-time adjustments, providing a level of precision unattainable in conventional models.

- **Remote Operation and Monitoring:** Through a dedicated web interface, our smoker allows users to monitor and control the smoking process remotely, a feature scarcely found in current market offerings.

- **Open-Source Design:** In contrast to the proprietary nature of many existing smokers, our open-source approach fosters community engagement and continuous product improvement.

1.2.2. GLOBAL AND SOCIETAL CONTEXT AND MOTIVATION

The broader impact of our automated smoker project extends beyond culinary innovation, addressing several contemporary global and societal challenges.

- **Environmental Sustainability:** Our design promotes energy efficiency and sustainable cooking practices. By optimizing the smoking process and reducing the need for constant manual adjustment, our smoker minimizes energy waste, contributing to a lower carbon footprint compared to traditional methods.

- **Technological Education and Open Source Community Engagement:** By adopting an open-source approach, the project encourages community involvement in technology. It provides a platform for shared learning and improvement, fostering a collaborative environment where enthusiasts and professionals can contribute to and benefit from collective knowledge. This approach also serves educational purposes, offering DIY enthusiasts and students an opportunity to engage with and learn about advanced control systems and web-based interfaces.

- **Health and Wellbeing:** Consistent and precise temperature control in food preparation is not just a matter of convenience or taste but also of health and safety. Our smoker ensures that foods are cooked at optimal temperatures, reducing the risk of foodborne illnesses. This is particularly important in smoking, where maintaining specific temperatures is crucial for safety.

- **Accessibility and Inclusivity in Culinary Arts:** By simplifying the smoking process with automation and remote monitoring capabilities, our project makes advanced smoking techniques more accessible to a wider audience, including beginners and those who might be intimidated by traditional methods. This democratization of culinary technology allows more individuals to explore and enjoy the art of smoking, regardless of their prior experience.

2. DESIGN AND METHODS

In this segment of our PCB Smoker project, we aimed to transform traditional smoking methods with our innovative, automated system. Our project's primary objectives included retrofitting a base smoker for automated integration of electrical and mechanical elements, establishing precise and stable temperature control, and developing an integrated system for automated wood chip dispensing. These objectives and their associated tasks, underpinned by detailed strategies and plans, were guided by our vision of setting a new standard in convenience, safety, and functionality for the food smoking industry.

2.1. GOALS AND TASKS

2.1.1. GOAL 1: Retrofitting the Base Smoker for Automated Integration

Description:
The primary objective of our PCB Smoker project was to retrofit a conventional smoker to accommodate various electrical and mechanical elements such as servo motors, fans, and vents. This foundational step was crucial to ensure the seamless integration of automated systems, which subsequently enabled precise and stable temperature control within the smoker. Task A focused on the assembly and configuration of essential hardware components, including microcontrollers, servos, power components, and thermometers, to align with our project's specifications. Task B shifted the emphasis to software control algorithms for temperature dynamics, aiming for code that reliably maintained internal temperatures within desired ranges. Task C involved hands-on testing starting at room temperature to verify hardware response in line with software logic. The final stage, Task D, was the meticulous integration of these components into the smoker's tailored compartments.

Challenges:
Task A: We faced the challenge of ensuring that all components initialized without issues once powered up. The risk here included potential malfunctions or incompatibilities between hardware components.

Task B: A major challenge was drafting effective software control algorithms that could accurately maintain the smoker's internal temperature. Potential risks involved software bugs or inaccuracies in temperature control.

Task C: This task faced the challenge of verifying the predictable response of each hardware component under varying temperature conditions. Inaccurate responses or hardware failures were potential risks.

Task D: The integration stage had to ensure that components fit perfectly while remaining accessible for maintenance, posing a challenge in precise design and fitting. Risks included improper fit leading to malfunction or inaccessibility for future tweaks.

2.1.2. GOAL 2: Development of Automated Wood Chip Dispensing System

Description:
The second major goal for our PCB Smoker project was the development of an automated wood chip dispensing system. This system was designed to work in synchronization with the smoker's temperature control system. Our primary focus was on achieving a balanced and stable environment for smoking by automating the wood chip dispensing process. Task E involved creating a reliable storage mechanism for wood chips. Task F was dedicated to programming the microcontroller for precise dispensing intervals, ensuring consistent temperature and smoke levels. Finally, Task G encompassed the physical integration of the wood chip system into the smoker, ensuring seamless operation and compatibility with other components.

Challenges:
Task E: We faced the challenge of designing a storage unit that held the wood chips. A potential risk was the seamless integration of the aftermarket parts into the base smoker.

Task F: The challenge lay in programming the microcontroller for optimal wood chip dispensing intervals. Risks included programming errors leading to irregular smoking conditions or temperature fluctuations.

Task G: The integration of the wood chip system into the smoker posed challenges in ensuring that it fit well and did not interfere with other smoker parts. Risks involved mechanical interference with other components or fitting issues.

2.1.3. GOAL 3: Enhancing Remote Operation Capabilities

Description:
The third major goal of our PCB Smoker project was to enhance its remote

operation capabilities through a robust Internet of Things (IoT) solution. This goal aimed to enable control of the smoker from any location with an internet connection, prioritizing user accessibility and system stability. Task H involved selecting a communication platform that was widely used and had robust security features, ensuring a stable connection over a significant distance. Task I centered around developing an intuitive user interface (UI) that allowed users to understand and operate the smoker remotely with ease. Finally, Task J included programming the microcontroller to receive and process commands sent via the remote platform, ensuring that the microcontroller recognized and acted on the commands without delay.

Challenges:
Task H: The challenge was to choose a communication platform that offered both robust security features and a stable connection. The risk involved selecting a platform that might not provide a consistent connection or lacked adequate security.

Task I: Developing a user-friendly UI posed challenges in ensuring intuitiveness and ease of use for all user levels. The risk here was creating an interface that might be too complex or not user-friendly for certain users.

Task J: The programming of the microcontroller to interact with the remote platform involved challenges in ensuring immediate and accurate recognition and execution of commands. Risks included delays in command execution or inaccuracies in processing, which could affect the smoker's performance.

2.1.4. GOAL 4: Mechanical Housings Construction for Automated Components

Description:
The fourth goal of our PCB Smoker project focused on the meticulous construction of mechanical housings for the smoker's automated components. This goal ensured that every component was securely housed without compromising functionality. Task K was dedicated to procuring a base smoker that aligned with the project's specifications, particularly in terms of size and design compatibility. Task L involved inspecting and strategizing the placement of each part, taking temperature thresholds and safety factors into account. In Task M, the actual construction of the housings was carried out, with each housing built according to precise design specifications. Task N centered on fitting all components into their respective housings, ensuring a snug fit without causing damage. The final task, Task O, emphasized practical testing of the smoker with all its components housed, aiming to confirm that no component overheated or malfunctioned due to its housing.

Challenges:

Task K: We encountered challenges in finding a base smoker that met all the project's modification needs, with risks including size incompatibility and design constraints.

Task L: This task involved the challenge of strategically placing components to avoid overheating, with risks including miscalculation of safety thresholds and component damage.

Task M: The construction of housings had to be precise, posing challenges in maintaining strict adherence to design specifications. Risks included construction errors and dimensional inaccuracies.

Task N: Fitting components into housings required precision to avoid damage, with risks including tight fittings that could harm components or improper installations.

Task O: The practical testing phase had to ensure all components functioned correctly in their housings. Risks included potential overheating or malfunctions due to housing design flaws.

2.2. DELIVERABLES

The final product delivered was the PCB Smoker, a state-of-the-art culinary smoker that expertly combined traditional smoking methods with advanced technology. This innovative smoker was designed to offer precision control and remote operability, ensuring convenient, consistent, and gourmet smoking results. Equipped with automated systems, IoT capabilities, and user-friendly features, the PCB Smoker simplified the smoking process, making it accessible to both seasoned enthusiasts and newcomers alike. Priced competitively, it stood as a cost-effective solution without compromising on quality or functionality, addressing the needs of modern families and contributing to cultural and communal dining experiences.

2.3. SPECIFICATIONS AND REQUIREMENTS

Our project was defined by a clear set of specifications and requirements, each aimed at delivering a product that not only met but exceeded expectations in terms of functionality, usability, and safety. We established quantitative, measurable metrics to track our progress and ensure the successful completion of the PCB Smoker. From precise automated temperature control within a tight tolerance to a wood chip dispensing system that ensured consistent flavor, our design was detailed and user-oriented. The remote operation and IoT integration expanded the smoker's usability, making it a modern culinary tool accessible from anywhere. The friendly user interface was crafted with amateur culinists in mind, ensuring a smooth and intuitive navigation experience. Lastly, the mechanical and electrical soundness of our smoker was paramount, ensuring robust construction, reliability, and adherence to safety standards. These rigorous requirements, underpinned by methodical verification processes, guided us toward a final product that was not only innovative but also safe, efficient, and user-friendly. For a detailed overview of our project's specifications and requirements, please refer to the comprehensive Requirements Matrix illustrated in **Figure 1** below.

REQUIREMENT	TITLE	DESCRIPTION	VERIFICATION
1	AUTOMATED TEMPERATURE CONTROL	The system must maintain a user set internal temperature within ±5° F.	The microcontroller will adjust servo motors and fans according to the most recent temperature from the PMOD and in turn adjust the temperature. The PMOD relays the current temperature reading. If the internal temperature can indefinititly maintain the user set temperature within ±5° F then this is requirement will be passed.
2	WOOD CHIP DISPENSING	The system will dispense wood chips from the hopper, into the fire box, at regular intervals using a servo motor and auger configuration.	The microcontroller will have a set dispense time and will dispense at this time expiration. If the fire is able to stay lit for the entirety of the cooking process. Then this requirement will be passed.
3	REMOTE OPERATION AND IOT INTEGRATION	The smokers data and accessibility will be accessible from devices in other locations.	One will beable to use their phone to set an operating temperature, and look at live data feedback from the smoker system. If these specifications are met, then this requirement will be passed.
4	FRIENDLY UI AND ACCESSIBILITY	The User Interface will be user friendly, of which amatuer culinists will beable to navigate.	Usability testing will be conducted with a group of users to assess the intuitiveness of the UI. Success will be measured by the ability of at least 90% of participants to complete a set of standard operations without assistance or reference to a manual within a designated timeframe.
5	MECHANICALY AND ELECTRICALLY SOUND	The smoker must be robustly constructed, ensuring all mechanical and electrical components are reliable, have a low failure rate, and comply with industry standards for safety and performance.	The smoker will undergo a series of mechanical and electrical safety tests, including stress testing to simulate extended usage and inspections to ensure compliance with safety standards. A successful outcome will be demonstrated by a pass in all regulatory safety inspections and the absence of mechanical or electrical failures during testing periods.

Figure 1: Requirements Matrix

3. TECHNICAL APPROACH AND RESULTS:

3.1. FINAL DESIGN

The PCB Smoker was meticulously designed to integrate traditional smoking methods with sophisticated automation and control technologies. Our final design emerged from a cohesive process involving conceptualization, detailed planning, prototyping, integration, and rigorous testing to ensure a balance between innovative features and practical usability.

Conceptualization and Requirements Definition

Our design process began with a visionary phase where we conceptualized the PCB Smoker, incorporating precision control with IoT capabilities. This phase involved extensive brainstorming and feasibility studies which helped define the detailed requirements for the project. Key aspects such as temperature control precision, automated wood chip dispensing, and remote operability were emphasized to set a robust framework for development.

Component Selection and Prototyping

With the requirements clearly defined, we selected high-quality components that aligned with our performance and quality standards. The iterative design phase saw the construction of several prototypes to refine our concepts and address the practical challenges encountered. Prototyping was crucial for testing our ideas in real-world scenarios and for making necessary adjustments before final integration.

Integration and System Testing
The integration phase involved the seamless assembly of hardware and software components ensuring they worked in harmony. We conducted extensive testing during this phase, ranging from individual component tests to whole-system validation, to ensure every part of the smoker functioned as intended and met safety standards.

Design Highlights

- **Automated Temperature Control:** Utilizes high-precision sensors and a servo-controlled vent system to maintain optimal conditions within the smoker.
- **Remote Monitoring and Control**: Features a user-friendly web interface that allows for remote adjustments and monitoring, enhancing the convenience for users.
- **Mechanical and Hardware Integrity:** The design includes custom-built mechanical housings for all electronic components ensuring durability and safety.

Technical Specifications

- **Base Unit:** Expert Grill 28" Offset Charcoal Smoker Grill modified for automation.
- **Control System:** Raspberry Pi Model 4B, providing a robust platform for software and connectivity solutions.
- **Temperature Sensing:** MAX31855 Thermocouple to Digital Converter, ensuring accurate temperature readings.
- **User Interface:** A Raspberry Pi-compatible HDMI touchscreen, facilitating direct user interaction with the smoker.

Throughout the design process, our focus remained on creating a product that not only met but exceeded the technical and usability expectations set out at the project's inception. The PCB Smoker represents a significant advancement in culinary technology, combining ease of use with advanced features to cater to both seasoned enthusiasts and beginners.

Product Name	Quantity
Expert Grill 28" Offset Charcoal Smoker Grill with Side Firebox, Black	1

Raspberry Pi Model 4B 4GB	1
MAX31855 Thermocouple to Digital Converter Interface Pmod™ Platform Evaluation Expansion Board	1
THERMOCOUPLE WIRE K-TYPE 1M	1
POWER STRIP	1
Raspberry Pi GPIO Terminal Block	1
20 AWG 100 FT Copper Wire Spool	2
270 Degree Miuzei 20 Kg Servo Motor	3
DC Power Jack Adapter 5.5mm (12 Volt 5 Amp)	1
DC Power Supply 5.5mm (5 Volt 4 Amp)	2
Raspberry Pi 10" HDMI TouchScreen	1

Table 1: Equipment List

3.2. RESULTS

The PCB Smoker project's technical approach is underpinned by a series of carefully selected tools, algorithms, and components, each chosen for their specific role in ensuring the reliability and functionality of the smoker. Here's how we approach the various aspects:

Mechanical Design: The smoker's mechanical system, including the servo motors and auger dispensing mechanism, is designed with precision to handle wood chips and manage airflow. We use CAD software for detailed 3D modeling, allowing us to visualize and refine the smoker's physical components before fabrication. Which can be seen below in **Figure 2.**

Mathematical and Formal Modeling: We apply mathematical models to predict the behavior of the smoker's thermal system. This includes calculating the optimal rate of wood chip dispensing based on the combustion rate, which is derived from the heat capacity of wood and the desired smoking temperature range.

Simulation Tools: For the software and control systems, we conduct simulations using a combination of PHP for web interface development and Python for backend logic control. These languages are selected for their robustness and flexibility, allowing us to create a user-friendly interface and reliable temperature feedback systems.

Testing Simulations:

PHP Website: Trial and error coding sessions are conducted to refine the user interface, ensuring it is intuitive and meets the users' needs.

Temperature Feedback System: We simulate heat fluctuations using a blow dryer to test the responsiveness of the temperature control system, including servo adjustments and PMOD (Peripheral Module) operations, without the risks associated with an active smoker.

Wood Chip Combustion Rate: The auger dispensing system's functionality is validated by determining the rate at which wood chips burn. This information is used to calibrate the auger's dispensing rate, ensuring consistent smoke and temperature levels.

Integrated System Testing: Once individual components are validated, we proceed to test the smoker as an integrated system. We monitor performance metrics such as temperature stability, response times, and fuel efficiency to ensure the smoker operates within the defined specifications.

Documentation and Code Analysis: Throughout the development process, we meticulously document our code, algorithms, and testing results. This documentation is crucial for understanding the system's behavior and for future troubleshooting or enhancements.

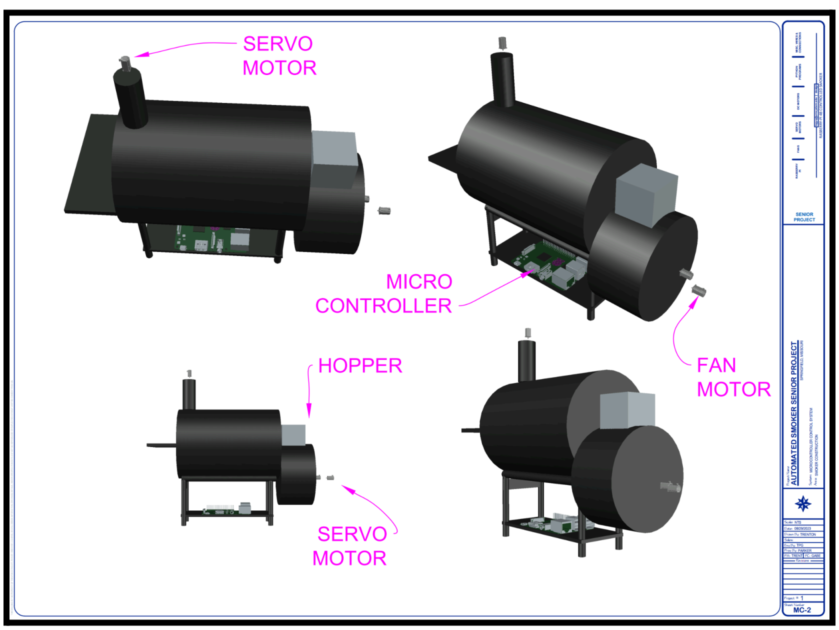

Figure 2: Initial Smoker Design

Figure 3: Final Construction

3.3. TOOLS

The PCB Smoker project employed a variety of tools, each selected for their ability to contribute effectively to different aspects of the project.

CAD Software for Mechanical Design: We used Computer-Aided Design (CAD) software to create detailed 3D models of the smoker's components. This tool allowed us to visualize the smoker's assembly, simulate the fit and function of parts, and make adjustments before physical prototypes were built.

Microcontroller – Raspberry Pi Model 4B: At the core of our control system was the Raspberry Pi 4B, which offered a balance of computational power, connectivity, and a supportive community for troubleshooting. Its GPIO pins allowed us to interface with various sensors and run tests simultaneously, making it an ideal choice for this project.

MAX31855 Thermocouple to Digital Converter: This converter was essential for accurate temperature measurements. It interfaced with the Raspberry Pi and provided reliable data that our control algorithms used to regulate the smoker's internal environment.

PHP and Python for Software Control: PHP was utilized for developing the smoker's web interface due to its widespread use and strong support for web development. Python, known for its simplicity and efficiency, was used to script the backend logic, controlling the smoker's hardware components.

Physical Components – Servo Motors and Thermocouples: The servo motors were chosen for their precision in controlling the smoker's vents, while the thermocouples were selected for their accuracy in temperature measurement. These components were tested for their durability and performance under high-temperature conditions.

Other Electrical Components: The selection of power adapters and copper wire spools was based on their capacity to handle the smoker's power requirements safely and efficiently. We used a power strip to distribute power among various components, ensuring a clean and organized setup.

TouchScreen Interface: The inclusion of a Raspberry Pi-compatible HDMI touchscreen provided a direct control interface on the smoker itself. This option was included for users who preferred a more tactile interaction or lacked immediate access to the web interface.

Documentation Tools: We used documentation tools, such as Google Drive, that supported collaborative editing and versioning, ensuring that all team members could contribute to and access up-to-date information.

3.4. HARDWARE DESIGN

In the PCB Smoker project, we meticulously selected and integrated several key hardware components to construct a robust and precise smoking apparatus. Our design hinged on the Expert Grill 28" Offset Charcoal Smoker, modified to incorporate a Raspberry Pi Model 4B 4GB for its computational power and expansive GPIO capabilities, allowing for various sensors and component connections. Temperature monitoring was achieved through a MAX31855 converter, which translates readings from a K-type thermocouple into digital data for the Raspberry Pi. Actuation is controlled by Muizei 20 Kg Servo Motors, and a DC motor which managed airflow and wood chip dispensation with high precision. The system's power is distributed through DC Power Jack Adapters and Power Strips, ensuring safe and efficient operation, while a Raspberry Pi-compatible HDMI TouchScreen offeres a direct user interface. The interconnectivity of these components is detailed in our comprehensive schematics, referred to as **Figure 3**, which served as a blueprint for the electronic system, ensuring correct installation and configuration. Each component underwent individual and systemic testing to validate performance, forming a reliable and user-friendly hardware foundation for the smoker.

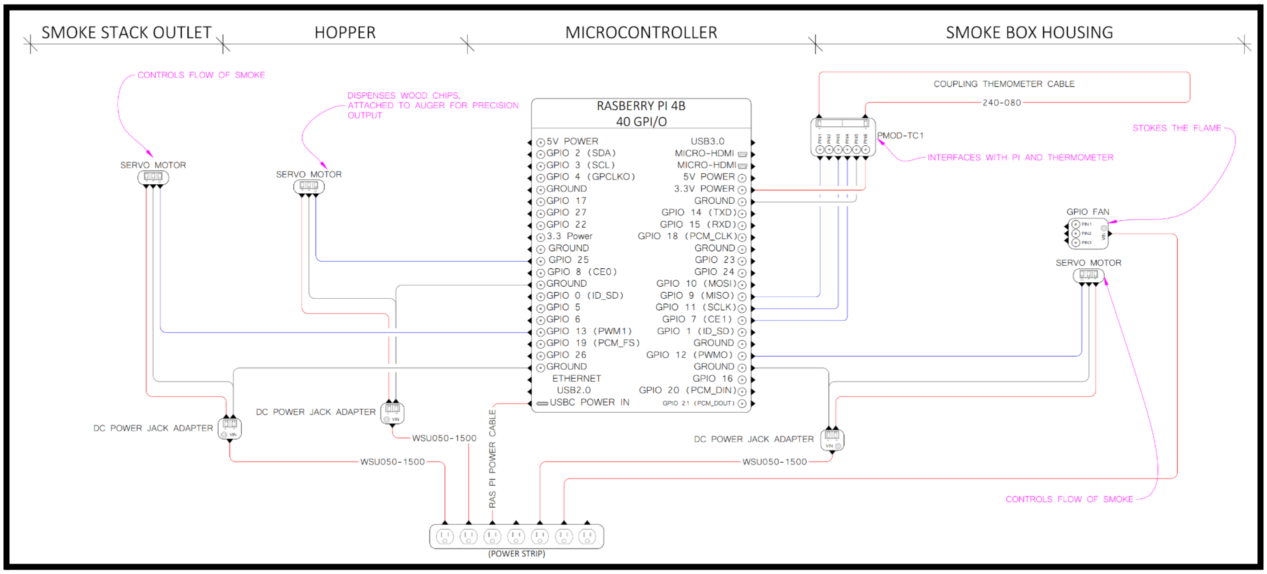

Figure 3: Smoker One-Line Diagram

3.5. SOFTWARE DESIGN

The PCB Smoker's software architecture is a combination of web-based interface control and backend logic to manage the hardware components. Our design leverages PHP for server-side processing and Python for direct hardware interaction, creating a seamless user experience and reliable system control.

PHP Scripts: The control_servo.php script is responsible for adjusting the servo motors based on the user's temperature settings, receiving inputs via POST requests and executing Python scripts to adjust the servos accordingly. get_temperature.php handles temperature readings, returning the current smoker temperature in JSON format, which is then displayed on the main control interface. A PHP script example can be seen below in **Figure 4.**

```
<?php
// Check if the set temperature is sent via POST
if ($_SERVER['REQUEST_METHOD'] === 'POST' && isset($_POST['set_temp'])) {
    $set_temp = $_POST['set_temp'];

    // Get the current temperature from the temperature.py script
    $output = shell_exec('python3 /var/www/html/temperature.py');
    if ($output && preg_match("/Temperature: ([\d.]+)/", $output, $matches)) {
        $current_temp = $matches[1];

        // Call the servo_control.py script with the current and set temperatures
        $servo_output = shell_exec("python3 /var/www/html/servo_control.py $current_temp $set_temp");
        echo $servo_output;
    } else {
        // Log the output if the temperature can't be extracted
        error_log("Failed to get temperature. Command output: " . $output);
        echo "Error: Could not get current temperature.";
    }
} else {
    echo "Error: No set temperature provided.";
}
?>
```

Figure 4: PHP Example Code

Python Scripts: The servo_control.py script calculates the necessary adjustments for the servo motors based on the temperature feedback. It uses the Pigpio library to control the GPIO pins on the Raspberry Pi, translating temperature differences into precise servo movements. temperature.py interacts with the thermocouple via the SPI interface to provide real-time temperature readings. A Python script example can be seen below in **Figure 5.**

```python
# -*- coding: utf-8 -*-
import spidev
import pigpio
import time

# Constants
SERVO_PIN = 12  # GPIO pin number for the servo
SERVO_MIN_PULSE_WIDTH = 500  # Minimum pulse width for the servo in microseconds
SERVO_MAX_PULSE_WIDTH = 2500  # Maximum pulse width for the servo in microseconds

# Initialize the pigpio library
pi = pigpio.pi()

# Initialize the SPI for PMOD TC1
spi = spidev.SpiDev()
spi.open(0, 0)  # Open SPI bus 0, device 0
spi.max_speed_hz = 50000  # 50kHz
spi.mode = 0b01

# Function to read the temperature from the PMOD TC1
def read_temperature():
    resp = spi.xfer2([0x00, 0x00, 0x00, 0x00])
    raw_data = (resp[0] << 24) | (resp[1] << 16) | (resp[2] << 8) | resp[3]
    if raw_data & 0x7:
        return None, "Fault detected"
    temp_data = (raw_data >> 18) & 0x3FFF
    if temp_data & 0x2000:
        temp_data -= 0x4000
    temperature_c = temp_data * 0.25
    temperature_f = temperature_c * 9/5 + 32
    return temperature_f, None

# Read a single temperature and exit
temperature, error = read_temperature()
if error:
    print("Error:", error)
else:
    print("Temperature: {:.2f} \u00B0F".format(temperature))

# Clean up
spi.close()
pi.stop()
```

Figure 5: Python Example Code

Main Website Interface: The smoker's control system is accessible through smoker_control.php, which offers an HTML5 interface for users to monitor and adjust the smoker's temperature. This file, designated as **Figure 6** in our documentation, features user-friendly controls for starting and stopping the smoker, as well as a dynamic display of the current and set temperatures. The structured pseudocode can also be observed below in **Figure 7.**

Figure 6: Smoker Control System Interface

```
function setTemperature(temp) {
    // Update the displayed set temperature
    document.getElementById('set-temperature').textContent = `${temp}°F`;
    // Send the set temperature to the server to adjust the servo
    updateServo(temp);
}

function updateServo(setTemp) {
    // POST request to the PHP script with the set temperature
    fetch(`control_servo.php`, {
        method: 'POST',
        headers: { 'Content-Type': 'application/x-www-form-urlencoded' },
        body: `set_temp=${setTemp}`
    })
    .then(handleResponse)
    .catch(handleError);
}

function handleResponse(response) {
    // Parse and log the response data
    console.log('Servo response:', response);
}

function handleError(error) {
    // Log any errors during the fetch operation
    console.error('Error:', error);
}
```

Figure 7: Smoker Structured Pseudocode

4. MANAGEMENT

4.1. PROJECT MILESTONES

The project milestones for the PCB Smoker have been strategically laid out across two semesters to ensure a systematic and efficient progression from concept to completion. The timeline, illustrated in our Gantt chart (referenced as Figure 8), captures the sequence and duration of each phase of the project.

Our critical path started with an initial "Brainstorm" session, setting the foundation for innovation and ideation. Subsequently, we moved through various technical design stages, the acquisition of electrical components, coding for the website, and temperature controls. Afterward, a series of rigorous "Run Tests" phases ensure functionality and reliability. Obtaining the smoker and fitting it accordingly represented the final practical steps toward realizing the smoker's design in a tangible form.

Key milestones include:

- Technical Design 1: Establishing the primary design framework.
- Technical Design Update 2: Refining the design based on initial feedback and testing.
- Acquire Electrical Components: Procuring all necessary electronic parts.
- Code Website: Developing the user interface for smoker control.
- Code Temperature Controls: Implementing the backend logic for temperature regulation.
- Run Tests: Testing each component and system integration comprehensively.
- Obtain Smoker: Acquiring the physical smoker unit.
- Fit Smoker Accordingly: Ensuring all electronic components are fitted correctly in the smoker.

This schedule was crafted not only to manage time effectively but also to allocate ample opportunity for refinement and iteration, crucial for addressing unforeseen challenges. The critical path method applied here ensures that tasks were completed in a logical order and that dependencies are managed to avoid bottlenecks. The full Gantt chart layout with the critical path can be observed below in **Figure 8.**

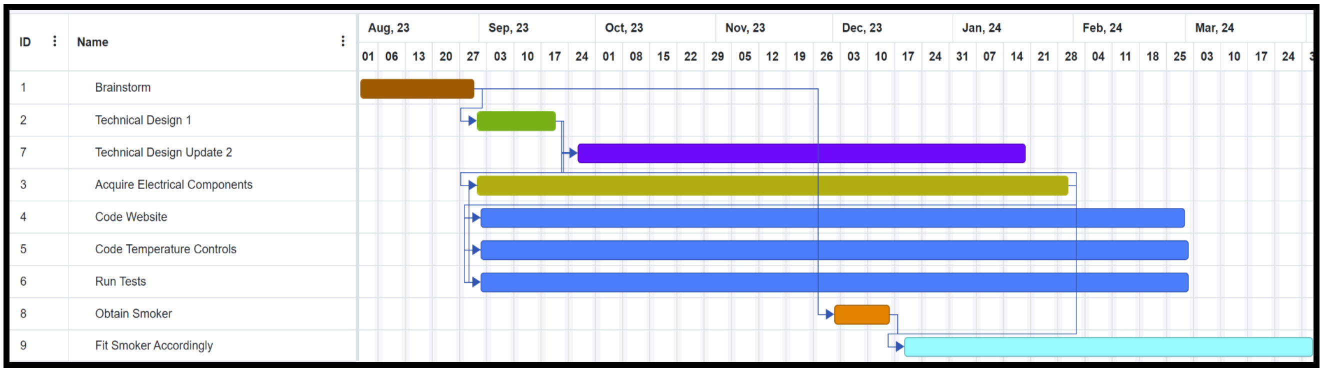

Figure 8: GANTT Chart

4.2. ENCOUNTERED CHALLENGES AND LESSONS LEARNED

Throughout the development of the smoker project, several significant challenges emerged, each offering valuable insights and opportunities for improvement. The following highlights some of the major challenges encountered and the lessons learned from addressing them:

Damage in Transit: Some parts of the smoker were damaged during transportation back to Springfield. This underscored the importance of careful packaging and handling when transporting delicate equipment. In the future, we will implement more robust packaging solutions to mitigate the risk of damage during transit.

Location and Testing Facilities: Finding a suitable location to work on the project and conduct safe testing was a recurring challenge. Housing the smoker at the e-factory initially seemed convenient but posed limitations on testing capabilities, particularly with concurrent programming during cooking. This experience emphasized the importance of having a dedicated and accessible workspace equipped for safe testing and experimentation.

Sealing Air Leaks: Air leaks within the smoke box proved to be a significant issue, causing unpredictable temperature control and impeding results. This highlighted the importance of thorough inspection and sealing of all potential leak points to ensure consistent and accurate temperature regulation.

Data Analysis Challenges: Attempts to create a temperature vs. time graph for a long cook revealed challenges in data analysis. While the matplotlib tool worked in trial runs, issues arose when attempting to graph the results of a prolonged cooking session. This experience highlighted the need for robust data analysis protocols and tools capable of handling large datasets reliably.

Mechanical and Electrical Issues: Various mechanical and electrical issues, such as servo motor glitches, auger malfunctions, and mounting challenges for the microcontroller and touchscreen, were encountered throughout the project. These issues emphasized the importance of thorough testing, troubleshooting, and continuous improvement in both hardware and software components.

Lessons Learned:

- Prioritize thorough packaging and handling procedures to prevent damage during transportation.
- Ensure access to a dedicated and well-equipped workspace for testing and experimentation.
- Conduct thorough inspections to identify and seal any air leaks, ensuring consistent temperature control.
- Invest in robust data analysis tools and protocols for accurate and reliable data interpretation.
- Implement rigorous testing and troubleshooting procedures to address mechanical and electrical issues promptly.
- Emphasize attention to detail and careful wiring to ensure proper functionality and integration of components.

By addressing these challenges and incorporating the lessons learned into our project management approach, we are better equipped to overcome future obstacles and achieve success in our smoker project.

4.3. TEAM ETHICS DISCUSSION

During the development of the PCB Smoker project, the team encountered various ethical challenges, particularly concerning health and safety considerations inherent in creating a smoker. Practices were implemented to establish a clean and sanitary environment within the smoker housing to mitigate food contamination risks. When addressing component damage incurred during transit, consideration was given to selecting materials that were food-safe. Although options like JB Weld or other hardening pastes could effectively seal gaps and provide support, their unsuitability for direct exposure to flame or pellets rendered them inappropriate. Consequently, a metal barrier was installed, wrapped with gasket material, HVAC tape, and a sealant to prevent any unsafe materials from contacting the inside of the firebox, while facilitating even heat distribution and containing smoke. In addition to addressing material concerns, measures were taken to enhance user safety through comprehensive subsystem control. Singular buttons were incorporated to enable users to control all subsystems individually. This feature not only allowed manual control of steady-state functions but also mitigated potential dangers such as fingers or clothing becoming entangled in motors. The ethical challenges encountered during the development of the PCB Smoker project underscored the importance of prioritizing health and safety considerations. By implementing stringent material selection criteria and enhancing user control capabilities, the team ensured compliance with safety standards and minimized potential risks to users and food integrity.

4.4. BUDGET

Our project's financial plan had been meticulously formulated to ensure that every dollar spent was an investment towards robustness, functionality, and user satisfaction. The budget, which amounted to $504.33, had been allocated across various components essential for building the PCB Smoker. This budget included the cost for the primary structure, the Expert Grill 28" Offset Charcoal Smoker Grill, the Raspberry Pi Model 4B as the microcontroller, a variety of sensors and actuators like the MAX31855 Thermocouple to Digital Converter, and other necessary electronic components and tools to bring the smoker to life.

The justification for this budget was rooted in the selection of high-quality, reliable components that promised longevity and performance. We had leveraged bulk purchasing where possible to reduce costs and had chosen parts that provided the best balance between price and capability. This strategic approach to budgeting ensured that we could deliver a top-quality product without excessive spending, adhering to the financial constraints of our project scope.

Product Name	Unit Cost ($)	Quantity	
Expert Grill 28" Offset Charcoal Smoker Grill with Side Firebox, Black	127	1	127
Raspberry Pi Model 4B 4GB	123.99	1	123.99
MAX31855 Thermocouple to Digital Converter Interface Pmod™ Platform Evaluation Expansion Board	24.99	1	24.99
THERMOCOUPLE WIRE K-TYPE 1M	9.99	1	9.99
POWER STRIP	35.99	1	35.99
Raspberry Pi GPIO Terminal Block	16.99	1	16.99
20 AWG 100 FT Copper Wire Spool	13.98	2	27.96
270 Degree Miuzei 20 Kg Servo Motor	11.99	3	35.97
DC Power Jack Adapter 5.5mm (12 Volt 5 Amp)	8.16	1	8.16
DC Power Supply 5.5mm (5 Volt 4 Amp)	16.65	2	33.3
Raspberry Pi 10" HDMI TouchScreen	59.99	1	59.99
		TOTAL	504.33

Table 2: Cost Breakdown

4.5. FUNDING SOURCE

The PCB Smoker project was fully funded by Trenton Cathcart, utilizing earnings from his internship.

4.6. HUMAN SAFETY ASSESSMENT

In assessing the human safety implications of the PCB Smoker project, we have identified and evaluated risks to both the development team and eventual customers. The probability of electrical shocks during development is low, yet the potential effects could be significant, prompting us to enforce strict electrical safety protocols and the use of personal protective equipment. Similarly, the medium risk of burns from soldering equipment is mitigated by comprehensive safety gear and training. For customers, the medium risk of burns from the smoker's hot surfaces is alleviated by the smoker's design, which includes protective casings and warning labels. The low risk of fire is addressed through the inclusion of manual shut-off mechanisms that the user has access to remotely and on site, underpinned by rigorous reliability testing. Lastly, the risk of smoke inhalation is also low, mitigated by providing clear guidelines on proper ventilation and safe usage durations. Our commitment to safety was reflected in our design choices and the educational resources provided, ensuring that all interactions with the smoker, whether in development or use, prioritize health and safety.

4.7. MEMBER CREDENTIALS, RESPONSIBILITIES, AND CAREER PLANS

4.7.1. TEAMWORK

The success of our PCB Smoker project is reinforced by a team that brings together a diverse array of skills, each member contributing their specialized expertise to our collaborative efforts. Our collective proficiency spans the spectrum of electrical engineering, hardware design, and IoT development, with each area being critical to the seamless execution of the project.

In the domains of team leadership and system integration, Trenton Cathcart took the helm, guiding the project with his dual expertise in Electrical Engineering and Physics. Parker Widmeyer complemented this leadership with his focus on IoT and documentation, driving the project's connectivity and user interface forward. Gabriel Boicu anchored the team's hardware design, ensuring that each component is meticulously crafted and integrated. Together, their collective efforts embodied the interdisciplinary nature of the project. However, our team acknowledges the gap left by the absence of a dedicated Computer Engineering (CPE) major, which has led to a more pronounced challenge in the IoT domain.

4.7.2. TRENTON CATHCART (tcgyq@mst.edu, EE & Physics Major)

Trenton took on the pivotal role of team leader for the PCB Smoker project. His broad oversight was critical, as it ensured he maintained a comprehensive understanding of the entire system, which was essential for effective communication and coordination within the team. His responsibilities included orchestrating regular team meetings to review our progress, troubleshoot issues, and strategize next steps.

As the central hub of information, Trenton was instrumental in relaying detailed updates between team members, ensuring everyone was aligned with the project's current status and objectives. His involvement in all aspects of the project, from design to execution, equipped him with the knowledge necessary to make informed decisions and provide guidance.

Moreover, as the point of contact for component delivery, Trenton managed the inventory of parts, which were sent directly to him. This centralization of materials helped to streamline the assembly process and safeguards against logistical complications. His role was integral to the project's success, as it hinged on the timely and precise integration of each part of the system.

4.7.3. PARKER WIDMEYER (pdwyzp@mst.edu, EE & Physics Major)

Parker helped with the documentation, making sure they were prepared for presentation. He provided feedback and guidance on each aspect of the slideshows and reports, as well as writing his own share. Additionally, Parker led the charge on the IoT capabilities. His strong understanding of the 'big picture' in regards to the different features of the smoker that can and should be manipulated allowed a well-thought plan to be created and followed.

Parker also wrote the commercial, and owned the edition portion. His creativity and vision helped make this out-of-profession assignment less daunting for the other members. While the commercial had less priority in relation to the rest of the project, it was able to be handled swiftly and efficiently with Parker's lead.

4.7.4. GABRIEL BOICU(gb5ry@mst.edu, EE Major)

Gabriel had the task of hardware design for the PCB Smoker project. He took a central position in steering the intricate details of hardware components to align seamlessly with project specifications. Drawing parallels with Trenton's broad oversight, Gabriel led from initial design concepts to final execution, ensuring the technical foundation is not only robust but also finely attuned to project objectives. Regular team meetings provided him with a platform to troubleshoot hardware-related intricacies, deliver progress updates, and foster effective coordination with fellow team members, maintaining a comprehensive grasp of the entire system's dynamics.

In tandem with his hardware-focused responsibilities, Gabriel also contributed to the documentation process, ensuring presentations exhibit clarity and completeness. He ensured all team members are well-informed about the crucial hardware design aspects integral to the project's overall success.

5. CONCLUSION AND FUTURE WORK

5.1. CONCLUSION AND LESSONS LEARNED

As the development of the Precision Controlled Bytes (PCB) Smoker progressed, the team has encountered several challenges, particularly in integrating Internet of Things (IoT) capabilities without a dedicated Computer Engineering specialist. This gap was approached with a hands-on attitude; self-study and continuous learning were the tools through which proficiency in this area was being fortified.

A key insight was the paramount importance of coordination and inventory management, especially when navigating supply chain intricacies. By orchestrating these logistics carefully, the team managed to keep the project on track. Team meetings played an essential role, providing a forum where each member's expertise contributes to overcoming hurdles and pushing the project forward.

The collaborative environment fostered by the team has been instrumental in the smooth progression of the project. The diverse skill set of the team members in electrical engineering, documentation, and hardware design proved to be a robust foundation for innovation.

While teamwork and inter-disciplinary collaboration were the project's strengths, the team acknowledges the need for specialized development in IoT—a field that has seen a proactive approach to improvement. By pursuing educational opportunities and hands-on training, the team was dedicated to bridging this gap.

The PCB Smoker project stands as a testament to the importance of adaptability, continuous learning, and a strong collaborative spirit. These qualities were the driving force behind the project.

The journey of the PCB Smoker project underscores the reality that in the realm of innovation, challenges are opportunities for growth. The lessons learned throughout this process are shaping not only the outcome of the project but also the professional development of the team members involved. The project's success is defined not just by its technical achievements but also by the collaborative and educational journey it represents.

5.2. SUGGESTED IMPROVEMENTS

If granted an additional six months for project development, several strategic enhancements and adjustments would be pursued to address identified shortcomings and further optimize project outcomes.

Foremost among the proposed improvements would be a comprehensive redesign of the project's hardware aspect to enhance its visual appeal without compromising functionality. This endeavor would involve meticulous attention to aesthetic considerations while ensuring alignment with the project's core objectives and technical specifications.

Furthermore, efforts would be directed towards sealing the leaks present in the smoker, a crucial step aimed at achieving finer control over temperature regulation. By reducing temperature fluctuations to within a narrower margin of approximately ±10 degrees, as opposed to the current ±20 degrees, the smoker's performance and reliability would be significantly enhanced, thereby facilitating more precise cooking outcomes.

In addition to these hardware refinements, a concerted emphasis would be placed on refining data collection methods to augment project documentation comprehensiveness. By dedicating ample time and resources to this aspect, the project would benefit from enhanced clarity, accuracy, and depth of data analysis, thereby facilitating more informed decision-making processes and enabling a more robust assessment of project performance.

Overall, the proposed adjustments and enhancements underscore a commitment to continuous improvement and optimization, aiming to elevate the project's overall quality, functionality, and appeal through strategic refinement of its hardware design, temperature regulation capabilities, and data collection methodologies.

6. REFERENCES

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