Thermal Mapping of Indoor Building Surfaces

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DEDICATION

Dedicated to the loving memory of my late father.
My mother and my cherished siblings, whose unwavering support and cooperation paved the way for this remarkable achievement.

ABSTRACT

Thermal Scanning of indoor Environments is crucial for System Optimization, Energy efficiency and Human comfort. Utilizing thermal maps generated through a thermal scanning system allows for the Identification of Temperature variations, design enhancement, anomalies detection and HVAC system optimization. This data-driven approach supports cost-effective energy conservation and helps contribute to regulatory compliance, health and safety standards in indoor environments. The developed scanning system integrates development components to provide a comprehensive solution for diverse applications within confined spaces. The thermal mapping system incorporates multimodule system, prominent components that record/capture data are Thermal camera, pi/web camera and a proximity/distance sensor. The system is equipped with real time and offline data processing capabilities, mainly Image Processing, object detection and data generation. Key features of the system include its adaptability to various indoor settings, enabling to extract temperature measurements, object detection, distance measurement and detection of thermal signature. The system's design facilitates rapid and accurate detection of anomalies, such as hotspots or cold zones, contributing to enhanced safety and efficiency in indoor environments. Thermal imaging system's versatility extends to its compatibility with multiple platforms, including handheld devices, drones, and fixed installations, ensuring flexibility in deployment. utilize the system for applications ranging from building diagnostics and energy efficiency assessments to fire prevention and security monitoring. In conclusion, the developed thermal imaging system represents a significant advancement in indoor environmental scanning technology. Its versatility, efficiency and ease of use make it an invaluable tool for professionals across various industries, promoting enhanced safety, efficiency, and data-driven decision-making in indoor spaces.

Keywords: Thermal mapping, Thermal Imaging, Anomalie detection, Image Processing, Indoor Environment, Penalization

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List of Acronyms

Artificial Intelligence	AI
Inertial Measurement Unit	IMU
Computer Vision	CV
Infrared	IR
Heating, Ventilation, and Air Conditioning	HVAC
Red,Green,Blue	RGB
Camera Serial Interface	CSI
Pulse Width Modulation	PWM
General Purpose Input/Output	GPIO
Computer-Aided Design	CAD

CHAPTER 1: INTRODUCTION

1.1 Background and Motivation

British astronomer Sir William Hersche discovered infrared radiation, which is invisible to the human eye but can be felt as heat. This laid the foundation for the development of thermal imaging technology.in late 19 and 20th century inventors and scientist began experimenting with devices that can detect infrared radiations. Most of the modern technology saw significant advancement in WW II infrared imaging technology was developed for military advancement in reconnaissance and targeting. After World War II, thermal imaging technology continued to evolve, with improvements in detectors, optics, and image processing techniques. These advancements expanded the range of applications for thermal imaging beyond military use. Thermal imaging technology has been integrated with other technologies, such as digital cameras and image processing software, to enhance its capabilities and usability. This integration has further expanded the range of applications for thermal imaging. Overall, the history of thermal imaging is characterized by a steady progression of technological advancements driven by military, industrial, and civilian needs. From its early beginnings as a tool for military reconnaissance to its widespread use in diverse applications today, thermal imaging has become an indispensable technology for seeing and measuring heat.

Thermography/Thermal imaging is crucial for detecting anomalies such as overheating in electrical systems, machinery, and HVAC components. Early detection allows for preventive maintenance, reducing downtime and minimizing the risk of equipment failure. Overheating equipment poses a fire hazard. Thermography helps identify potential fire risks before they escalate, enhancing overall safety in indoor environments and reducing the risk of accidents or injuries[2]. Identifying inefficiencies in HVAC systems and insulation, thermography can help optimize energy usage, leading to cost savings and a more sustainable operation.

Without thermographic monitoring, faults and anomalies may go undetected until they lead to catastrophic equipment failure, resulting in unexpected downtime, loss of productivity, and expensive repairs. Overheating electrical components or machinery can lead to fires, especially in environments where flammable materials are present. Without thermographic monitoring, potential fire hazards may remain undetected until it's too late, posing significant risks. Failure to detect and address inefficiencies through thermographic monitoring can lead to higher operational costs over time due to energy wastage and increased maintenance expenses.

Combining thermal and RGB cameras offers a more comprehensive monitoring solution, providing both temperature data and visual context for easier interpretation. Integration of thermal and RGB data enables more accurate insights into temperature patterns and anomalies, leading to better decision-making and more effective maintenance strategies. Thermal monitoring systems using both thermal and RGB cameras can improve safety by detecting potential hazards and enhance operational efficiency by identifying inefficiencies. Such systems can be designed to be scalable and adaptable to various indoor environments, increasing their utility and market reach. Integration with other technologies such as IoT devices and automation systems enables real-time monitoring, predictive maintenance, and automated responses to anomalies, further enhancing operational efficiency.

1.2 Problem statement

In indoor environments, there's a critical need for a comprehensive thermal monitoring and scanning system that effectively detects anomalies, ensures safety, and optimizes energy usage in equipment and machinery. Existing monitoring methods often lack the ability to provide comprehensive insights, leading to increased risks of equipment failure, safety hazards, and unnecessary operational costs. Moreover, the high cost associated with advanced thermal imaging solutions poses a barrier to adoption for many organizations. Therefore, there is an urgent need for an affordable yet comprehensive thermal monitoring solution that integrates advanced thermal imaging technology with RGB cameras, providing real-time monitoring, enhanced visualization, actionable insights, and cost-efficiency for indoor environments. Current monitoring systems may not reliably detect temperature variations and anomalies in equipment, leading to potential equipment failures and unexpected downtime. Inadequate thermal monitoring increases the risk of safety hazards such as overheating equipment, which can result in fires and endanger personnel and property. Undetected anomalies in HVAC systems and other equipment lead to unnecessary energy consumption and inflated operational costs. High costs associated with advanced thermal imaging technology hinder widespread adoption, limiting access to comprehensive monitoring solutions.

1.3 Objective

The first objective of this research is to develop a comprehensive thermal monitoring and scanning system for indoor environments. Design and develop a thermal monitoring and scanning system capable of capturing and analyzing thermal and Visual data in indoor environments. Integrate advanced and cost-effective imaging technology with appropriate sensors to ensure accurate temperature measurements and anomaly detection. Implement robust data processing algorithms to analyze thermal data, identify anomalies, and generate actionable insights. Design the system to be scalable and adaptable to various indoor environments, accommodating different sizes and types of facilities.

The second objective of this research is to conduct multiple scanning experiments and micro-scanning to record data and analyze it. Thirdly, utilizing the recorded data, compare it with contact-based methods to detect non-uniform thermal distribution. Design and execute a series of scanning experiments in diverse indoor environments to capture comprehensive thermal data using the developed monitoring system. Implement micro-scanning techniques to acquire detailed thermal images, facilitating accurate analysis of temperature distribution. Collect thermal data from scanning experiments and analyze it using advanced data analysis techniques to identify temperature variations and anomalies. Utilize contact-based temperature measurement methods, such as thermocouples or infrared thermometers, to obtain ground truth temperature data for comparison with the thermal imaging results.

1.4 Thesis Overview

The chronological breakdown of this article is in the following order:

1. Chapter 2 shows the work done by inventors and researchers in Thermal Imaging.
2. Chapter 3 shows the design and development of the system.
3. Chapter 4 Experimental Setup
4. Chapter 5 Experiment 01
5. Chapter 6 Experiment 02
6. Chapter 7 Conclusion and Future Recommendations

CHAPTER 2: LITERATURE REVIEW

The process of conducting a literature review serves as a crucial step in any research endeavor, enabling researchers and developers to contextualize their work within existing knowledge, identify research gaps, and draw upon methodologies employed by predecessors. In the domain of thermography, a comprehensive understanding of historical developments, technological advancements, and limitations forms the foundation for contemporary research. This literature review synthesizes key findings from various studies to elucidate the evolution of thermography, calibration processes for thermal cameras, diverse applications spanning agriculture, quality control, and safety [7], as well as emerging trends such as artificial intelligence (AI) integration and mobile robotics for thermal mapping.

The history of thermography traces back to its inception as a tool for thermal imaging. Over time, advancements in technology have revolutionized the field, leading to the development of high-quality thermal imaging sensors. As technological capabilities expanded, so too did the manufacturing processes associated with thermal imaging sensors, resulting in heightened precision and sensitivity. Central to the reliability and accuracy of thermal imaging is the calibration process. Budzier (2015) delves into the intricacies of calibrating uncooled thermal infrared cameras, elucidating the procedures and techniques essential for ensuring optimal performance [5]. By understanding and implementing rigorous calibration protocols, researchers can mitigate errors and enhance the credibility of their thermal imaging data. The versatility of thermal imaging technology is evidenced by its diverse applications across multiple sectors. In agriculture, thermal cameras are instrumental in monitoring crop health, detecting pests and diseases, and optimizing irrigation practices. Similarly, in quality control processes, thermal imaging facilitates non-destructive testing, defect detection, and product evaluation[9]. Moreover, thermal cameras play a vital role in ensuring safety across various environments, enabling early detection of fires, electrical faults, and hazardous conditions.

A notable application of thermal imaging technology involves its utilization in indoor environments for monitoring human activity [2]. Studies such as the one conducted by MDPI/Sensors Journal explore the efficacy of thermal imaging detection systems in tracking human movement within indoor spaces [3]. By capturing the influx and outflux of heat signatures, thermal cameras offer valuable insights for crowd management [8], security, and resource allocation. In response to the growing demand for enhanced capabilities and automation, researchers are exploring the integration of artificial intelligence with thermal imaging technology. By leveraging AI algorithms, thermal cameras can analyze complex thermal data in real-time, enabling predictive maintenance [4], anomaly detection, and decision support systems [11]. Furthermore, the development of wheeled mobile robots equipped with thermal mapping capabilities represents a novel approach to spatial data collection and environmental monitoring [6]. The literature review underscores the multifaceted nature of thermography, encompassing historical evolution, calibration methodologies, diverse applications, and emerging trends. By synthesizing insights from prior research, this review provides a comprehensive framework for guiding future investigations and innovations in the field of thermal imaging technology. As advancements continue to unfold, the integration of thermography with AI, robotics, and other cutting-edge technologies holds promise for addressing complex challenges and unlocking new possibilities across various domains.

CHAPTER 3: DESIGN AND DEVELOPMENT

The First Industrial Revolution, which began in the late 18th century, marked a pivotal shift from agrarian societies to industrialized ones. Central to this transformation was the invention of the steam engine, which powered machinery in textile mills and factories. Mechanized spinning and weaving processes revolutionized textile production, leading to increased efficiency and output. Concurrently, the iron and coal industries flourished, providing the necessary materials for construction and energy. This era witnessed the rise of factories and urban centers, as people migrated from rural areas to cities in search of employment opportunities. The introduction of steam-powered transportation, such as railways and steamships, facilitated the movement of goods and people, laying the groundwork for global trade networks. The Second Industrial Revolution, occurring in the late 19th and early 20th centuries, was built upon the foundations laid by its predecessor. Key innovations during this period included electricity, the internal combustion engine, and advances in steel production. Electricity revolutionized manufacturing processes, enabling the widespread adoption of electric lighting, motors, and machinery. The internal combustion engine powered automobiles and transformed transportation, while advancements in steel production facilitated the construction of bridges, skyscrapers, and railways. Telecommunications also played a crucial role, connecting distant regions and facilitating the exchange of information. This era witnessed the rise of industrial giants and the consolidation of large corporations, driving economic growth and urbanization on a global scale.

The Third Industrial Revolution, often referred to as the Digital Revolution, unfolded in the latter half of the 20th century with the emergence of digital technologies. Central to this era were advancements in computing, telecommunications, and the internet. The invention of the computer and the development of microprocessors paved the way for automation and digitalization across various industries. The internet revolutionized communication and commerce, enabling the rapid exchange of information and the creation of global networks. This period witnessed the proliferation of personal computers, the birth of the internet age, and the rise of digital platforms and services. The third industrial revolution transformed economies into knowledge-based ones, with a growing emphasis on information technology, telecommunications, and digital innovation. We are currently experiencing the Fourth Industrial Revolution, characterized by the convergence of digital, physical, and biological technologies. This era is marked by advancements in artificial intelligence, machine learning, robotics, the Internet of Things (IoT), 3D printing, nanotechnology, and biotechnology. These technologies are revolutionizing industries and reshaping the way we live, work, and interact with the world. Smart factories equipped with automation and IoT sensors are optimizing production processes and enabling real-time data analytics. AI and machine learning algorithms are driving innovation in fields such as healthcare, finance, and transportation, leading to personalized experiences and predictive capabilities. The fourth industrial revolution is blurring the lines between the physical and digital worlds, creating new opportunities for innovation, but also raising concerns about automation, job displacement, and ethical considerations surrounding emerging technologies.

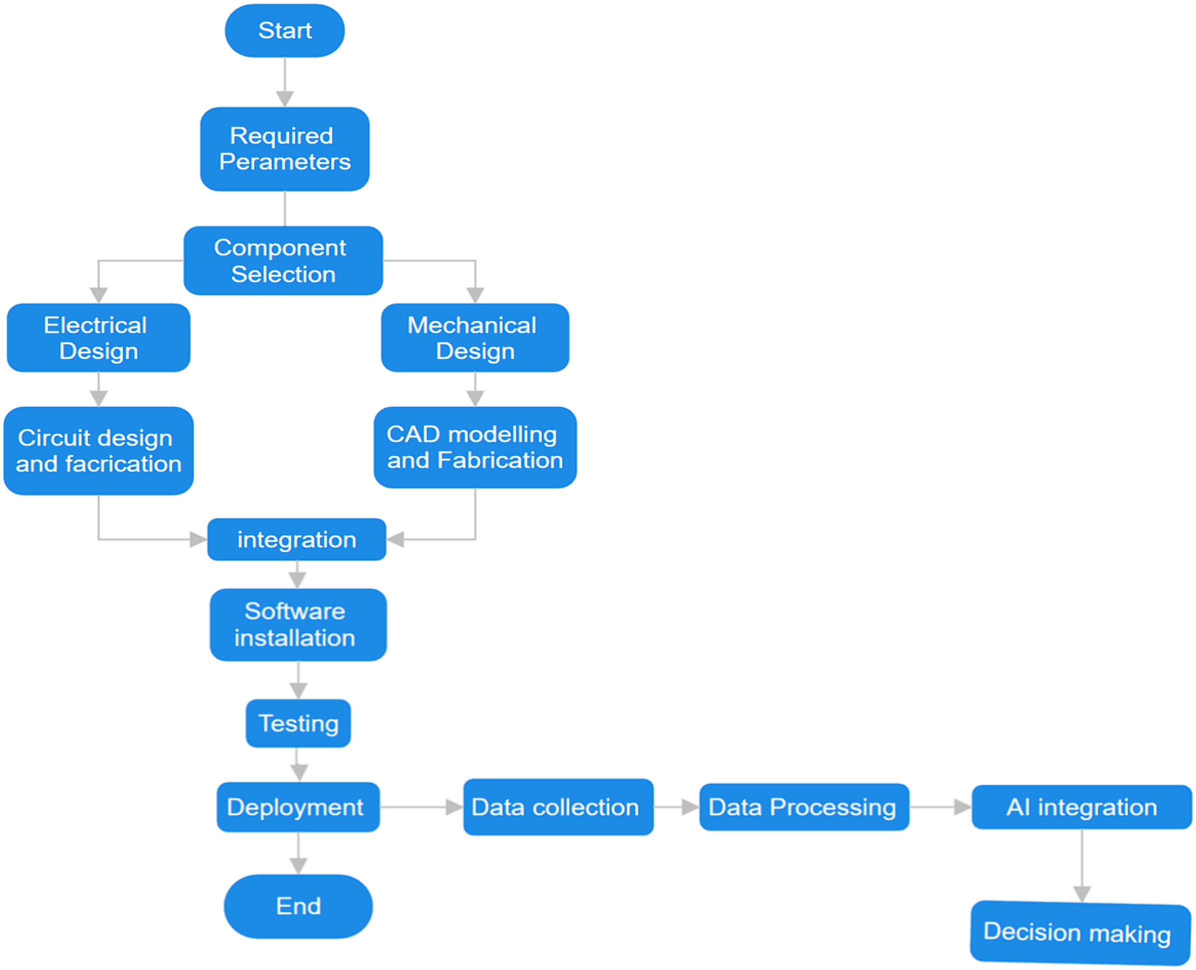

Figure 3.1: Basic Flow of Equipment Development

3.1 Component Selection

3.1.1 *Flir-lepton 2.5 dev*

The FLIR Lepton 2.5 Dev Kit is a cutting-edge thermal imaging solution designed for developers and engineers seeking to integrate thermal imaging capabilities into their projects. At its core lies the FLIR Lepton 2.5 sensor, renowned for its compact size and high performance. With a thermal resolution of 80x60 pixels, the Lepton 2.5 captures detailed thermal images, enabling users to detect temperature variations with precision. The dev kit provides a seamless integration experience, featuring a simple interface and compatibility with popular development platforms such as Raspberry Pi and Arduino. Its plug-and-play functionality allows developers to quickly start capturing thermal data and exploring its applications. The kit also includes essential components like a breakout board, enabling easy connection to other devices and peripherals. With its versatility and user-friendly design, the FLIR Lepton 2.5 Dev Kit empowers developers to innovate across various industries, from home automation and security to industrial monitoring and beyond.

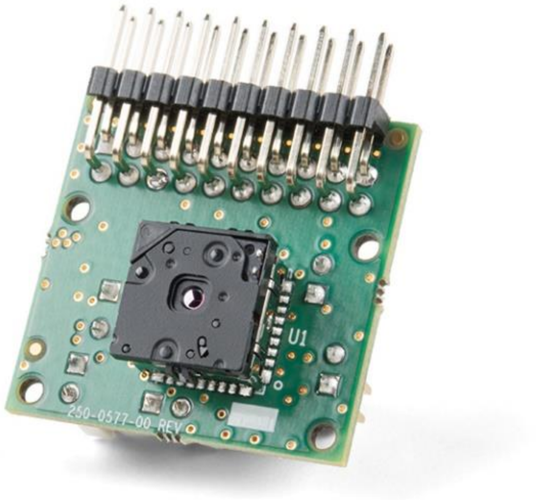

Figure 3.2: Flir Lepton 2.5 Dev Kit

3.1.2 Pi-cam / webcam

The Pi-Cam, short for Raspberry Pi Camera Module, is a compact and versatile imaging solution designed specifically for use with Raspberry Pi single-board computers. This camera module boasts high-resolution imaging capabilities, offering users the ability to capture still images and video footage with exceptional clarity. Equipped with a high-quality sensor, the Pi-Cam delivers sharp and detailed visuals, making it suitable for a wide range of applications, including photography, videography, surveillance, and machine vision. Its small form factor and easy connectivity via the CSI (Camera Serial Interface) connector make it a convenient option for integrating imaging capabilities into various projects and applications. Additionally, the Pi-Cam is supported by a robust software ecosystem, providing users with access to a wealth of tools and libraries for image processing and manipulation. Whether used for hobbyist projects, educational purposes, or professional applications, the Pi-Cam offers a cost-effective and accessible solution for capturing and processing visual data with Raspberry Pi devices.

Figure 3.3: Pi-Cam / Webcam

3.1.3 Sharp Ir Proximity Sensor

The Sharp IR Proximity Sensor is an advanced sensing device designed to detect the presence of objects within its detection range. Utilizing infrared technology, this sensor emits infrared light and measures the intensity of the reflected signal to determine the proximity of objects. With its precise detection capabilities, the Sharp IR Proximity Sensor can accurately measure distances ranging from a few centimeters to several meters, depending on the specific model and configuration. This makes it ideal for applications requiring reliable object detection and proximity sensing, such as robotics, automated manufacturing, and security systems. The sensor's compact size and low power consumption make it easy to integrate into various electronic systems, while its rugged construction ensures durability and reliability in challenging environments. Additionally, the sensor typically features analog or digital output options, allowing seamless integration with microcontrollers and other electronic devices. Whether used for obstacle detection, motion sensing, or distance measurement, the Sharp IR Proximity Sensor offers precise and reliable performance for a wide range of applications.

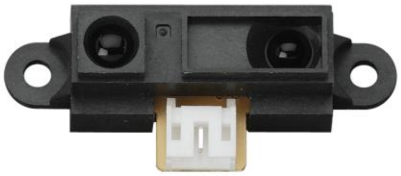

Figure 3.4: Sharp Ir Proximity Sensor

3.1.4 IMU (MPU-6050)

The Inertial Measurement Unit (IMU) MPU-6050 is a highly integrated motion tracking device that combines a 3-axis gyroscope and a 3-axis accelerometer on a single chip. Developed by Intenseness, the MPU-6050 offers precise motion sensing capabilities suitable for a variety of applications, including motion tracking, orientation estimation, and gesture recognition. The gyroscope measures angular velocity along the X, Y, and Z axes, providing accurate information about rotational motion, while the accelerometer measures acceleration along these axes, enabling the detection of changes in linear motion. The MPU-6050 features a digital interface compatible with microcontrollers, allowing seamless integration into embedded systems and wearable devices. With its low power consumption and compact form factor, the MPU-6050 is well-suited for battery-powered applications and mobile devices. Additionally, the MPU-6050 often includes built-in motion processing algorithms to simplify motion data fusion and sensor calibration, further enhancing its usability for developers and engineers. Whether used in robotics, virtual reality, or drone navigation systems, the MPU-6050 IMU offers precise motion tracking capabilities essential for a wide range of motion sensing applications.

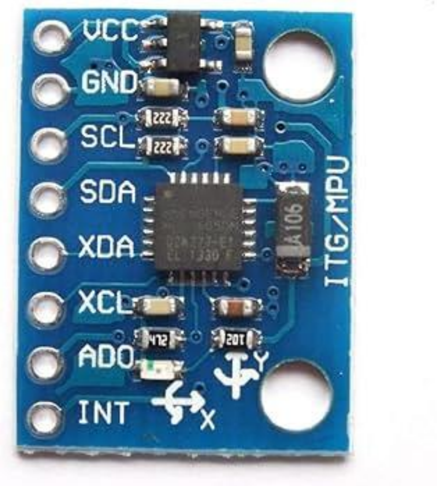

Figure 3.5: IMU (MPU6050)

3.1.5 Raspberrypi-4

The Raspberry Pi 4 is a powerful single-board computer renowned for its versatility and performance. Developed by the Raspberry Pi Foundation, this compact yet robust device features a quad-core ARM Cortex-A72 processor, offering significant improvements in processing power compared to its predecessors. With options for 2GB, 4GB, or 8GB of RAM, the Raspberry Pi 4 can handle a wide range of computing tasks, from basic programming and web browsing to multimedia playback and even light gaming. It boasts a variety of connectivity options, including gigabit Ethernet, dual-band Wi-Fi, Bluetooth 5.0, and multiple USB ports, allowing seamless integration with peripherals and networking devices. The Raspberry Pi 4 also supports 4K video output via its HDMI port, making it suitable for multimedia applications and digital signage. Its GPIO (General Purpose Input/Output) pins enable interfacing with sensors, actuators, and other electronic components, making it an excellent platform for DIY projects and prototyping. Moreover, the Raspberry Pi 4 runs a range of operating systems, including Linux-based distributions like Raspberry Pi OS (formerly Raspbian), Ubuntu, and others, providing users with flexibility in software development and experimentation. Whether used for educational purposes, home automation, or as a development platform for IoT (Internet of Things) projects, the Raspberry Pi 4 offers a versatile and affordable computing solution with robust performance and extensive connectivity options.

Figure 3.6: Raspberry-pi 4

3.1.6 Arduino

Arduino is an open-source electronics platform that has gained widespread popularity for its simplicity and versatility in prototyping and creating interactive projects. At the heart of the Arduino platform is the Arduino board, which typically consists of a microcontroller, input/output pins, and various other components. The microcontroller serves as the brain of the Arduino, executing programs written in the Arduino programming language, which is based on C/C++. Arduino boards come in various shapes and sizes, catering to different project requirements and levels of complexity. They offer a wide range of input and output options, including digital and analog pins, PWM (Pulse Width Modulation) outputs, communication ports like UART, I2C, and SPI, as well as onboard sensors and modules. Additionally, Arduino boards can be easily expanded with shields—add-on boards that provide additional functionalities such as Ethernet connectivity, wireless communication, or motor control. The Arduino IDE (Integrated Development Environment) provides a user-friendly platform for writing, compiling, and uploading code to Arduino boards, making it accessible even to beginners in programming and electronics. With its extensive community support, vast collection of libraries, and compatibility with a wide range of sensors and actuators, Arduino empowers enthusiasts, students, and professionals alike to bring their ideas to life in fields ranging from robotics and automation to IoT and wearable technology.

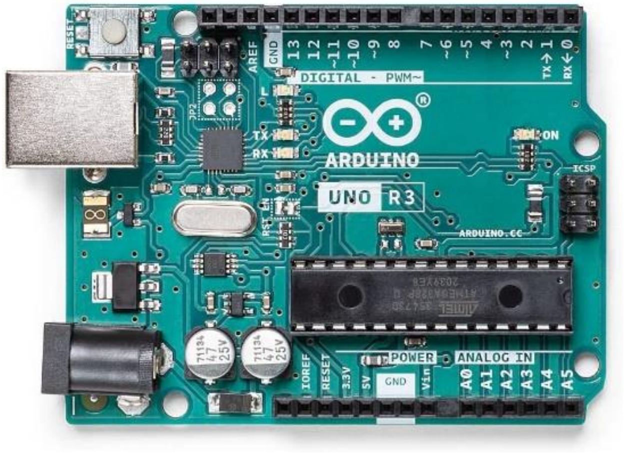

Figure 3.7: Arduino UNO

3.1.7 Servo Motor

A servo motor is a highly precise rotary actuator that operates based on feedback control mechanisms. It comprises a motor coupled with a feedback device, typically an encoder or a resolver, allowing for precise control of angular position, velocity, and acceleration. Servo motors are commonly used in various industrial and automation applications where accurate and controlled motion is critical. They offer high torque-to-inertia ratio, enabling rapid response to changes in control signals. The motor's position is controlled by comparing the actual position feedback with the desired position reference, and adjustments are made using a closed-loop control system to minimize error. Servo motors are available in different sizes and configurations to suit a wide range of applications, offering versatility and reliability in demanding environments.

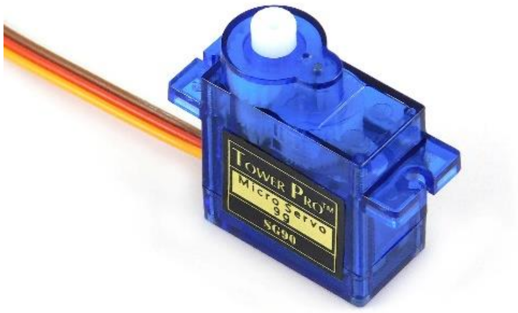

Figure 3.8: Servo Motor

3.1.8 Limit Switch

A limit switch is a crucial component in automation and control systems designed to detect the presence or absence of an object or to monitor the position of a moving part. It consists of a mechanical lever or plunger actuator that makes or breaks electrical contacts based on the physical motion of the switch. When the actuator is triggered by an object or reaches a predefined position, it activates the switch mechanism, causing a change in the electrical output. Limit switches are commonly used in industrial machinery, conveyor systems, and automated equipment to control the movement of components, prevent overtravel, and provide feedback for system operation. They are available in various configurations, including lever-type, roller-type, and plunger-type switches, each tailored to specific application requirements. Limit switches offer reliability, durability, and precision, making them indispensable for ensuring safe and efficient operation in automated systems.

Figure 3.9: Limit Switch

3.1.9 5V Stepper motor

A stepper motor is a specialized electromechanical device designed for precise control of rotational motion. Unlike conventional motors, which continuously rotate, a stepper motor moves in discrete steps, making it ideal for applications requiring accurate positioning and controlled motion. Stepper motors consist of a rotor and stator, with the rotor typically containing teeth or poles and the stator comprising coils arranged in a specific configuration. By energizing the coils in a sequence determined by a controller, the magnetic field interacts with the rotor, causing it to move incrementally. Stepper motors offer precise control over speed, position, and acceleration, making them widely used in various applications such as 3D printers, CNC machines, robotics, and automated systems. They come in different types and sizes, including bipolar and unipolar configurations, each suited for specific performance requirements and control methods. Stepper motors are valued for their reliability, ease of control, and ability to operate in open-loop systems, making them indispensable in industries requiring accurate and repeatable motion control.

Figure 3.10: 5v Stepper Motor

3.2 CAD Design

3.2.1 Camera Housing

The CAD designing of a camera housing for integrating three components, namely a FLIR thermal camera, a webcam, and a Sharp IR sensor, involves meticulous attention to detail and precision engineering. The process begins with analysing the specifications and dimensions of each component to ensure proper fit and alignment within the housing. Using Computer-Aided Design (CAD) software, a virtual model of the housing, considering factors such as, structural integrity, and accessibility for maintenance. Careful consideration is given to cable routing and connection points to ensure seamless integration and ease of assembly. The design may incorporate features such as mounting brackets, lens enclosures, and ventilation channels tailored to the specific requirements of each component. Iterative prototyping and testing are conducted to validate the design and optimize performance before moving to production. The result is a meticulously crafted camera housing that not only houses the components securely but also enhances the functionality and reliability of the integrated system.

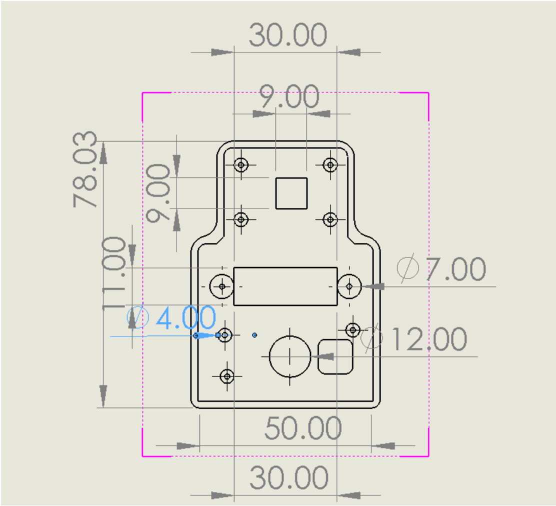

Figure 3.11: CAD Drawing Camera Housing

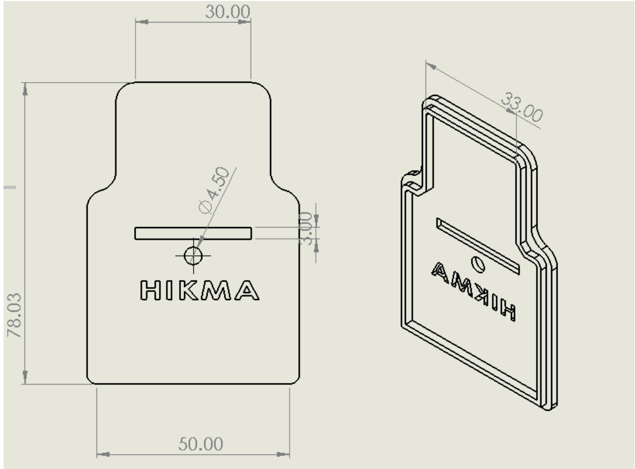

Figure 3.12: CAD Drawing Back Cover

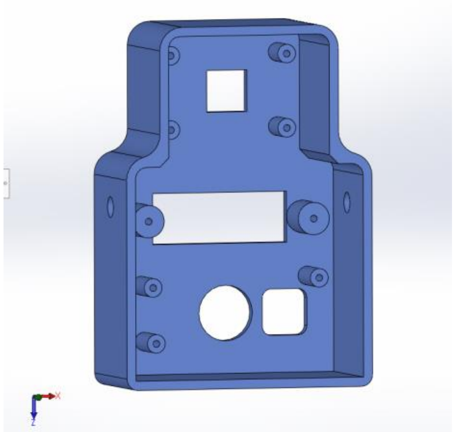

Figure 3.12: Camera Housing 3D Simulation.

3.3 Gimbal Frame

The design of the gimbal frame prioritizes three degrees of freedom while ensuring ample rotation space to accommodate a full 180-degree flip of the camera. This configuration allows for versatile and dynamic camera movement in three axes: pitch, yaw, and roll, providing flexibility in capturing shots from various angles and orientations. Careful attention is paid to the structural layout and geometry of the frame to enable smooth and unrestricted rotation of the camera. Special consideration is given to the clearance and spacing within the frame to prevent any physical obstructions or interference during camera movement. By incorporating these design features, the gimbal frame offers filmmakers and photographers the ability to achieve seamless and precise camera control, facilitating the capture of cinematic and creative footage with ease.

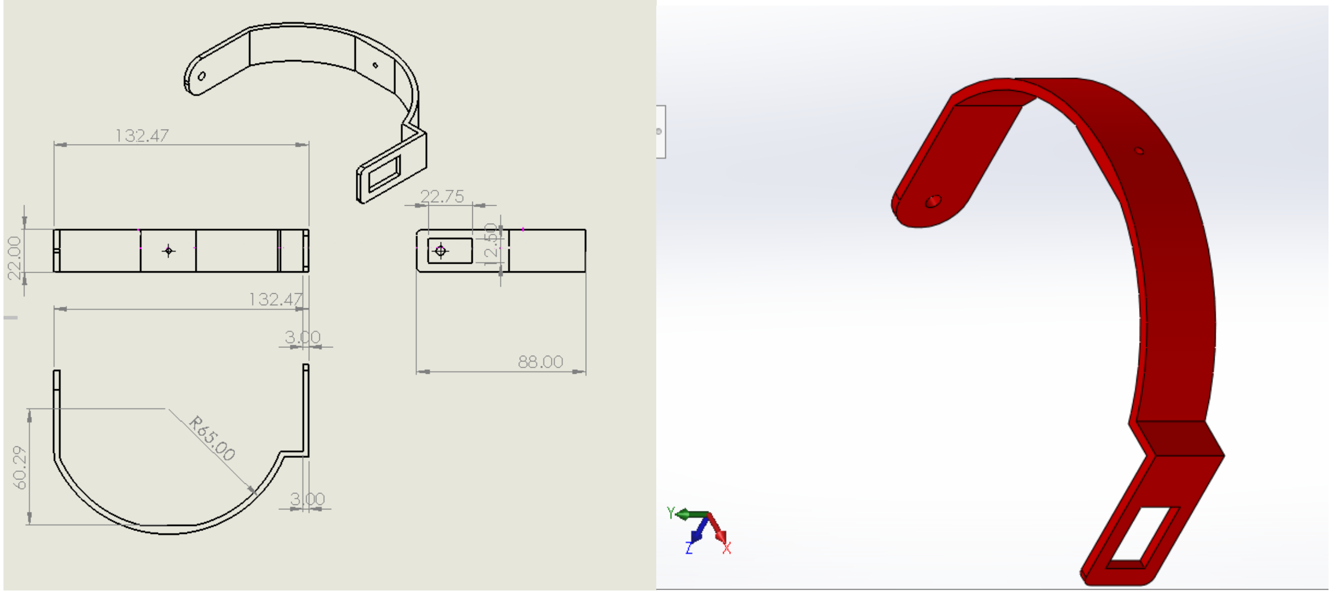

Figure 3.13: Gimbal Frame (yaw and pitch axis link)

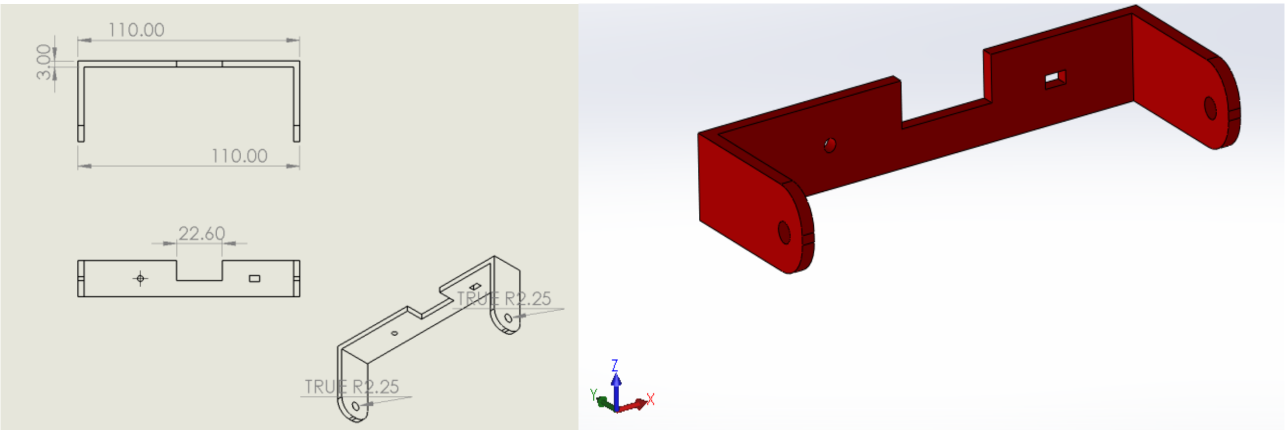

Figure 3.14: Gimbal Frame (pitch and tilt axis link)

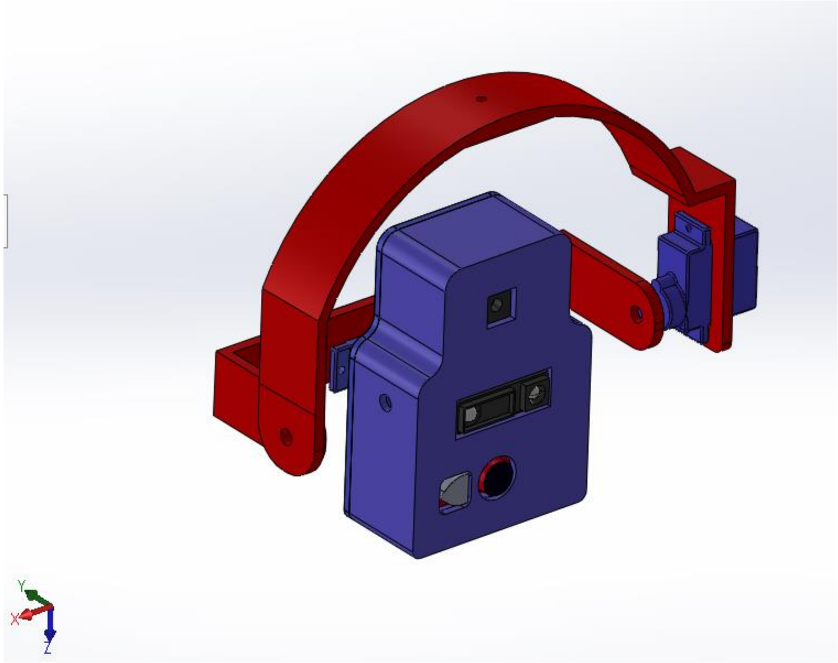

Figure 3.15: CAD Assembly (Camera and gimbal)

3.4 Electrical Design

The electrical design of the thermal scanning system integrates multiple components for seamless communication and operation. At the core of the system is the Raspberry Pi, serving as the central processing unit and interfacing hub. The thermal camera and webcam are connected to the Raspberry Pi via USB and serial communication protocols, allowing for data transfer and control. Additionally, the Arduino acts as an intermediary between the Raspberry Pi and various peripherals, managing the communication and control of devices such as the IMU, limit switch, servo, and stepper motor. The connection between the Arduino and Raspberry Pi is established using various communication interfaces, including ISP, I2C, and serial communication, ensuring efficient data exchange and synchronization between the two microcontrollers. The ISP (In-System Programming) interface facilitates programming and firmware updates of the Arduino directly from the Raspberry Pi, enhancing flexibility and ease of maintenance.

The peripherals connected to the Arduino, including the IMU (Inertial Measurement Unit), limit switch, servo, and stepper motor, play critical roles in the functionality of the thermal scanning system. The IMU provides orientation and motion sensing capabilities, enabling the system to compensate for movements and maintain stability during operation. The limit switch serves as a safety mechanism, preventing overtravel or unintended movements of the scanning system. The servo and stepper motor are responsible for precise control of positioning and scanning motions, ensuring accurate data acquisition and imaging. To power the entire system, a buck converter is employed to regulate the voltage from a 12V power supply. This converter efficiently steps down the voltage to the required levels for each component, ensuring stable and reliable operation while minimizing power consumption and heat generation. Overall, the electrical design of the thermal scanning system integrates various components and communication protocols to enable seamless interaction and precise control, ensuring optimal performance and functionality in diverse applications.

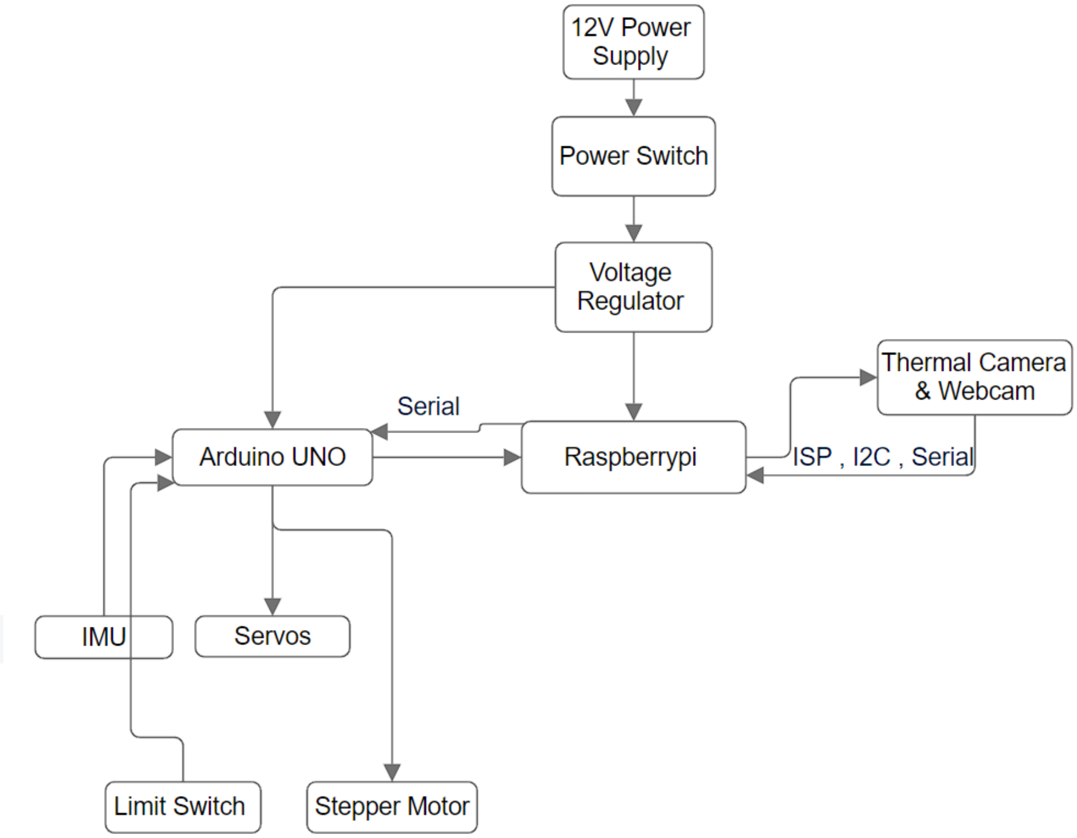

Figure 3.16: Electrical schematic.

3.5 Fabrication and Assembly

The structural components of the gimbal and camera housing are meticulously crafted using state-of-the-art 3D printing technology, ensuring precision and durability in their fabrication. Within the camera housing, provisions are made to seamlessly accommodate the thermal camera, webcam, and proximity sensor, enhancing the system's versatility and functionality. Meanwhile, the gimbal frame is designed with specific locations to house servos, strategically positioned to optimize the balance and stability of the gimbal. To facilitate smooth movement and flexibility in camera positioning, flexible ribbon cables are employed to route connections for the thermal camera, webcam, and Sharp IR sensor. Additionally, the central hub serves as the nerve center of the system, housing critical components such as the Arduino, Raspberry Pi, IMU, and stepper motor. This centralized arrangement streamlines communication and control, enabling efficient coordination and synchronization of the thermal scanning system for precise data acquisition and analysis.

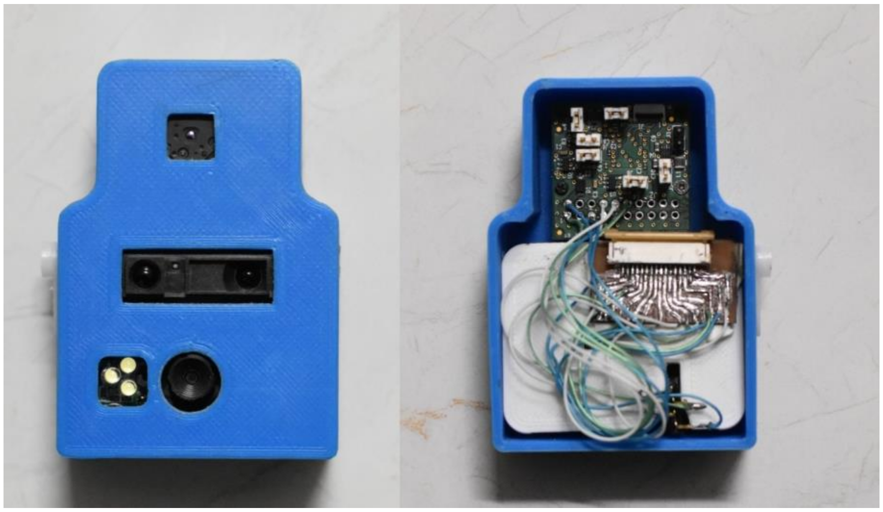

Figure 3.17: Fabricated and Assembled Camera unit

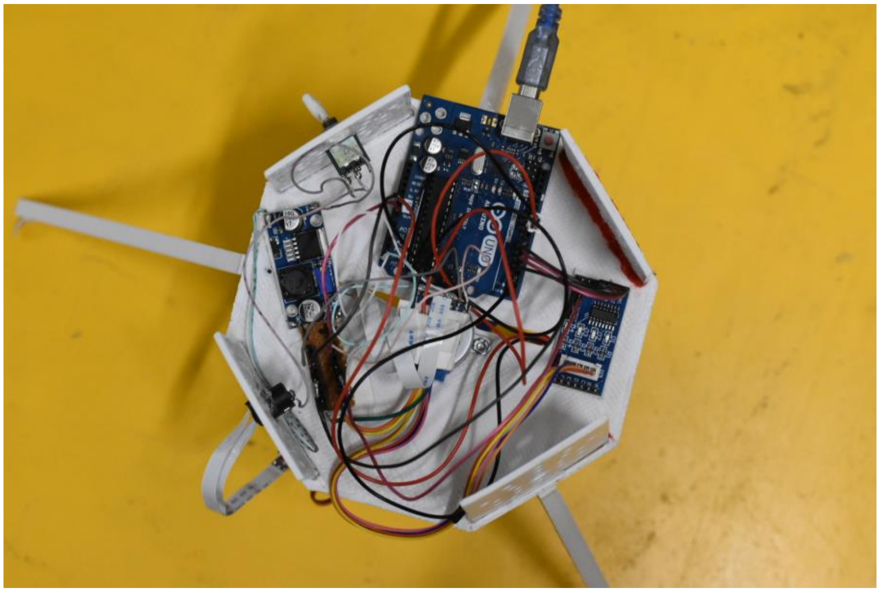

Figure 3.18: Control Hub

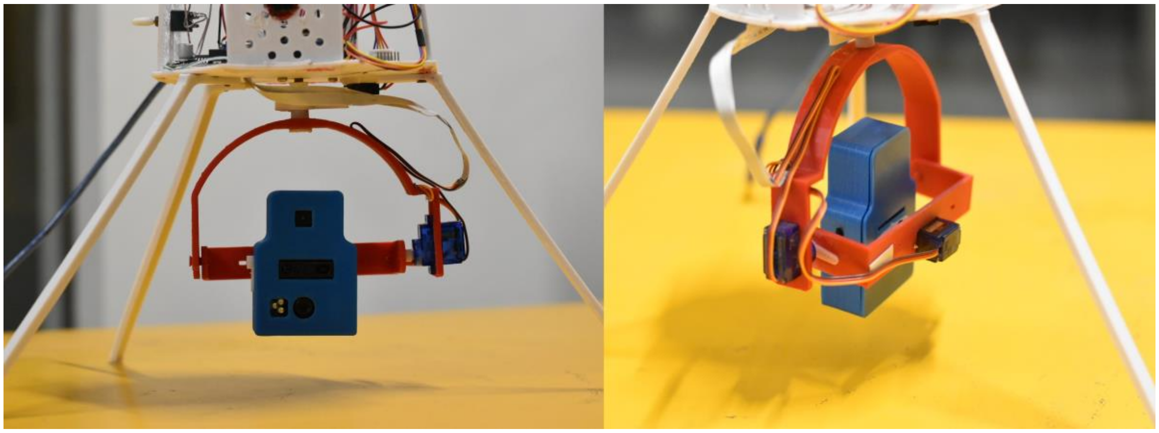

Figure 3.19: Completed Assembly

3.6 Software Development

3.6.1 Algorithms for Gimbal Stabilization and Control

Gimbal stabilization and precise position control are paramount for capturing accurate data in various applications, from aerial photography to thermal imaging. In our setup, the gimbal is controlled using an Arduino microcontroller, which incorporates data from an Inertial Measurement Unit (IMU) to maintain stability and adjust orientation. Initially, a preset zero position is calibrated for the gimbal, providing a reference point for angular positioning. The IMU continuously tracks the orientation of the gimbal, and this data is mapped onto the gimbal to ensure proper alignment. Additionally, to offer flexibility and ease of control, position adjustments can be made using an onboard computer, specifically a Raspberry Pi, or an external joystick. The Raspberry Pi acts as the central control unit, providing commands to the Arduino for position adjustments based on user input or pre-defined parameters.

```
initialize_gimbal()
calibrate_zero_position()
initialize_IMU()
while True:
    imu_data = read_IMU()
    gimbal_angle = map_IMU_data_to_gimbal(imu_data)
    adjust_gimbal_position(gimbal_angle)
    if external_input_received():
        input_data = read_external_input()
    if input_data == joystick_input:
        adjust_gimbal_position(input_data)
    else if input_data == computer_command:
        process_command(input_data)
```

In this pseudo-code, the algorithm continuously reads IMU data to track the gimbal's orientation. The data is then mapped onto the gimbal to adjust its position accordingly. Additionally, the algorithm checks for external inputs, such as joystick commands or computer commands from the Raspberry Pi, to allow for manual adjustments or automated control of the gimbal position.

$$Position = \frac{im - im_{min}}{im_{max} - im_{min}}(s\_max - s\_min) + s_{\boldsymbol{min}} \qquad Equation\ 1$$

Equation 1

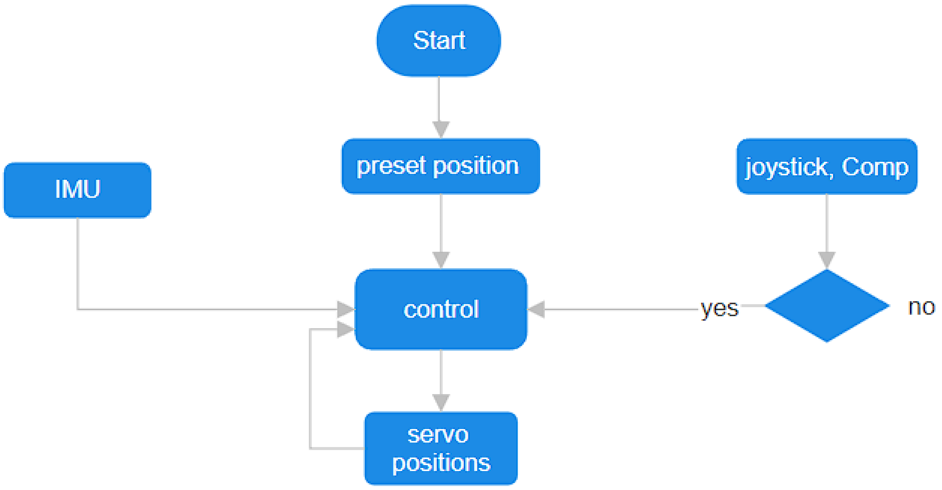

Figure 3.20: Gimbal Control System

3.6.2 Algorithms for Data Collection and Processing

The algorithm for data collection and processing in the thermal scanning system is crucial for gathering and analysing multimodal data effectively. This includes thermal images and RGB images captured simultaneously from the same frame, alongside camera positioning information relative to the frame of origin and proximity data from objects in the environment. The raw thermal data is acquired using the Pylepton library from GitHub, where each pixel represents the intensity of infrared radiation emitted by the corresponding area, providing temperature data in Kelvin. This data is then converted to Celsius for standardization and ease of interpretation. Subsequently, the collected data is normalized and scaled to generate images, with the presentation method determining the specific scaling and normalization techniques applied. Additionally, colour-mapping is utilized to enhance the visualization of the thermal images based on user preferences. Both thermal and RGB images are overlapped and calibrated meticulously to ensure precise alignment, enabling accurate correlation between thermal and visual data. Finally, the calibrated data is stored and presented for further analysis, facilitating the identification of heat signatures, objects, and areas with high thermal significance.

```
import pylepton
def data_collection_and_processing():
    initialize_data_collection()
while data_collection_active:
        raw_thermal_data = capture_raw_thermal_data()
        processed_thermal_data_celsius = convert_to_celsius(raw_thermal_data)
        normalized_thermal_image = normalize_and_scale(processed_thermal_data_celsius)
        thermal_image_with_colormap = apply_colormap(normalized_thermal_image)
         rgb_image = capture_rgb_image()
        camera_position = get_camera_position()
        proximity_data = get_proximity_data()
        overlapped_image = overlay_images(thermal_image_with_colormap, rgb_image
        calibrated_image = calibrate_image(overlapped_image, camera_position)
        store_data(calibrated_image, camera_position, proximity_data)
        if termination_condition_met():
            data_collection_active = False
```

This pseudo-code outlines the steps involved in collecting, processing, and storing data from the thermal scanning system. It captures both thermal and RGB data, processes the thermal data, converts temperature units, generates images, applies colour-mapping, overlays and calibrates the images, and stores the calibrated data along with camera position and proximity information for further analysis.

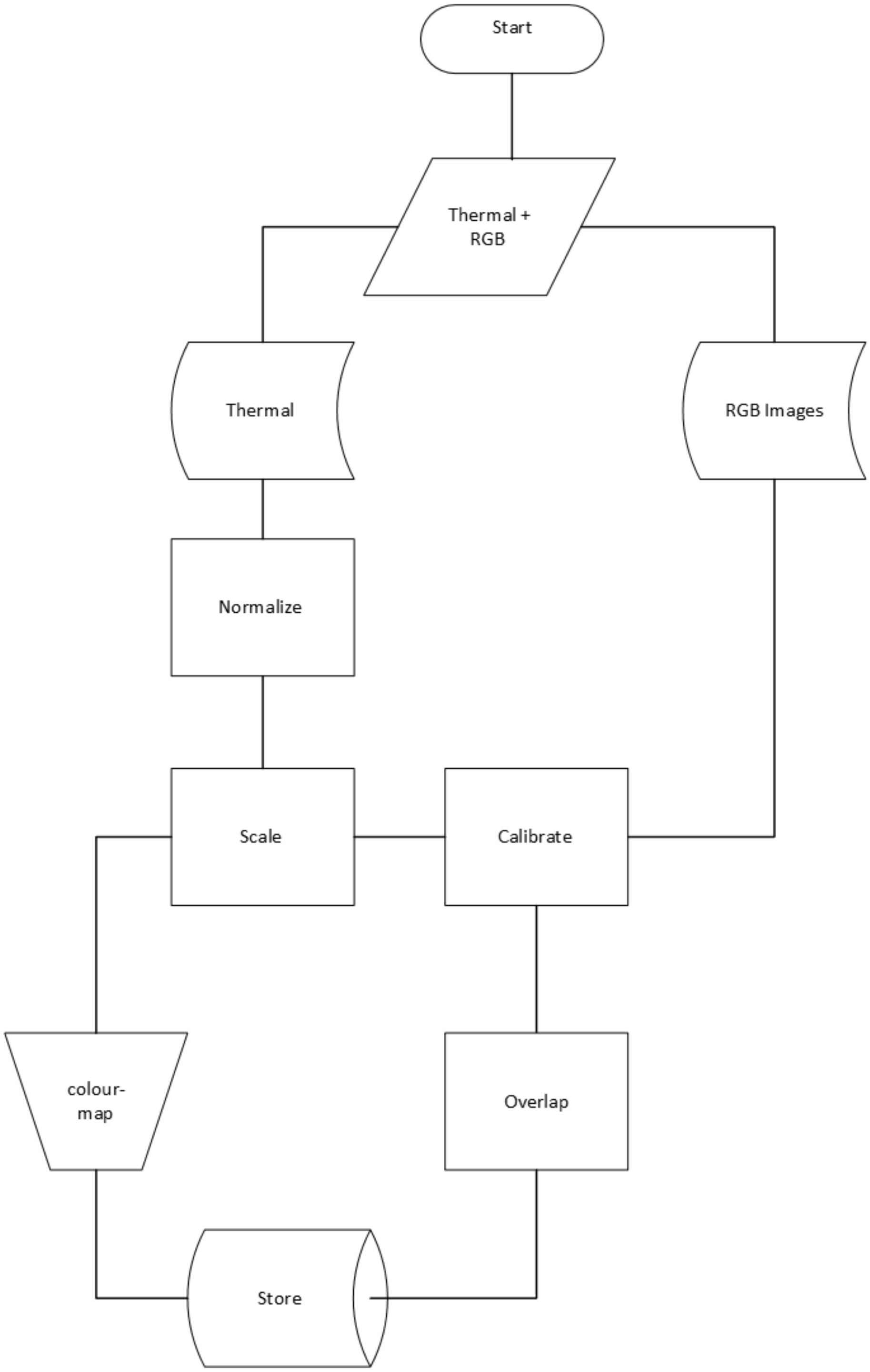

Figure 3.21: Data Collection and Processing

T Celsius = T Kelvin−273.15

$$X_{normalized} = \frac{x - x_{min}}{x_{max} - x_{min}} \qquad Equation\ 2$$

Equation 2

$$X_{Scaled} = X_{normalized} * \left(\underset{scaled}{max} - \underset{scaled}{min}\right) - \underset{scaled}{min} \qquad Equation\ 3$$

Equation 3

3.7 Implementation details

When initiating the thermal scanning system in an indoor environment, the process begins with setting the camera to its preset home position or zero position. This step ensures consistency and alignment before data collection begins. Subsequently, the Inertial Measurement Unit (IMU) undergoes calibration, which typically takes a minute to complete. Once calibrated, the gimbal stabilization system initiates, maintaining the camera at a level position. This stabilization is crucial for a system capable of being mounted on both mobile and fixed platforms, ensuring steady and accurate data acquisition. By stabilizing the camera, the system minimizes motion blur and distortion, enabling precise thermal imaging even in dynamic environments.

Following the initialization and stabilization process, the thermal scanning system proceeds with capturing data in a systematic manner. The camera is programmed to rotate a full 360 degrees, with data captured at predefined increments determined by the user. At each step of rotation, data from the thermal camera is captured, processed, and stored for subsequent analysis. Depending on user preferences and the specific requirements of the scanning task, adjustments to the tilt and pitch of the camera can be made after each complete rotation to optimize data capture. This flexibility allows users to adapt the system to varying environmental conditions and specific data collection objectives, ensuring comprehensive coverage and accurate analysis of thermal signatures and spatial features within the indoor environment.

CHAPTER 4: EXPERIMENTAL SETUP

4.1 Environment Overview

In an indoor laboratory environment, two meticulously designed experiments aim to leverage the capabilities of a thermal scanning system for comprehensive data collection and analysis. In the first experiment, the thermal scanning system is securely mounted on a fixed platform positioned at the centre of the laboratory. This setup allows for consistent and controlled scanning of the environment. Multiple objects and operating equipment are strategically placed at specific positions within the lab, each emitting distinct thermal signatures. Some objects are intentionally heated to serve as the primary radiating sources within the environment. Notable examples include a semi-circle metallic disk, a heating copper pipe, a laptop, and a 3D printer. The thermal scanning system, equipped and programmed to capture both thermal and RGB images, systematically records and stores these images for subsequent analysis.

In the second experiment, the focus shifts to monitoring a metallic disk over a duration of 20 minutes while subjecting it to controlled heating. This controlled heating process allows for the observation of dynamic changes in the thermal signature of the metallic disk over time. By continuously scanning and capturing thermal data at regular intervals, the thermal scanning system provides invaluable insights into the thermal behaviour of the heated metal disk. The results obtained from this experiment are not only significant but also conclusive, offering valuable data for further analysis and interpretation. These experiments demonstrate the versatility and effectiveness of the thermal scanning system in capturing and analysing thermal signatures in controlled laboratory settings, paving the way for deeper understanding and exploration of thermal dynamics in various applications.

Figure 4.1: Panoramic View of Lab Environment

4.2 Scanning Procedure

In a meticulously controlled indoor laboratory environment, utmost priority is given to safety protocols and measures before the initiation of any experimental procedures. Comprehensive risk assessments are conducted to anticipate and mitigate potential hazards, ensuring a safe working environment for all personnel involved. Precautionary measures are put in place to address any equipment failures or fire hazards that may arise during the experimental process. Once these safety measures are meticulously calculated and implemented, the thermal scanning system is strategically positioned at a specific location within the laboratory. With the scanning process initiated, the system, equipped with a thermal camera and multiple sensors, springs into action. Designed to execute a sweeping motion of 360 degrees, the thermal scanning system systematically traverses the laboratory space, meticulously capturing and recording data at regular intervals or iterations of its sweeping motion. At each interval, both RGB and thermal images of the same section of the environment are captured simultaneously, ensuring a comprehensive and synchronized dataset for subsequent analysis. This meticulous approach not only facilitates the accurate monitoring of thermal dynamics within the laboratory environment but also underscores the commitment to safety and precision in scientific experimentation.

Figure 4.2: Thermal Scanning System in Fixed mounting Position.

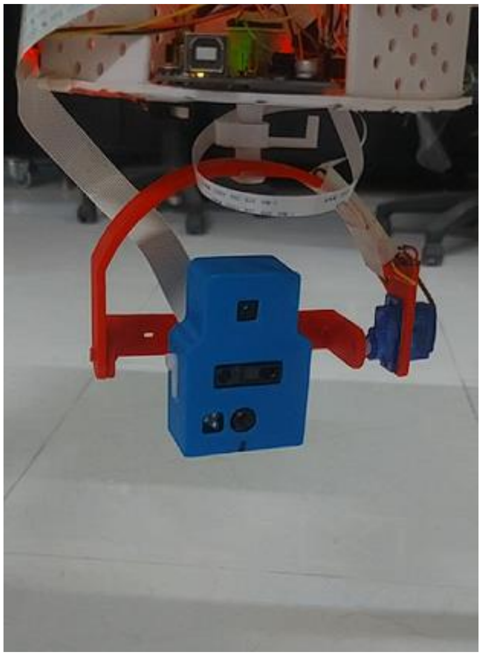

Figure 4.3: Thermal Scanning System in Mobile mounting Position.

4.3 Calibration and Data Collection

In the realm of scientific experimentation, the calibration and data collection process are pivotal components that heavily hinge on the nature and intricacies of the experiment at hand. Each experiment demands a tailored approach to calibration, which often involves meticulous data manipulation to ensure accuracy and reliability. In the case of experiments necessitating post-process calibration, this stage becomes particularly critical. Here, data manipulation techniques are applied to align collected data with known parameters, facilitating precise analysis and interpretation. However, this calibration process is not without its challenges. Factors such as internal noise, thermal fluctuations, and varying environmental conditions can introduce complexities, necessitating careful consideration and adjustment. Moreover, the duration of data collection itself is often time-consuming, further adding to the intricacy of the process. The accuracy and integrity of the collected data hinge on the interplay of these factors, underscoring the importance of methodical calibration and vigilant monitoring throughout the data collection phase. Ultimately, the success of the experiment relies on the meticulous calibration and rigorous data collection procedures employed, ensuring that the resulting data is robust and dependable for subsequent analysis and scientific inquiry.

CHAPTER 5: EXPERIMENT 01

Indoor Lab Environment Scanning

5.1 Objective

The primary objective of the First Experiment is to validate the scanning capability of the Thermal Scanning System, which has been meticulously developed after an extensive process of designing and engineering. This experiment serves as a crucial validation step, aiming to assess the system's effectiveness in capturing and analyzing thermal data within the laboratory environment. Through this experiment, researchers seek to evaluate the system's ability to systematically scan and record thermal signatures across the designated area, providing valuable insights into the thermal dynamics of the laboratory setting. The experiment also serves to analyze the lab environment comprehensively, shedding light on temperature variations, heat distribution patterns, and potential sources of thermal fluctuations. By validating the scanning capability of the Thermal Scanning System, researchers can gain confidence in the system's performance and accuracy, paving the way for further exploration and utilization in various scientific applications. Additionally, the data collected from this experiment will be instrumental in fine-tuning and optimizing the system for future use, ensuring its reliability and effectiveness in diverse research scenarios. Ultimately, the First Experiment serves as a critical milestone in affirming the capabilities of the Thermal Scanning System and elucidating the thermal characteristics of the laboratory environment for scientific inquiry and analysis.

5.2 Setup

This configuration enables systematic and regulated scanning of the environment. Positioned at the laboratory's focal point, the scanning system meticulously captures data. Various objects and operational equipment are strategically positioned throughout the lab, each emitting unique thermal signatures. Some objects are deliberately heated to act as the primary sources of thermal radiation within the environment. These include a semi-circle metallic disk, a copper pipe undergoing heating, a laptop, and a 3D printer.

5.3 Results and Analysis

As a multimodule system, the thermal scanning system produces output data categorized into four distinct types. Firstly, it generates separate RGB (Red, Green, Blue) and thermal images, offering detailed visual representations of the environment's characteristics. These images provide insights into both the visual appearance and thermal properties of the objects and surfaces within the scanned area. Secondly, the system produces overlapped images, where the thermal data is superimposed onto the RGB images. This integration offers a comprehensive view, combining visual and thermal information in a single image for enhanced analysis. Additionally, the system generates a log file containing relevant data pertaining to the position and orientation of the scanning system during data acquisition. This log file serves as a crucial reference for correlating the captured images with specific spatial locations within the environment.

The outcomes of the experiment underscore the significance of the thermal scanning system in environmental analysis. By leveraging its capabilities, researchers can effectively identify hot and cold spots within the scanned area. These hot and cold spots indicate areas of elevated or reduced thermal activity, offering valuable insights into temperature variations and distribution patterns. Moreover, the system facilitates the detection of thermal anomalies, such as unexpected temperature fluctuations or irregular thermal patterns. By pinpointing these anomalies, researchers can identify potential issues or abnormalities within the environment, enabling timely interventions or adjustments as needed. Overall, the thermal scanning system serves as a powerful tool for analyzing environmental conditions, providing invaluable data for research, monitoring, and decision-making purposes.

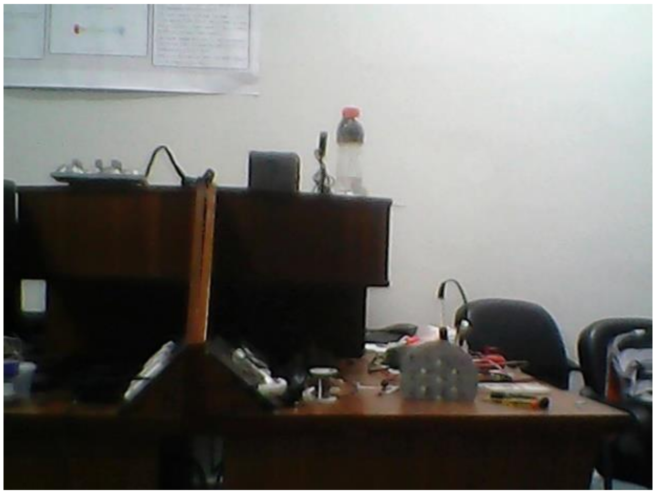

Figure 5.1: Basic RGB Image

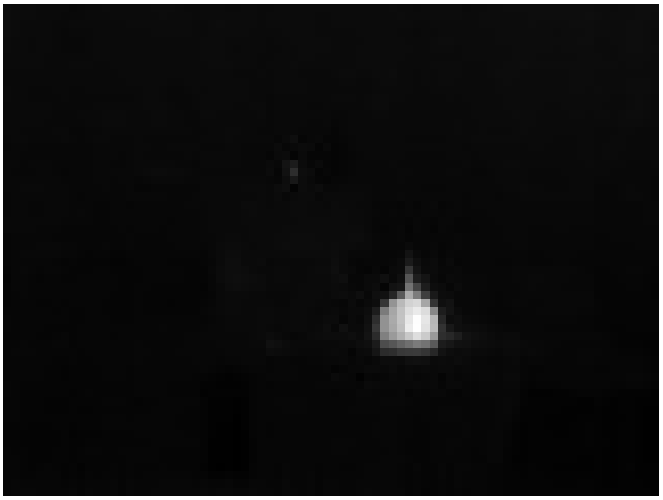

Figure 5.2: Thermal Image

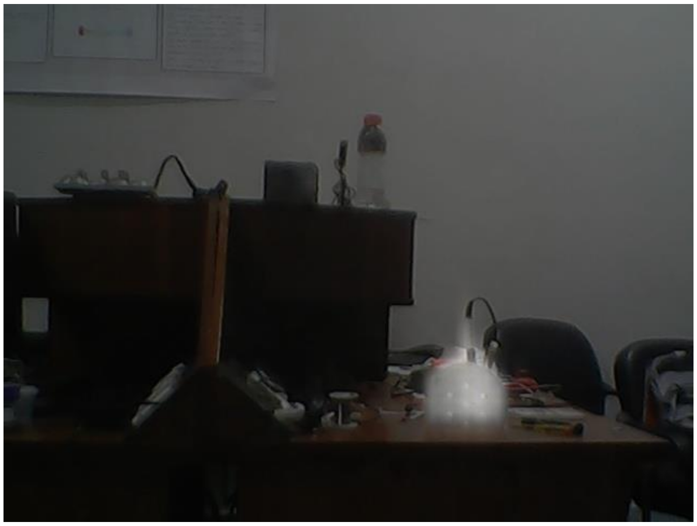

Figure 5.3: Overlapped Image

5.4 Discussion

The output generated by the thermal scanning system is inherently data-rich, providing detailed thermal signatures of each object within the environment under scrutiny. This wealth of information opens numerous possibilities for leveraging advanced technologies such as artificial intelligence (AI) to enhance the system's capabilities. By integrating the thermal scanning system with AI algorithms, significant advantages can be realized, particularly in the detection of anomalies. One notable application of integrating AI with the thermal scanning system is in the detection of anomalies. AI algorithms can be trained to analyze thermal data and identify deviations from expected thermal patterns. For example, anomalies such as overheating components in machinery, electrical systems, or building structures can be detected early, allowing for timely intervention to prevent potential failures or safety hazards. Additionally, AI can be programmed to recognize patterns associated with specific types of anomalies, enabling the system to provide targeted alerts and recommendations for corrective actions.

Moreover, the application of the thermal scanning system extends beyond anomaly detection to encompass a wide range of safety concerns and fire hazard applications. By continuously monitoring temperature variations and thermal patterns in real-time, the system can serve as an early warning system for detecting potential fire hazards or unsafe conditions. For instance, abnormal temperature rises in electrical circuits or overheating equipment can be promptly detected, helping to prevent accidents and mitigate risks. Overall, the integration of AI with the thermal scanning system holds immense potential for enhancing safety, efficiency, and productivity across various industries. The data-rich nature of the thermal signatures provided by the system, coupled with the advanced capabilities of AI algorithms, offers unprecedented opportunities for proactive monitoring, predictive maintenance, and intelligent decision-making. As technology continues to advance, further innovations in this area are expected to revolutionize the way we detect and address safety concerns and fire hazards in our environments.

CHAPTER 6: EXPERIMENT 02

Micro-Scanning of a Heated Disk

6.1 Objective

The primary objective of this experiment is to detect nonuniform thermal distribution over a metal surface utilizing the developed system and comparing it with a grid-based contact method [1]. The thermal camera integrated into the system boasts a manufacturer-specified accuracy of ±5 degrees Celsius, which imposes limitations on its capabilities. Therefore, the focus of this experiment is to conduct a comparative analysis to assess the system's ability to detect nonuniform thermal distributions accurately. By comparing the results obtained from the thermal scanning system with those obtained from a grid-based contact method, researchers aim to evaluate the system's performance in capturing subtle variations in temperature across the metal surface. Given the inherent limitations of the thermal camera's accuracy, the experiment also aims to explore post-processing techniques to enhance the accuracy of the collected data. These techniques may involve data manipulation and calibration procedures to refine the thermal measurements and mitigate errors. Furthermore, the experiment lays the groundwork for leveraging the collected data to train an AI system capable of compensating for inaccuracies and improving the overall accuracy of thermal measurements. By enhancing the accuracy of the data through post-processing and AI-based approaches, researchers aim to unlock the full potential of the thermal scanning system for precise temperature analysis and monitoring applications.

6.2 Setup

A controlled experiment involving non-uniform heating, a paper-laminated galvanized iron disk measuring 2mm in thickness and 15.5cm in diameter. The semi-disk configuration incorporates seven circular patterned punched holes. To precisely monitor localized temperature fluctuations, twelve K-type thermocouples are strategically arranged in a grid pattern with a 3cm spacing. Positioned at 170mm, a thermal camera is employed to capture thermal images. The heating process is administered using an adjustable soldering iron set to a temperature of 400°C. Temperature data is meticulously recorded utilizing an Arduino Uno connected to the thermocouple sensors and the thermal imaging system. Data collection spans a duration of 20 minutes, with measurements captured at one-minute intervals.

The Thermal Imaging system features an FLIR Lepton 2.5 radiometric infrared camera, renowned for its declared accuracy of ±5 degrees Celsius and a resolution of 60x80 pixels, which is linked to a Raspberry Pi. The Pylepton library is used to capture raw sensor data, where each pixel represents the thermal value in (100 Kelvin) of the area it covers, resulting in a total of 4800 pixels or data points. Post-processing involves normalization and scaling of the raw sensor data, culminating in the generation of a 60x80 pixel image. Subsequently, image processing techniques are employed to apply color mapping, facilitating the visualization of thermal distribution. Additionally, segmentation techniques are utilized to partition the image into distinct regions based on temperature variations.

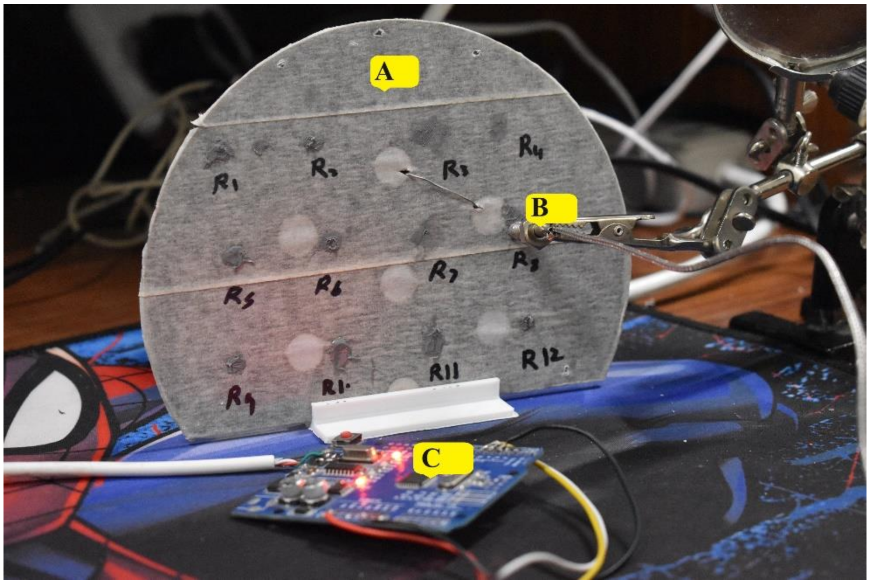

Figure 6.1: Heated Disk with Thermocouple placed. A(Heated Disk), B(Thermocouple), C(Arduino)

A. H. Khan and A. Javaid, "Image processing and Grid-Based analysis for detection of non-uniform Heat Distribution: A comparative study," *2023 3rd International Conference on Digital Futures and Transformative Technologies (ICoDT2)*, Islamabad, Pakistan, 2023, pp. 1-6, doi: 10.1109/ICoDT259378.2023.10325809.

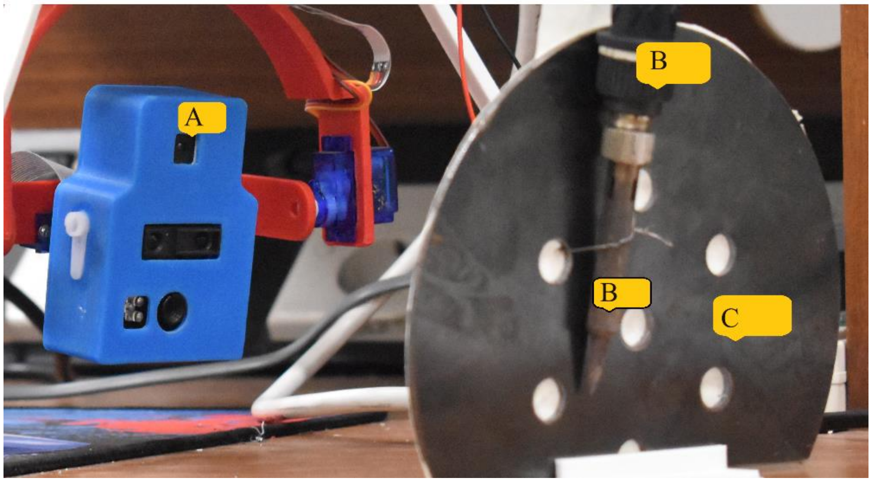

Figure 6.2: Thermal Camera Placed Infront of Heated Disk. A(Camera), B(Heating Element), C(Heated Disk)

A. H. Khan and A. Javaid, "Image processing and Grid-Based analysis for detection of non-uniform Heat Distribution: A comparative study," *2023 3rd International Conference on Digital Futures and Transformative Technologies (ICoDT2)*, Islamabad, Pakistan, 2023, pp. 1-6, doi: 10.1109/ICoDT259378.2023.10325809.

6.3 Results and Analysis

The findings from the experiment provide clear evidence that despite its superior accuracy, the grid-based thermocouple data is insufficient in detecting nonuniform thermal distributions effectively. While thermocouples are renowned for their precision, their inability to capture subtle variations across surfaces becomes apparent when aiming to detect nonuniform thermal patterns. Achieving this level of detail with thermocouples would necessitate a grid with significantly higher resolution, an impractical solution especially in field applications where resources and logistics pose constraints. Conversely, the data obtained from a thermal camera offers a compelling advantage in its ability to visually represent thermal variations across surfaces. The thermal images produced by the camera vividly illustrate temperature disparities shown in **Figure 6.5**, providing a comprehensive and intuitive depiction of the thermal landscape. This visual representation proves invaluable, particularly in scenarios where precision is not the primary concern. In such cases, a low-cost thermal camera emerges as a practical and effective alternative, offering satisfactory performance without compromising accuracy to a significant degree.

Furthermore, while thermocouple data may fall short in directly capturing nonuniform thermal distributions, it proves highly beneficial in post-processing stages aimed at enhancing the accuracy of thermal camera data shown in **Figure 6.6**. Through data fusion techniques and algebraic manipulation, the complementary nature of thermocouple and thermal camera data can be harnessed to refine and improve the accuracy of the overall dataset. By integrating the precise temperature readings from thermocouples with the visual thermal images captured by the camera, discrepancies and inaccuracies in the thermal data can be identified and corrected. This fusion process allows for the creation of a more comprehensive and reliable dataset that accurately reflects the thermal dynamics of the environment under study. Thus, while thermocouples may not excel in capturing nuanced thermal patterns on their own, their integration into a multi-modal data fusion approach can significantly enhance the accuracy and utility of thermal imaging systems in various applications.

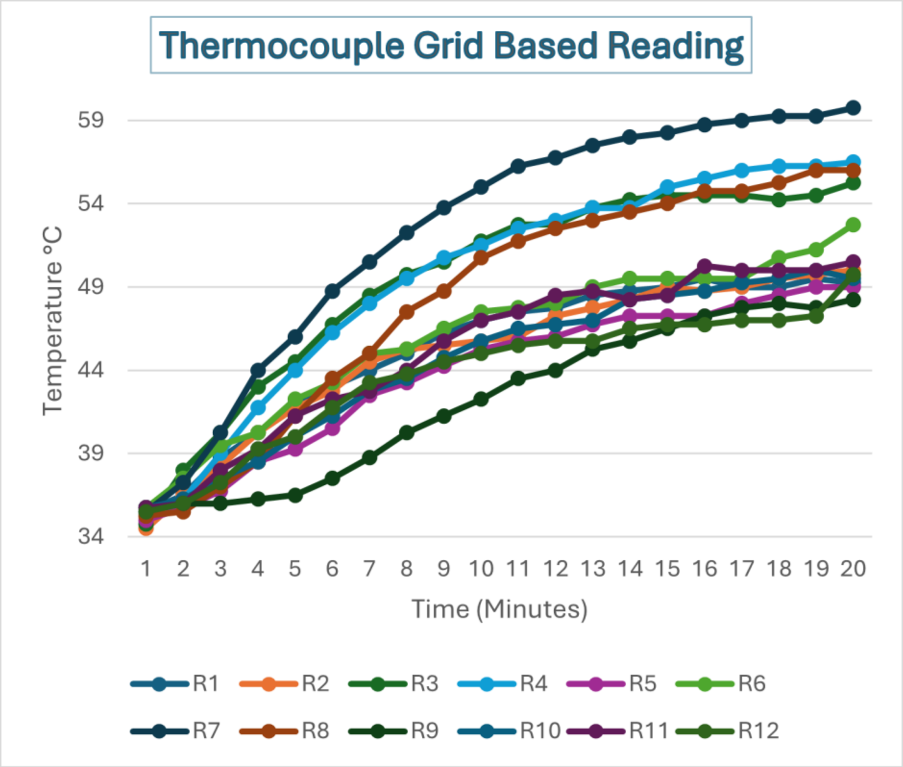

Figure 6.3 : Graphical Representation of Thermocouple values over 20 min span

A. H. Khan and A. Javaid, "Image processing and Grid-Based analysis for detection of non-uniform Heat Distribution: A comparative study," *2023 3rd International Conference on Digital Futures and Transformative Technologies (ICoDT2)*, Islamabad, Pakistan, 2023, pp. 1-6, doi: 10.1109/ICoDT259378.2023.10325809.

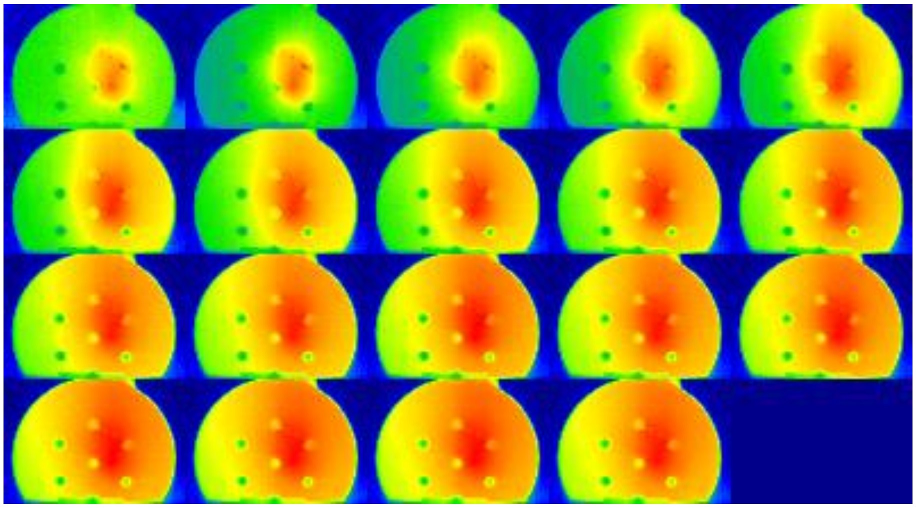

Figure 6.4 : Thermal images stacked over the span of 20 min.

A. H. Khan and A. Javaid, "Image processing and Grid-Based analysis for detection of non-uniform Heat Distribution: A comparative study," *2023 3rd International Conference on Digital Futures and Transformative Technologies (ICoDT2)*, Islamabad, Pakistan, 2023, pp. 1-6, doi: 10.1109/ICoDT259378.2023.10325809.

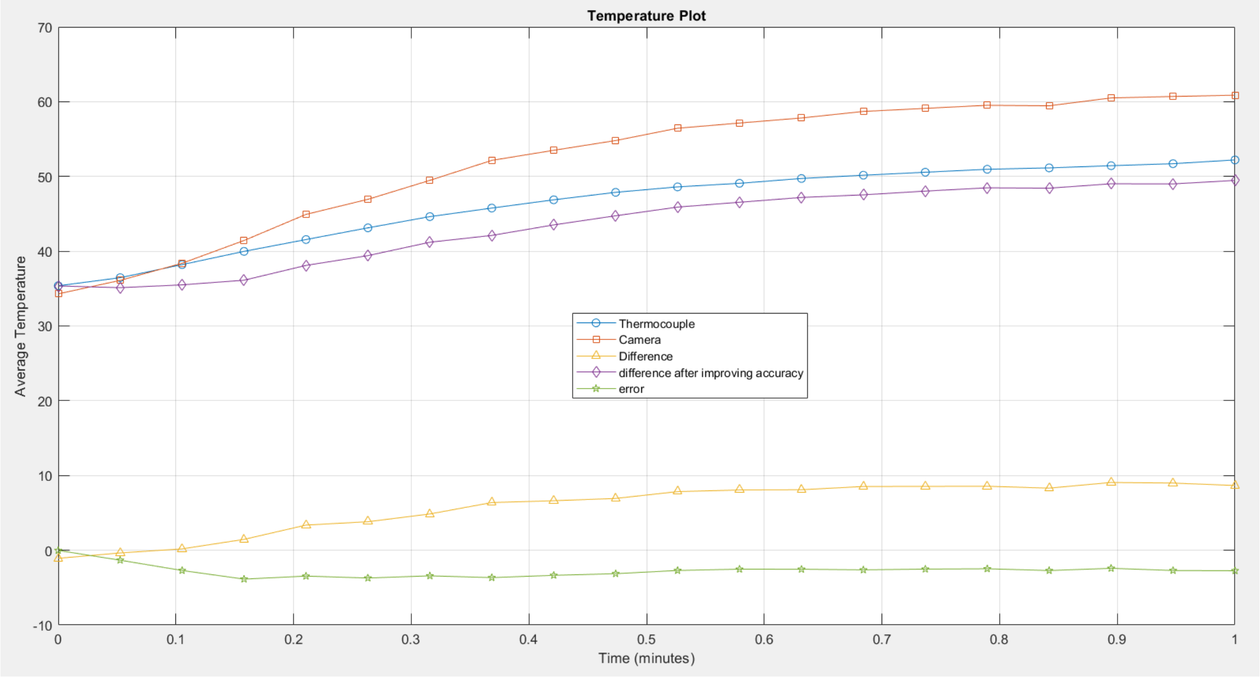

Figure 6.5: Average Temperatures and differences at each Time Interval

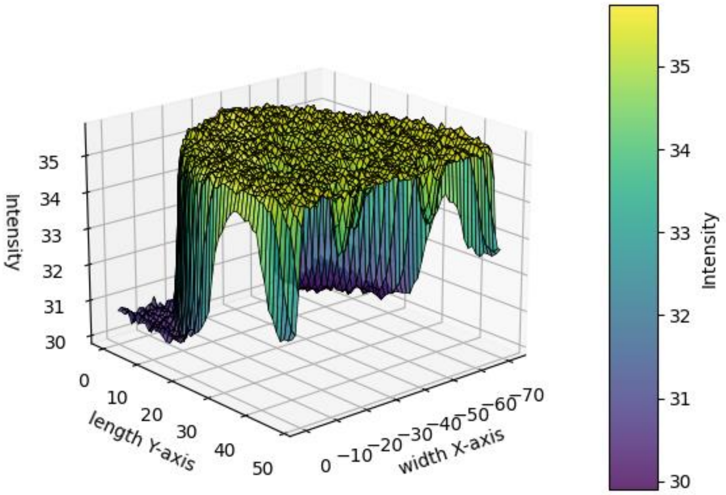

Figure 6.6: 3D Surface Plot at Time Interval t = 0

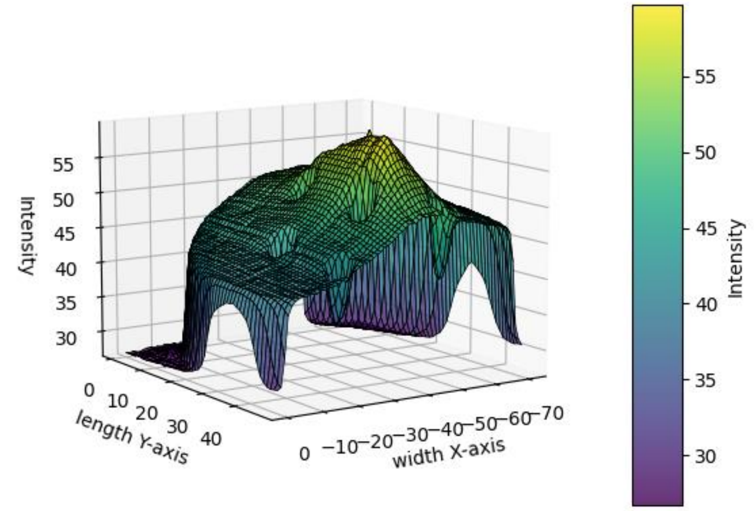

Figure 6.7: 3D surface Plot at Time Interval t = 20

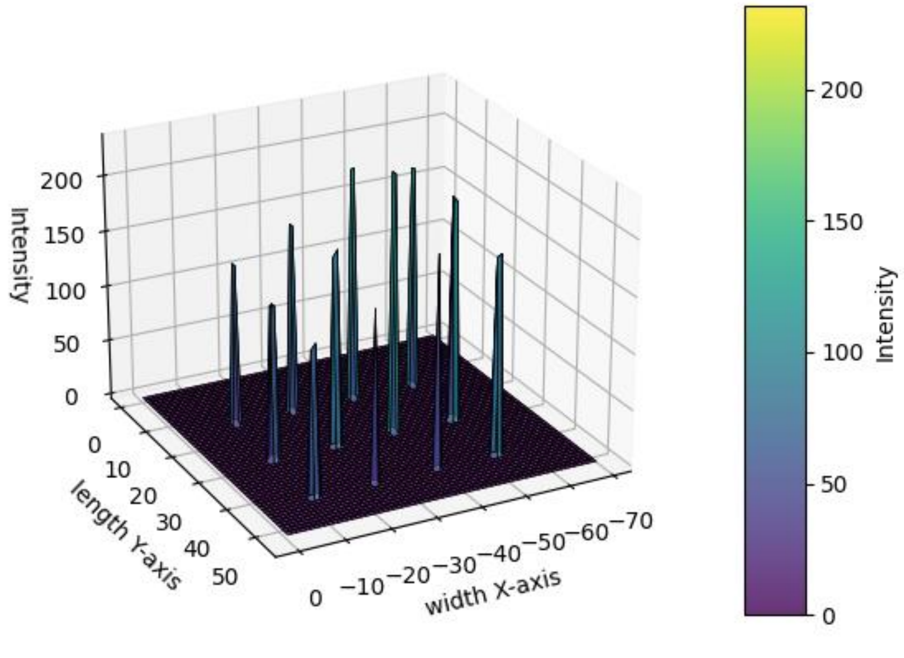

Figure 6.8 : Thermocouple visual representation for non-uniform thermal distribution

6.4 Discussion on Findings

The experiment's results highlight that while grid-based thermocouples offer higher accuracy, they struggle to detect nonuniform thermal distributions effectively. Achieving this with thermocouples would demand a high-resolution grid, impractical for field use. Conversely, thermal camera data visually represents thermal variations across surfaces, making it suitable if precision isn't paramount. In such cases, low-cost thermal cameras perform well without sacrificing much accuracy.

While thermocouples may not directly capture nonuniform thermal distributions effectively, they prove invaluable in post-processing stages. Through data fusion and algebraic manipulation, the precise temperature readings from thermocouples, combined with visual thermal images from cameras, enhance the overall dataset's accuracy. This fusion enables the creation of a more reliable dataset, reflecting the true thermal dynamics of the environment under study. Thus, while thermocouples alone may not excel, their integration into multi-modal data fusion approaches significantly enhances thermal imaging system accuracy.

Table 1 : Data Type and Errors

Data	Average Difference	Mean Square Error
Camera	5.8°C	45.1
Improved Camera	2.7°C	8.1

$$MSE = \frac{1}{N} * \sum_{i=1}^{n} (y_i - y_i)^2 \qquad Equation\ 4$$

Equation 4

SUMMARY OF RESEARCH WORK

The research work encompasses the comprehensive development, evaluation, and application of a sophisticated thermal scanning system tailored for environmental analysis. This multimodule system integrates a thermal camera, RGB imaging components, and various sensors to capture and analyze thermal data with precision. Through meticulously designed experiments conducted in controlled laboratory settings, the system's capabilities are rigorously tested and evaluated. The experiments reveal insights into the system's strengths and limitations, showcasing its effectiveness in detecting nonuniform thermal distributions, identifying thermal anomalies, and analyzing environmental conditions.

One key finding is the system's ability to provide detailed visual representations of thermal patterns across surfaces, offering valuable insights into temperature variations and distribution patterns. While grid-based thermocouple data offers superior accuracy, it struggles to capture subtle thermal variations effectively. However, through post-processing techniques such as data fusion and algebraic manipulation, the accuracy of thermal data captured by the system can be significantly enhanced. Overall, the research underscores the significance of the thermal scanning system in environmental analysis, highlighting its potential to identify hot and cold spots, detect thermal anomalies, and facilitate informed decision-making and intervention strategies. The findings contribute to advancing our understanding of thermal dynamics in various environments and underscore the importance of utilizing advanced technologies for precise environmental monitoring and analysis.

CHAPTER 7: CONCLUSION AND FUTURE RECOMMENDATION

In conclusion, our research has demonstrated the efficacy and versatility of the developed thermal scanning system for comprehensive environmental analysis. Through meticulous design, testing, and evaluation, we have shown that the multimodule system, integrating thermal imaging, RGB imaging, and sensor technologies, can effectively capture and analyze thermal data in diverse environmental settings. Our experiments have revealed the system's ability to detect nonuniform thermal distributions, identify thermal anomalies, and provide valuable insights into environmental conditions.

While grid-based thermocouple data offers superior accuracy, it has limitations in capturing subtle thermal variations effectively. In contrast, thermal camera data provides visually rich representations of thermal patterns across surfaces, proving advantageous for practical applications where precision is not paramount. Furthermore, post-processing techniques, including data fusion and algebraic manipulation, have been explored to enhance the accuracy of thermal data captured by the system. Overall, our research underscores the significance of the thermal scanning system in environmental analysis, highlighting its potential to facilitate informed decision-making and intervention strategies. By providing detailed insights into temperature variations and distribution patterns, the system contributes to advancing our understanding of thermal dynamics in various environments. Moving forward, further research and development efforts will focus on refining the system's capabilities and expanding its applications in fields such as environmental monitoring, industrial process control, and infrastructure inspection.

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