Remote Viewing Within High Voltage Apparatus

Blake Bagley

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Erica Mathew

Remote Viewing Within High Voltage Apparatus Final Report

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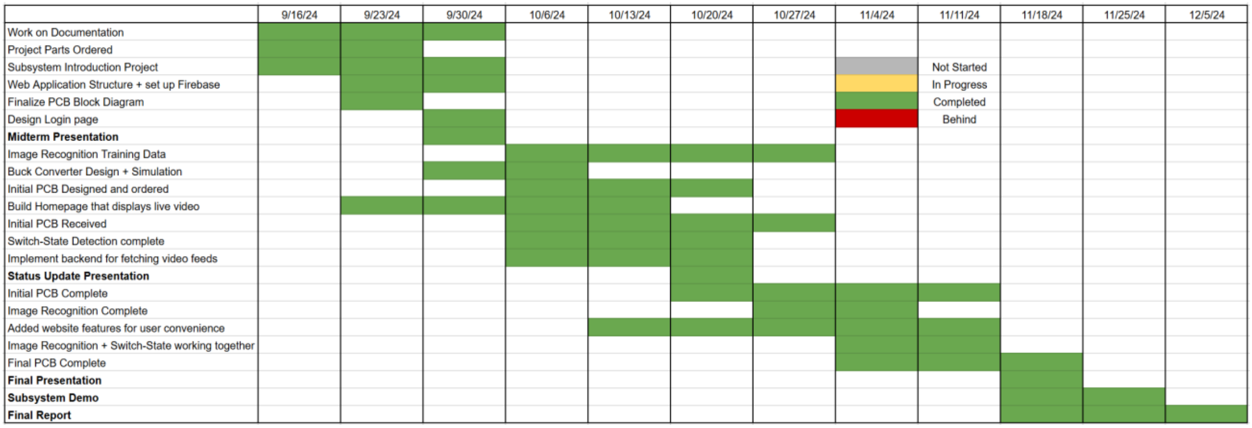
Schedule and Validation

REVISION – 3
26 April 2025

Schedule


9/16/24
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11/4/24
11/11/24
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Work on Documentation
Project Parts Ordered
Subsystem Introduction Project
Web Application Structure + set up Firebase
Finalize PCB Block Diagram
Design Login page
Midterm Presentation
Image Recognition Training Data
Buck Converter Design + Simulation
Initial PCB Designed and ordered
Build Homepage that displays live video
Initial PCB Received
Switch-State Detection complete
Implement backend for fetching video feeds
Status Update Presentation
Initial PCB Complete
Image Recognition Complete
Added website features for user convenience
Image Recognition + Switch-State working together
Final PCB Complete
Final Presentation
Subsystem Demo
Final Report
Not Started
In Progress
Completed
Behind


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PCB Updated
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Parts Ordered
Researched Integration
Microcontroller Code Modified
Website Code Modified
Status Update #1
New boards soldered
Verify Server can receive data from microcontroller
Buck converters tested
Website and Microcontroller Connection
ABS sheet ordered
Status Update #2
MCU and Website communication tested
PCB and Microcontroller Integration
MCU and Website Communicate Switch State
Status Update #3
Website and Microcontroller Fully Integrated
Full System Integration
Status Update #4
Plastic Insulating Box made
Dielectrics Testing
Troubleshoot any issues
Practice Demo
Status Update #5
Final Presentation
Final Demonstration
Final Report
Not Started
In Progress
Completed
Behind

Validation

Test Name	Success Criteria	Methodology	Status	Engineers
Input Voltage	Voltage powering the PCB should be ~3.7 Volts.	Use multimeter to measure the DC voltage.	PASSED	Julia
Converter Voltage	Buck converter providing voltage should output ~3.3 Volts.	Use multimeter to measure the DC voltage.	PASSED	Julia
Board Communication	ESP32 should receive data from camera	Use oscilloscope to measure the data stream.	PASSED	Julia
Microcontroller connects to website	Website successfully received an HTTP POST request from the ESP32.	Checking the console log of both the website and microcontroller.	PASSED	Erica + Blake
Microcontroller sending image data	The website successfully received raw image data.	Checking console log on website and converting the raw image data to a png.	PASSED	Erica + Blake
Switch State Determination	The microcontroller should be able to identify the Switch State of a makeshift switch.	The microcontroller will monitor a box with a body heat source to demonstrate switch state determination.	PASSED	Blake
Dielectrics Test	The PCB should pass the dielectrics test and not cause any interference with the switchgear.	This will be tested at POWELL Industries.	PASSED	Julia
Switch State Determination Display	The website should be able to accurately display the Switch State Determination.	Switch State Determination with a makeshift switch.	PASSED	Erica + Blake
Website can load and display images in real time	The website should be able to display a few frames per second to mimic a slow video stream.	When the camera is running, the operator will monitor the latency on the website.	PASSED	Erica + Blake
Website is functioning as expected	The Login/Registration pages, Overview page, Map Builder page, and Video page are properly working.	The user will go through the components of the website and confirm it’s working properly.	PASSED	Erica

Remote Viewing Within High Voltage Apparatus

Blake Bagley

Julia Garcia

Erica Mathew

Concept of Operations

REVISION – 3

26 April 2025

Concept of Operations

FOR

Remote Viewing within High Voltage Apparatus

Team 54

Approved by:

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Project Leader Date

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Prof. Kalafatis Date

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T/A Date

Change Record

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1	12/5/2024	Erica Mathew		Draft Release
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1. Executive Summary

As industry demand grows, space within medium voltage switchgear has become increasingly limited. Manufacturers once had the luxury of allotting one device to a dedicated space, but now they must fit multiple apparatus for distinct functions into that same confined space. Manufacturers are additionally being asked to include safety devices within the switchgear. These safety devices are often not in areas that are easily accessible by the operator which makes visual inspection challenging. The goal of this project is to create a solution that enables operators to remotely view the safety devices inside the switchgear. This will significantly improve both safety and efficiency for the customer by providing continuous monitoring of the mechanical switches.

2. Introduction

This document is an introduction to our Proposed Thermal Remote Viewing System within High Voltage, a system capable of monitoring the mechanical safety switches within medium voltage switchgears. This project will allow operators to remotely confirm the state of the switchgear without putting themselves in danger.

2.1. Background

Currently, there is not a good system for monitoring the inside of a switchgear. Operators currently rely on a flashlight through a small window to get a view of the inside. This method is extremely inefficient because it provides extremely limited visibility and is unable to view regions that are covered by wires. This can also be extremely dangerous and can expose the operator to the dangers of high voltage.

Our plan of creating a remote viewing system will allow operators to monitor the switchgear from a distance. Real time streaming with the use of thermal sensors will provide a comprehensive view of the switchgears. By placing thermal sensors close to the safety switches, we are able to get a visual representation of hard-to-reach areas.

2.2. Overview

Our system will be used to monitor safety switches within a medium voltage switchgear to check for gaps between contacts. We will use thermal sensors to create a temperature profile of the switchgear in real time. This raw thermal data from the sensor is sent to our microcontroller which converts the data into an image stream. Here we will have to perform linear interpolation to smooth the images. Our microcontroller would then send the processed data over a network via Wi-Fi. Finally, we will create a website for the operators to easily interface with that displays the thermal image stream.

2.3. Referenced Documents and Standards

- IEEE Standard C37.20.2 IEEE Standard for Metal-Clad Switchgear
- IEEE Standard C37.04 IEEE Standard for Ratings and Requirement for AC High-Voltage Circuit Breakers with a Rated Maximum Voltage Above 1000V
- IEEE Standard C37.09 IEEE Standard Test Procedures for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V
- ANSI C37.54 American National Standard for Alternating Current High-Voltage Circuit Breakers Applied in Metal-Enclosed Switchgear—Conformance Test Procedures
- NFPA 70E Standard for Electrical Safety in the Workplace
- NFPA 70 National Electrical Code

3. Operating Concept

3.1. Scope

The goal of this project is to create a system that allows operators to remotely view a switch within a switchgear without opening it to ensure safe grounding. When an operator wants to see if the designated switch is open or closed, he/she will open a computer application that will connect to the microcontroller. A thermal image sensor will first capture an image of the designated switch; then the microcontroller will send that image to the application. One of the big constraints of this project is that we need to make sure that the dielectric integrity within the switchgear still meets industry standards. Due to budget constraints, the project will entail making this system for only one vertical tower of switchgear. We will still make this system expandable by having multiple towers connected to the application with their own dedicated sensors and microcontrollers. This system will help to make switchgear operators' jobs much safer and more convenient.

3.2. Operational Description and Constraints

This system is intended to be used by switchgear operators to make sure switchgear can be safely operated. The operator should be able to open an application on a computer and connect to the switchgear he/she is operating on to see the desired switch's state. An image will be taken by a thermal image system placed in the switchgear, which will then be sent to an application through a microcontroller for the operator to see.

According to the sponsors of this project, the system must allow the users to see the designated switch. Graphical representations are not enough for customers and are not enough for operators to feel certain that the switchgear they are operating on is in the right state. The system must not cause the dielectrics to fail integrity tests due to the system's addition to the switchgear. Also, no modifications will be made to the switchgear other than allowing for the ability to mount the system. The system is purely an addition to the switchgear.

3.3. System Description

There are three main parts of this system. The first part of this system is the thermal image sensor. This is what will create the image of the switch needed to be examined. The sensor will be placed within the switchgear at a reasonable distance from the switch so that interference isn't a problem. The second part of the system is the microcontroller. This part will configure the sensor, process the information read from the sensor, turn the information into something readable by an application, and send off the information through wi-fi. The final part of the system is an application that will take the information sent from the microcontroller and transform it into a viewable format for the operator. The system can be expanded upon by having more vertical towers connected to the application. Each vertical tower will have its own microcontroller and thermal image sensor to allow the application to connect to and view the inside of each tower.

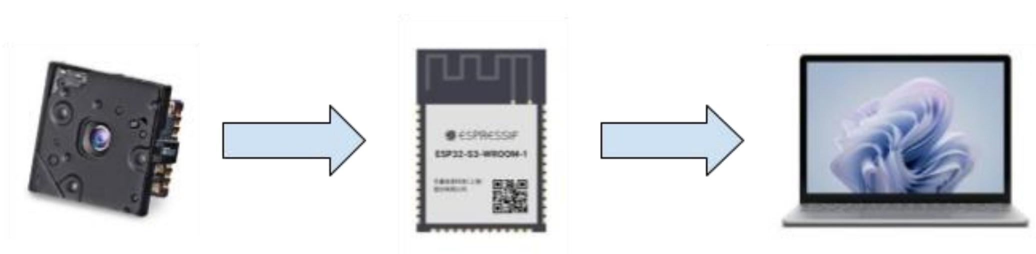

Figure 1: Remote Thermal Viewing System Overview

3.4. Modes of Operation

The operator only needs to view the switch through some type of produced image. The only difference between cases is that the switch might be located in a different part of the switchgear, which will cause the sensor to be placed in a new location. If this project were to be later expanded for use in multiple towers, then this could entail the operator choosing which tower of switchgear needs to view on the website.

3.5. Users

The users of this system, as stated throughout this report, will be switchgear operators. These operators are highly trained and knowledgeable of the hardware being observed by the proposed system. It is common for these users to have engineering and/or technical degrees. Thermal sensors are commonly used in procedures for switchgear, so operators should have some knowledge of how they work. Being that a substantial portion of these operators' jobs are maintenance and safety, our system will ensure that their job is much easier by giving the operator a good visualization of the state that the switchgear is in.

When it comes to the proposed system, there won't need to be any training for installation. The only training needed will be for the use of the application. The application should be simple to learn as it is supposed to be a tool for visualization.

3.6. Support

Support for our system will be given in the form of a manual on how to operate the system. It will detail the assembly of the system, configuration of the hardware, and operation of the application.

4. Scenario(s)

4.1. Ensuring State of Switchgear

The use of our thermal viewing system is to ensure the mechanical safety switches are open. If a maintenance worker needs to open up a switchgear and work inside, they can use our system to make sure it is not powered. The main problems with the switchgear are the density of electronics and lack of inner lighting. These issues make checking that the equipment is depowered extremely difficult. The operator cannot see the gaps from the window on the door, but our system will fix this. With a thermal image of the mechanical safety switches inside the switchgear, operators on the outside can visually see the open gaps, proving it is depowered and safe to open.

5. Analysis

5.1. Summary of Proposed Improvements

- The proposed system will make operating a switchgear much safer than it currently is. By having a thermal image sensor placed inside the switchgear, it is no longer necessary for the operator to open the back of the switchgear to check the status of the safety switch.
- The system will also utilize wi-fi which will make the switch observable from longer distances.
- We could expand upon this project by making the system use machine learning. This will allow it to automatically classify switches as “open” or “closed,” which will improve the workflow for operators overseeing multiple switchgears.

5.2. Disadvantages and Limitations

Our proposed thermal viewing system will have some limitations which include:

- The size of the system is extremely limited due to the scant amount of space available within the switchgear.
- All equipment/components used in the system must be able to withstand high temperatures.
- The sensor and accompanying equipment must be shielded to ensure they don’t interfere with the dielectrics within the switchgear.
- The locations where the thermal sensor can be mounted are limited due to the space constraints within the switchgear.
- Due to budget constraints, the resolution of the picture won’t be very sharp.

5.3. Alternatives

Some alternatives to our proposed thermal viewing system are:

- Placing small flags behind the safety switches and using a flashlight to see inside a window on the front door of the switchgear. If the flag is visible, an operator can conclude the switches are open and the switchgear is depowered.
- Using a “normal” camera with a light source and streaming video of the switches to remote locations.
- A window placed on the backside of the switchgear closer to the mechanical safety switches. With this solution, the operator would need a light source of their own.

5.4. Impact

- There are no ethical concerns because the proposed system is being created to ensure the safety of anyone who works with switchgear. The system is intended to protect people at no cost to any other part of the overall switchgear.
- The environmental impact of our system is minimal. Our only impact comes from power consumption, which isn’t high.
- The societal impact would be minimal, as this would only affect the everyday lives of the operators that work directly with switchgear.

Remote Viewing Within High Voltage Apparatus

Blake Bagley

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Functional System Requirements

REVISION – 3

26 April 2025

FUNCTIONAL SYSTEM REQUIREMENTS

FOR

Remote Viewing within High Voltage Apparatus

TEAM 54

APPROVED BY:

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Project Leader Date

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Prof. Kalafatis Date

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T/A Date

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1	12/5/2024	Erica Mathew		Draft Release
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6. Introduction

6.1. Purpose and Scope

As industry demand grows, space inside medium voltage switchgear has become increasingly limited. Manufacturers are required to fit more devices and wires within the same limited space. Additionally, manufacturers are now being asked to include a remote viewing system within the switchgear to monitor a physical ground switch. This ground switch is physically blocked, by wires, from the view of the operator. Our project, Thermal Remote Viewing System within High Voltage, provides a real time visual depiction of the ground switch that an operator can view from a safe distance away from the switchgear. We will use a thermal sensor to create an image of the ground switch, which will then be sent to the microcontroller to process the information into a viewable format. The image information will then be sent to a web application for the operator to interface with. Our system will increase safety and efficiency for switchgear operators.

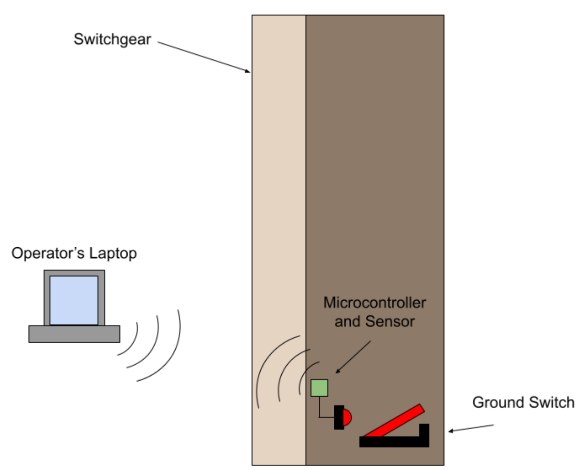

Figure 2: Conceptual Image

6.2. Responsibility and Change Authority

Erica Mathew will make sure all requirements detailed in the Functional System Requirements will be met. Requirements can only be changed if Erica and our sponsors at Powell Industries approve of the changes. Below are the responsibilities of everyone in the team.

Subsystem	Responsibility
Thermal Image Sensor	Julia Garcia
Microcontroller	Blake Bagley
Web Application	Erica Mathew

Table 1: Responsibilities

7. Applicable and Reference Documents

7.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
IEEE Standard C37.20.2	2015-09-22	IEEE Standard for Metal-Clad Switchgear
IEEE Standard C37.04	2019-05-31	IEEE Standard for Ratings and Requirement for AC High- Voltage Circuit Breakers with a Rated Maximum Voltage Above 1000V
IEEE Standard C37.09	2019-04-11	IEEE Standard Test Procedures for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V
ANSI C37.54	2023	American National Standard for Alternating Current High-Voltage Circuit Breakers Applied in Metal-Enclosed Switchgear—Conformance Test Procedures
NFPA 70E	2024	Standard for Electrical Safety in the Workplace
NFPA 70	2023	National Electrical Code

Table 2: Applicable Documents

7.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
1	Version 1.9	ESP32-S3 Series Datasheet
2	Revision 400	FLIR LEPTON® Engineering Datasheet
3	12/22/2020	GlobTek, Inc. Li-Ion Polymer 3.7V Battery Pack
4	Version 2	DS-16912-FLiR Lepton Breakout Board V2
5	Revision 100	Female_Headers.100_DS

Table 3: Reference Documents

7.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings, or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

8. Requirements

8.1. System Definition

The Thermal Remote Viewing System within High Voltage is a system specifically designed for remotely monitoring ground switches within a medium voltage switchgear. It allows operators to confirm a vertical tower is properly grounded before opening the switchgear. This system provides a real-time image stream of the grounding switch that will be broadcast to an online website. The system consists of a thermal image sensor, microcontroller, and a website.

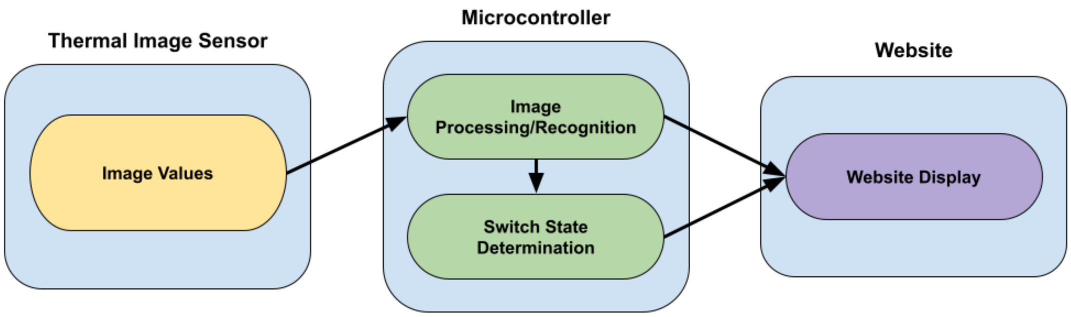

Figure 3: Block Diagram of System

There are three main components to this system. The first block represents the first main component which is the thermal image sensor. This sensor will take in infrared values and turn them into an image for the microcontroller to process. This sensor will need to be configured to be in the image format that will be used by the microcontroller.

The second block, which is the microcontroller, will use an algorithm to determine where the switch is located and to determine if the grounding switch is open or closed. The image and switch state will be then sent from the microcontroller to the website to be viewed by the operator.

8.2. Characteristics

8.2.1 Functional / Performance Requirements

8.2.1.1. Connection to Website

The Thermal Remote Viewing System shall allow for the microcontroller and thermal image sensor to be connected to the website.

Rationale: This will allow the operator to view multiple vertical towers.

8.2.1.2. Determination Accuracy

The Switch State Determination done by the microcontroller shall not have an error rate exceeding 10%.

Rationale: This will allow the machine learning of the microcontroller to perform as accurately as needed.

8.2.1.3. Thermal Sensor Node Area

The thermal sensors should take a visual image that covers a minimum viewable area of 6x6 inches.

Rationale: This is a requirement specified by our customer to properly see the gap between contacts in the ground switches.

8.2.1.4. Video Latency

The website should output images frame by frame to mimic a slow video stream.

Rationale: This is a requirement specified by our customer to properly view the gap between contacts in the ground switches.

8.2.1.5. Image Resolution

The image output shall have a pixel resolution of 160x120 pixels.

Rationale: This is the resolution of the thermal sensor chosen. This will allow for a clear image for the operator to observe.

8.2.2 Physical Characteristics

8.2.2.1. Volume Envelope

The volume envelope of the Remote System shall be less than or equal to 6 inches in height, 6 inches in width, and 6 inches in length.

Rationale: This is a requirement specified by our customer due to constraints of the switchgear where the system will operate.

8.2.2.2. Mounting

The thermal sensor should be mounted facing the grounding switch to allow for a complete view. The mounting information shall be captured in the Remote Viewing System within High Voltage ICD.

Rationale: This is a requirement specified by our customer to provide a clear image for the operator.

8.2.2.3. Installation

The installation information for The Thermal Remote Viewing System within High Voltage shall be provided to the customer through a user manual.

8.2.3 Electrical Characteristics

8.2.3.1. Inputs

No inputs of the operator shall inhibit the function of The Thermal Remote Viewing System.

Rationale: By design, this should limit the risk of the system becoming damaged.

8.2.3.1.1. Power Consumption

The maximum peak power of the system shall not exceed 3 watts.

For our class demonstration we will use a battery pack to power our system. If this system were to be added into a switchgear, it shall pull power from the switchgear itself.

Rationale: This is specified by the ESP32-S3 Series Datasheet and FLIR LEPTON® Engineering Datasheet.

8.2.3.1.2. Input Voltage Level

The input voltage level for the Search and Rescue System shall be +3.7 VDC to +4.2 VDC.

Rationale: This is specified by GlobTek, Inc. Li-Ion Polymer 3.7 V Battery Pack Datasheet.

8.2.3.2. Outputs

8.2.3.2.1. Data Output

The Thermal Remote Viewing System within High Voltage shall include a website interface compatible with the microcontroller to view the ground switch.

Rationale: The Thermal Remote Viewing System within High Voltage information passes directly to the customer's system.

8.2.3.2.2. Image Output

The Thermal Remote Viewing System shall output an 8-bit grayscale image stream for the operator to view on the system's website.

Rationale: This is a requirement specified in the FLIR LEPTON® Engineering Datasheet.

8.2.3.3. Connectors

The Thermal Remote Viewing System within High Voltage shall follow the America National Standard for Electrical Connectors ANSI C119.6-2011.

Rationale: This is a requirement specified in accordance with our battery.

8.2.4 Environmental Requirements

The Thermal Remote Viewing System shall be designed to withstand and operate in the environments and laboratory tests specified in the following section.

Rationale: This is a requirement specified by our customer due to constraints of the switchgear where the system will operate.

8.2.4.1. Thermal Resistance

The Thermal Remote Viewing System should be able to properly operate in an environmental temperature up to 80° C.

Rationale: This is a requirement specified in the FLIR LEPTON® Engineering Datasheet.

8.2.4.2. Dielectrics Test

The Thermal Remote Viewing System shall not compromise the integrity of the dielectrics already within the switchgear.

Rationale: This is a requirement specified by our customer due to constraints of the switchgear where the system will operate.

8.2.5 Failure Propagation

If the website doesn't receive image input, the website shall display a notice that the 'Server is Down'.

Rationale: This will allow the user to know if something is wrong with the system.

9. Support Requirements

The Thermal Remote Viewing System shall require internet connection and a computer in order to interact with the website application.

Remote Viewing Within High Voltage Apparatus

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Interface Control Document

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INTERFACE CONTROL DOCUMENT

FOR

Remote Viewing within High Voltage Apparatus

TEAM <54>

APPROVED BY:

Project Leader Date

Prof. Kalafatis Date

T/A Date

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10. Overview

This document is provided to detail how the thermal sensor will interface with the microcontroller and how the microcontroller will interface with the website. It will list all inputs, outputs, and how the system manages each. An explanation of the inputs from the thermal sensor to the microcontroller will be provided. Then, an explanation of how that input will be transferred from the microcontroller to the website will follow.

11. References and Definitions

11.1. References

Refer to section 2.2 of the Functional System Requirements document.

11.2. Definitions

mA	Milliamp
mW	Milliwatt
g	Grams
mm	Millimeters
V	Volts

12. Physical Interface

12.1. Weight

12.1.1 Weight of Printed Circuit Board Version 1

Component	Weight [g]	Number of Items	Total Weight [g]
PCB without battery	18.391	1	18.391
PCB with battery	34.015	1	34.015

Table 4: Original Printed Circuit Board Weight

12.1.2 Weight of Printed Circuit Board Version 2

Component	Weight [g]	Number of Items	Total Weight [g]
PCB without battery	13.737	1	13.737
PCB with battery	29.361	1	29.361

Table 5: Updated Printed Circuit Board Weight

12.1.3 Weight of Complete System

Component	Weight [g]	Number of Items	Total Weight [g]
PCB inside the case, without battery	54.737	1	54.737
PCB inside the case, with battery	70.361	1	70.361

Table 6: System Weight

12.2. Dimensions

12.2.1 Dimensions of Printed Circuit Board Version 1

Component	Length [mm]	Width [mm]	Height [mm]
Original PCB	66.929	51.435	10

Table 7: Original Printed Circuit Board Dimensions

12.2.2 Dimensions of Printed Circuit Board Version 2

Component	Length [mm]	Width [mm]	Height [mm]
Updated PCB	66.929	42.545	37.5

Table 8: Updated Printed Circuit Board Dimensions

12.2.3 Dimensions of Complete System

Component	Length [mm]	Width [mm]	Height [mm]
Updated PCB inside the case	77.47	58.04	59.06

Table 9: System Dimensions

12.3. Mounting Locations

The thermal sensor will be mounted at least 6 inches away from and facing the grounding switch at the back of the switchgear. The sensor must face the grounding switch because the operator is viewing the switch. It can only fit in the back due to space constraints within the switchgear.

13. Thermal Interface

The case protecting the system is made of ABS which is rated to withstand temperatures up to 95 °C.

The case has a window made of IR material to increase the accuracy of the sensor.

14. Electrical Interface

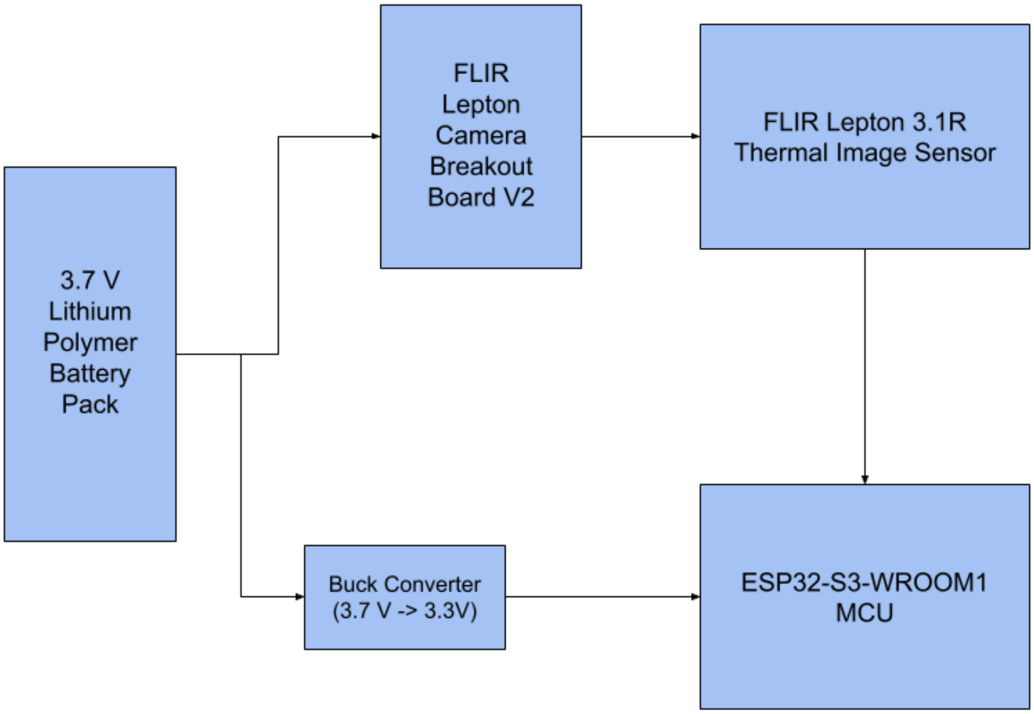

Figure 4: Electrical Interface Diagram

14.1. Primary Input Power

The system will be battery powered using a rechargeable 3.7 V lithium-ion polymer battery. When implemented into the switchgear, the system will be powered by the switchgear itself.

14.2. Voltage and Current Levels

14.2.1 Maximum Values

Component	Voltage [V]	Current [mA]	Power [mW]
FLIR Lepton 3.1R Thermal Sensor	4.8	16	76.8
FLIR Lepton 3.1R Thermal Sensor Core	1.5	110	165
FLIR Lepton 3.1R Thermal Sensor I/O	4.8	310	1488
ESP32-S3-WROOM-1	3.6	1500	3600

Table 10: Maximum Voltage, Current, and Power Levels

14.2.2 Nominal Values

Component	Voltage [V]	Current [mA]	Power [mW]
FLIR Lepton 3.1R Thermal Sensor	2.8	14	39.2
FLIR Lepton 3.1R Thermal Sensor Core	1.2	84	100.8
FLIR Lepton 3.1R Thermal Sensor I/O	3.1	235	728.5
ESP32-S3-WROOM-1	3.3	500	1650

Table 11: Nominal Voltage, Current, and Power Levels

14.3. Data Interface

The thermal sensor will send raw image data to the microcontroller through serial pins (SPI), the microcontroller is mounted to the PCB and the sensor is housed in the breakout board connected to the board.

14.4. User Control Interface

The user control interface is a website that communicates with the microcontroller. The user will login using credentials provided through their companies. Then, the user will be able to select what switchgear vertical tower will be viewed. The user can select the desired image stream from the overview page, or the user can use the search bar to find their desired image stream.

15. Communications / Device Interface Protocols

15.1. Wireless Communications

15.1.1 Wi-Fi

The microcontroller has a built-in Wi-Fi module using IEEE 802.11b/g/n standards. This connection will be used to stream live images to the operator's website.

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Subsystem Reports

REVISION – 3
26 April 2025

SUBSYSTEM REPORTS

FOR

Remote Viewing within High Voltage Apparatus

TEAM 54

APPROVED BY:

Project Leader	Date
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Change Record

Rev.	Date	Originator	Approvals	Description
1	12/5/2024	Erica Mathew		Draft Release
2	4/2/2025	Julia Garcia		April Update
3	4/26/2025	Julia Garcia		Final Release

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16. Introduction

The first subsystem is the thermal sensor and PCB, the power supply is housed on the board along with the microcontroller. The thermal sensor is housed on the breakout board attached to the main PCB. All components are housed in an ABS plastic encasing. Below is the subsystem breakdown for our Thermal Remote Viewing System.

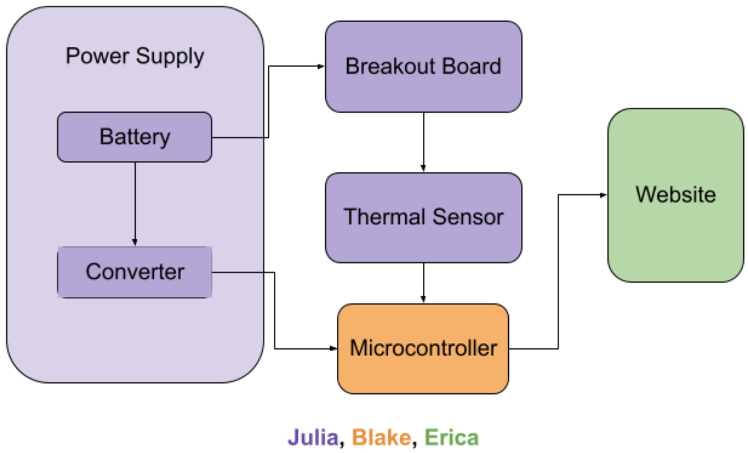

Figure 5: Subsystem Breakdown

17. Thermal Sensor/PCB Subsystem Report (Julia Garcia)

17.1. Subsystem Introduction

The thermal sensor/PCB is the subsystem that contains all the hardware of the system. This includes the power supply, the microcontroller, the camera module, and the ABS plastic encasing. For the power supply, a lithium-ion battery pack is connected to a buck converter to power the microcontroller and to the breakout board for the camera module. The microcontroller will be connected to the camera module through serial communication (SPI). The purpose of this subsystem is to provide power to both major components, ensure data transfer between them, and protect the system and the switchgear.

The breakout board replaced three buck converters that provided power to the camera module directly. The camera socket wasn't able to be hand soldered while maintaining the functionality of the part. The breakout board adds height and weight to the overall system, but it reduces the size of the main board, and the number of parts needed. The breakout board attaches to the board with a connector and is removable, though this isn't relevant to the operator because they don't interact with the hardware.

The ABS plastic encasing protects the sensor from the high voltage of the switchgear and ensures the dielectric integrity within the switchgear is maintained.

17.2. Subsystem Details

A block diagram of the subsystems is shown below.

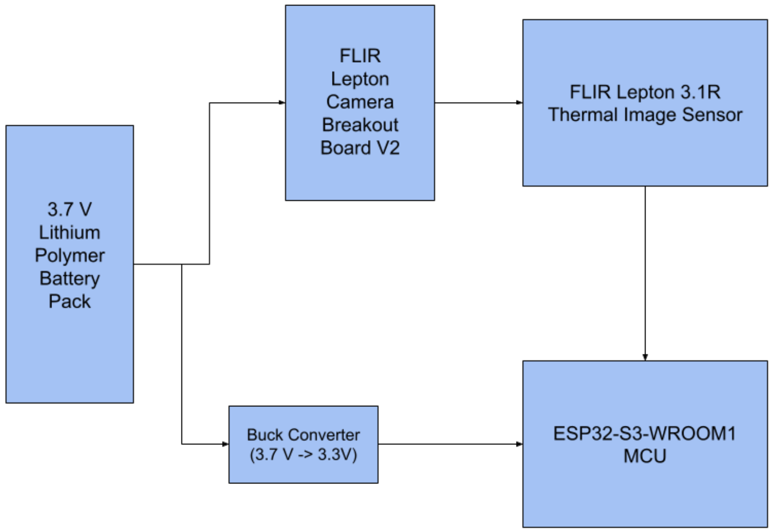

Figure 6: Functional Block Diagram of the Thermal Sensor/PCB Subsystem

The camera module needs three separate power inputs to operate. The core of the camera (VDDC), the sensor itself (VDD), and the input/output ring (VDDIO) all need to be powered separately. This is done by the breakout board that houses the camera socket.

The microcontroller needs pull-down resistors and push-buttons to function and be programmed, while also needing to be powered. The SPI interface between the microcontroller and the camera module requires four pins on each device to be allocated in order for the data to transfer properly.

The layout of the buck converter is shown in the figure below.

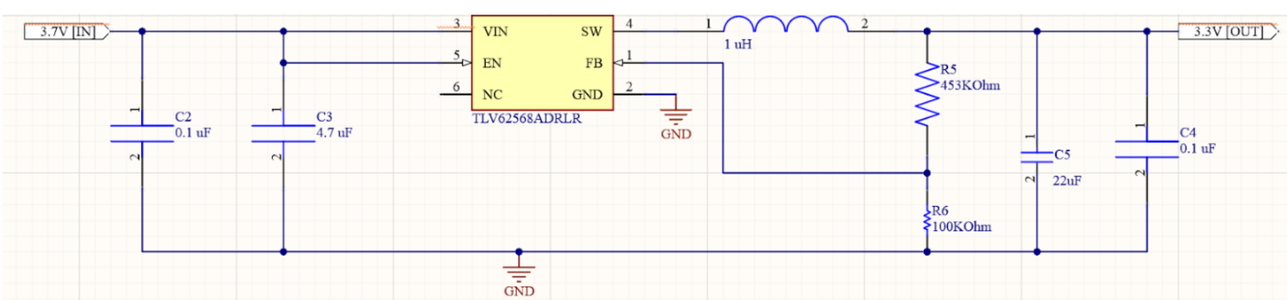

Figure 7: Buck Converter Schematic for ESP32 Input

The connections for the microcontroller are shown in the figure below.

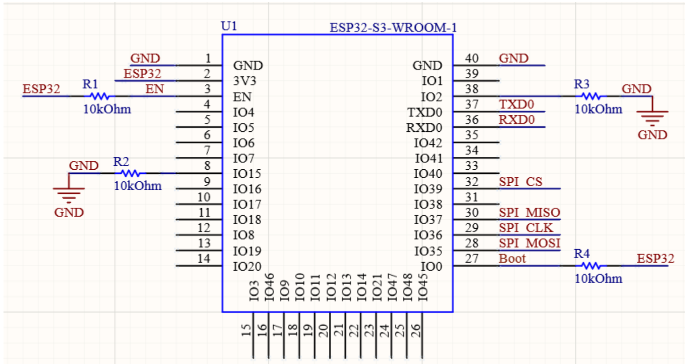

Figure 8: ESP-S3-WROOM-1 Connections

The overall layout of PCB is shown in the figure below.

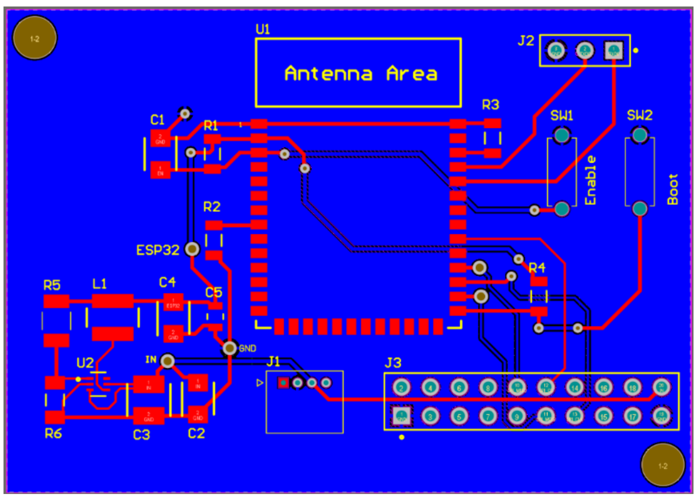

Figure 9: PCB Layout

The ABS plastic encasing is shown in the figure below.

Figure 10: ABS Plastic Case

17.3. Subsystem Validation

To validate the functionality of the PCB, the buck converter was tested with a multimeter to ensure the output value was within acceptable limits. The values on the data sheets of the components were nominal values, therefore slightly higher or lower would still power the components. The output was also tested with an oscilloscope to see if the DC voltage had an acceptable ripple.

The three figures below show the results of the buck converter, the input for the microcontroller, and the data stream between the sensor and microcontroller.

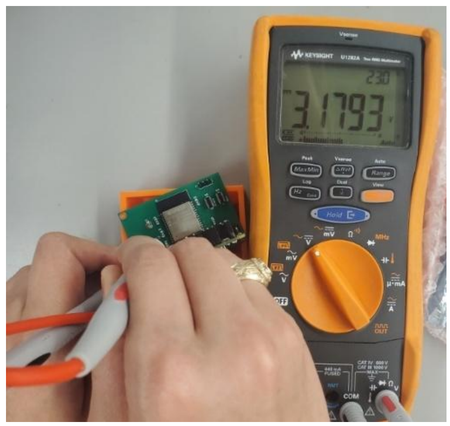

Figure 11: Results of ESP32 Buck Converter Shown by Multimeter

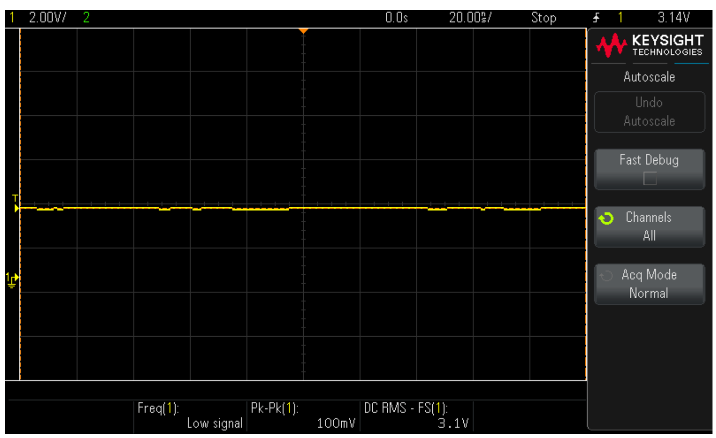

Figure 12 : ESP32 Buck Converter Output Voltage on Oscilloscope

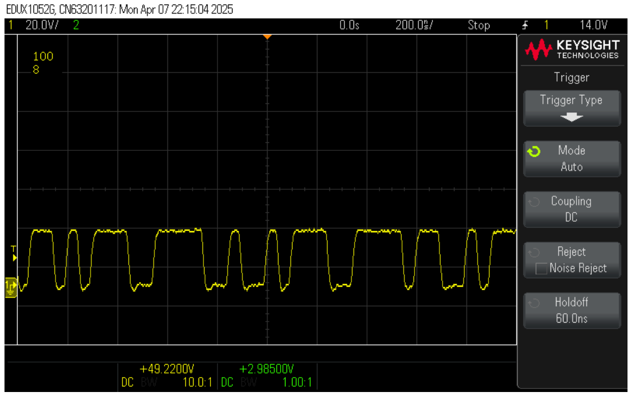

Figure 13: Data Stream Between the Sensor and Microcontroller on Oscilloscope

17.4. Subsystem Conclusion

The goal of this subsystem is to ensure the two major components can receive power and communicate with each other. The hardware of the system is what provides the images for the microcontroller to send and for the website to receive.

This subsystem was changed from one board with four buck converters, the microcontroller and the thermal sensor all mounted on it to a board with one buck converter, the microcontroller, and a connector with a breakout board, which houses the thermal sensor, attached. All four buck converters were functional, and the microcontroller was able to download code, but the camera socket wasn't able to be hand soldered without losing functionality. This caused the change of the socket to be mounted directly to the board to the breakout board being separated and attached through a connector.

The subsystem is completely functional, the correct voltage level is provided to the breakout board and the microcontroller. The microcontroller is able to download and run the code provided by subsystem two (microcontroller). The thermal sensor and microcontroller communicate successfully which allows image data to be displayed by subsystem three (website).

The figure below shows the completed subsystem.

Figure 14: Completed System Hardware

18. Microcontroller Subsystem Report (Blake Bagley)

18.1. Subsystem Introduction

This subsystem is made up of the microcontroller and the code that will be uploaded to it. As stated previously in this report, the microcontroller has three main jobs: Take the image data from the thermal image sensor and process the image to determine if the switch is open or closed and send both the image data and the determination to the website.

18.2. Subsystem Details

The microcontroller will first attempt to connect to the operator's laptop. It does this by declaring itself as a station and sets a connection to the laptop's hotspot. This hotspot will give the microcontroller the ability to access the website.

The next thing the microcontroller does is capture the image data from the thermal camera. To describe how the microcontroller takes in the data from the thermal imager, we first need to understand how the thermal imager is sending data. The Lepton 3.1R uses SPI communication to send its data. It does this by separating rows of pixel data into packets.

Each packet consists of 80 pixels of data. Those packets are then separated into four different segments each containing 60 packets. Through SPI communication, the thermal imager will send one packet per falling edge of the chip select signal. Also, for each segment, the twentieth packet will have the ID of the segment that is currently being read.

With all of this in mind, the following is how the microcontroller takes in the image data. First, the code will continuously read for valid packets until it reads a packet with an ID of zero. Then, it will start to store the packets into memory until the twentieth packet is read. If the segment number is invalid, the memory will be reset and the reading process from before will start again. If not, the segment will finish being read, and the code will restart the process of looking for the next segments until all segments are read and stored.

Below is a flowchart to further describe the code snippet.

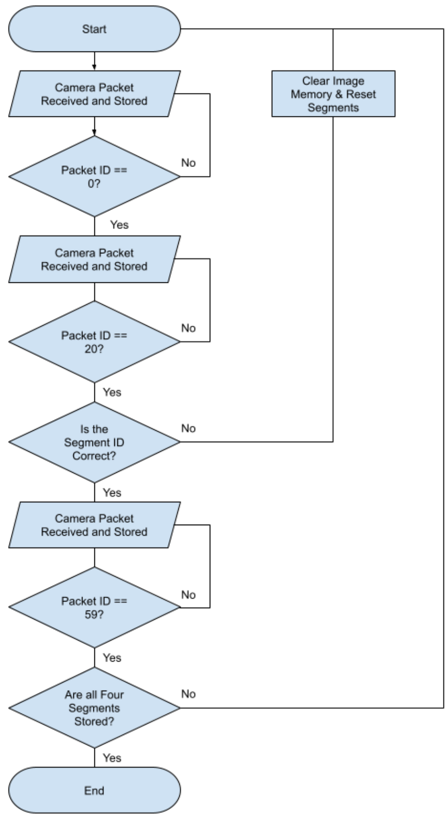

Figure 15: Camera Communication Flowchart

Next, the code will compress the image and process it to determine if the switch that the camera is fixed on is open or closed. It will do this by reading temperature differences between the entire frame and a smaller area of the frame in which the contact of the switch is located when the switch is closed. Firstly, the image data stored isn't normalized at all, so it would be fairly difficult to do math that could read temperature differences. So, the code normalizes the pixel data to range from 0 to 255 using the equation below.

$$T_n = (t_i - t_{min})\left(\frac{255}{t_{max} - t_{min}}\right)$$

Figure 16: Normalization Equation

$T_n = normalized\ temperatures$
$t_i = current\ temperature$
$t_{max} = maximum\ temperature$
$t_{min} = minimum\ temperature$

This will also make the image data quicker to send to the website as well as provide a clearer image. Then the code will calculate the average temperatures of both areas and determine the switch's state on whether the difference in the temperatures is high enough or not. If there is a significant difference, the microcontroller will determine that the switch is closed. The flowchart below further describes the code's process.

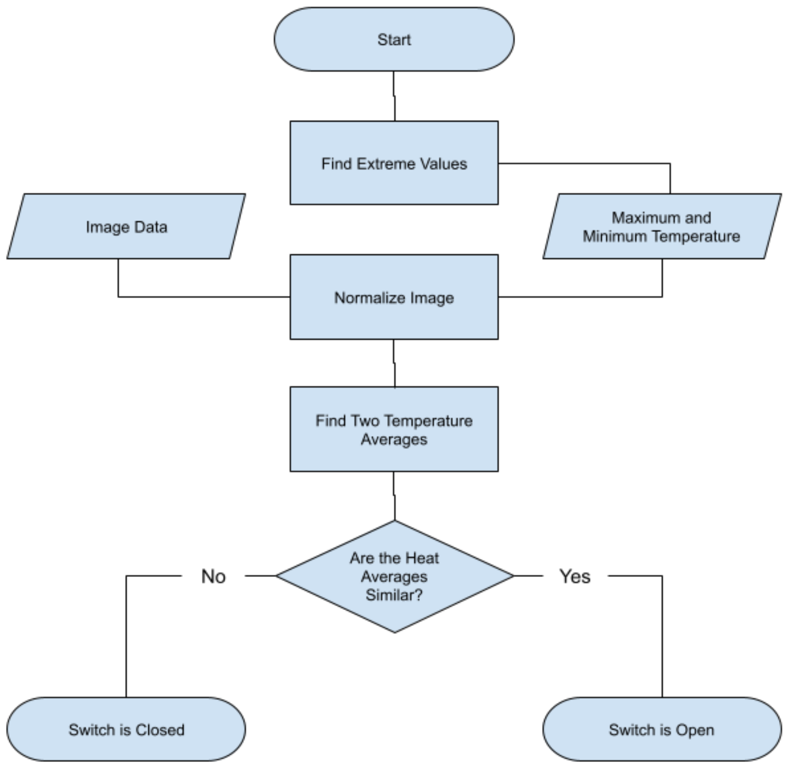

Figure 17: Image Processing Flowchart

Finally, the code will send the image data and the determination to the website. This is done by using HTTP post requests. The microcontroller will create a post request that has the image, and the determination stored in separate headers. In other words, it will configure an HTTP Client to connect to the website, set the post request, and then send it to the website. The code will then loop back to trying to read an image from the camera and keep looping.

18.3. Subsystem Validation

To validate the Wi-Fi connection of the microcontroller, a laptop was used as a device for the microcontroller to connect to. It was specifically set for the microcontroller to connect to the laptop's hotspot. The snapshots from the laptop and the ESP-IDF console below show that the Wi-Fi connection is made.

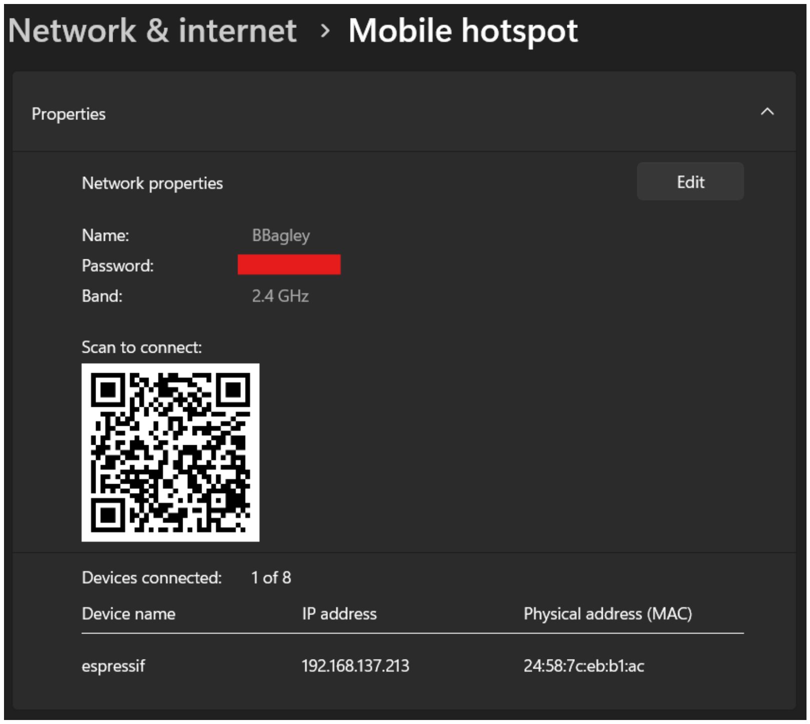

Figure 18: Wi-Fi Connection (Laptop View)

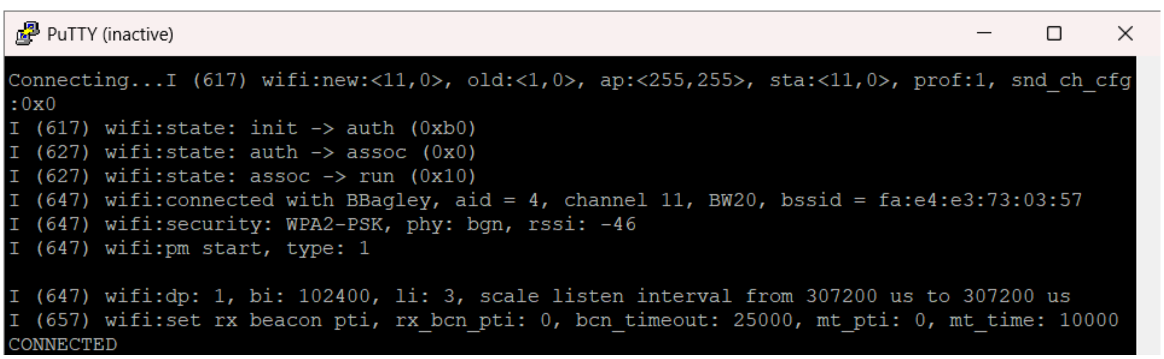

Figure 19: Wi-Fi Connection (PuTTY View)

To validate the communication between the camera and the microcontroller, three tests were performed. The first test was to see if the pixel data was being stored in the correct order. This was done by having the code print the segment ID at the twentieth packet of each segment and then checking stored values to see if they aligned. The snapshot below shows that the code read through invalid segments until it finally got to the correct ones and stored them. The first number on the left represents the segment ID and the second number represents the packet ID. The segment ID should read in order as 1, 2, 3, and 4. However, when the data is read in, the numbers for the segment ID are shifted by 4 bits. Therefore, in the screenshot, they should read as 16, 32, 48, and 64. It also does a check to see if the packets were stored correctly by printing the ID of the twentieth packet of the stored data. The ID should be 16 if the data is stored correctly.

```
SEGMENT ID: 0 , 20

SEGMENT ID: 0 , 20

SEGMENT ID: 0 , 20

SEGMENT ID: 0 , 20

SEGMENT ID: 0 , 20

SEGMENT ID: 0 , 20

SEGMENT ID: 0 , 20

SEGMENT ID: 0 , 20

SEGMENT ID: 0 , 20

SEGMENT ID: 0 , 20

SEGMENT ID: 16 , 20

SEGMENT ID: 32 , 20

SEGMENT ID: 48 , 20

SEGMENT ID: 64 , 20

ID 0: 16 , 20
```

Figure 20: Segment ID Test

The second test checks if the code will ignore invalid frames. In the previous figure, it shows that the segments whose ID is 0 get skipped until a valid ID of 16, 32, 48, or 64 is read.

The next test is to check temperature reading to make sure they align with the temperature in front of the camera. This was done by putting two different heat readings in front of it. One of the temperature readings had nothing in front of the camera. The other had a hand fully covering the view of the camera.

There are two screenshots below. The first showing the first 10-pixel values of the camera when nothing is in frame and the second showing pixel values of the camera when a hand is in frame. The screenshots show that a higher pixel intensity is read when a hand is in front of the camera. Therefore, the microcontroller is correctly reading temperature increases and decreases from the camera.

```
PIXEL 0: 115 , 127
PIXEL 1: 115 , 118
PIXEL 2: 115 , 121
PIXEL 3: 115 , 141
PIXEL 4: 115 , 127
PIXEL 5: 115 , 127
PIXEL 6: 115 , 145
PIXEL 7: 115 , 136
PIXEL 8: 115 , 132
PIXEL 9: 115 , 114
```

Figure 21: Room Temperature Test

```
PIXEL 0: 117 , 170
PIXEL 1: 117 , 147
PIXEL 2: 117 , 130
PIXEL 3: 117 , 139
PIXEL 4: 117 , 124
PIXEL 5: 117 , 128
PIXEL 6: 117 , 114
PIXEL 7: 117 , 112
PIXEL 8: 117 , 120
PIXEL 9: 117 , 112
```

Figure 22: Hand Temperature Test

Finally, it was tested by pulling the image data from the microcontroller and displaying it in MATLAB. The image below is of a desk showing that the microcontroller is receiving image data correctly.

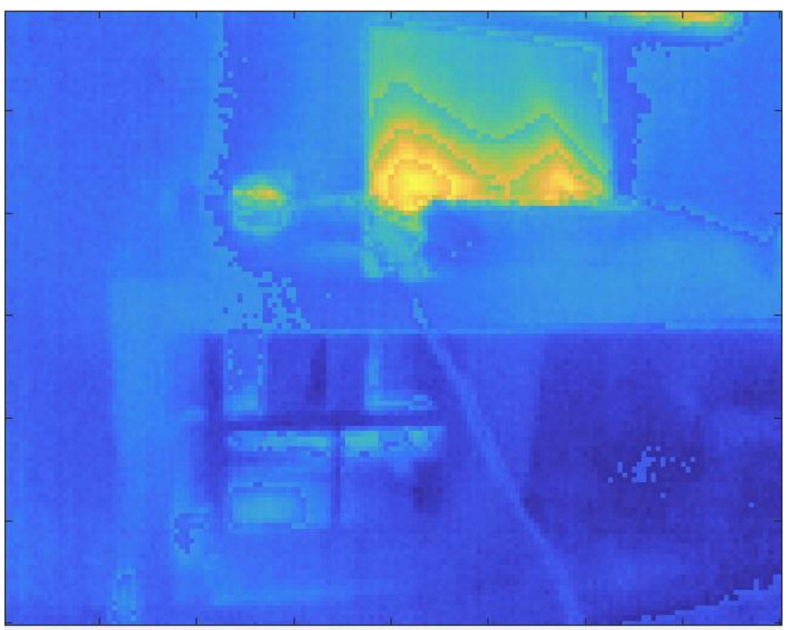

Figure 23: MATLAB Photo Test

To validate the image processing, the code needed to be checked to ensure it was reading the temperature differences in the correct regions. The region of check should be located around the top left corner of the camera's sight. To test this, a makeshift switch was created, using a cardboard box that has two holes to mimic the positions of the real switch. One of the holes was located in the window of check and the other is located in the opposite corner. Below is a photo of the box.

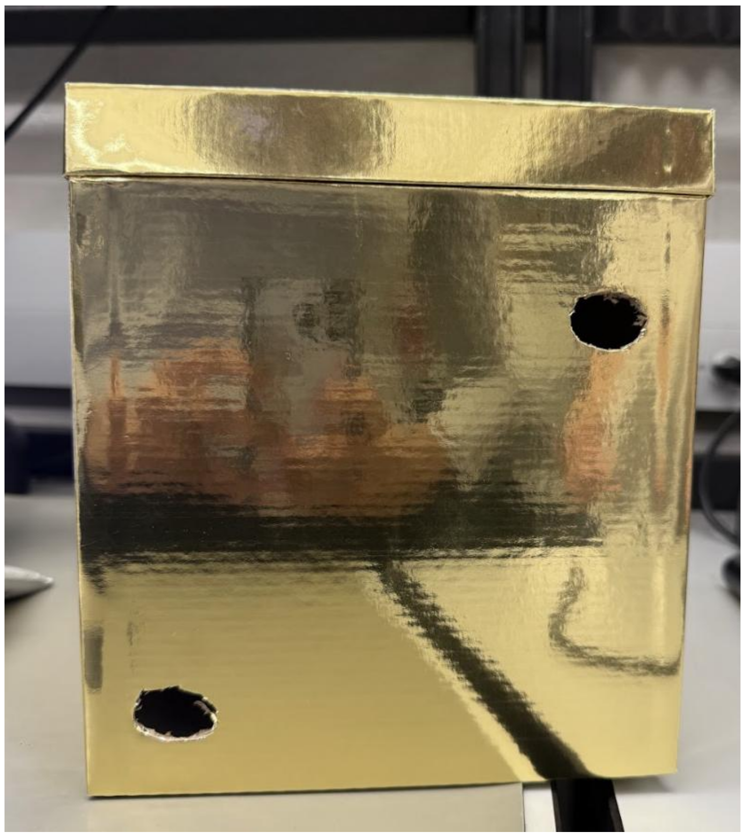

Figure 24: Makeshift Box for Testing

While the system is running, if heat is read in the top hole, the microcontroller should output “Closed”, otherwise it should output “Open”. The two screenshots were taken from the website showing that the microcontroller is making the correct determinations.

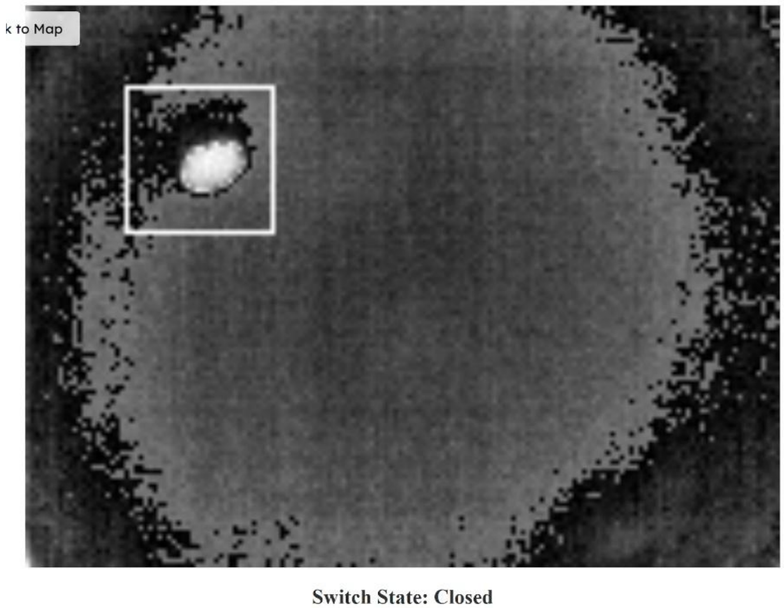

Figure 25: Switch State Test (Closed)

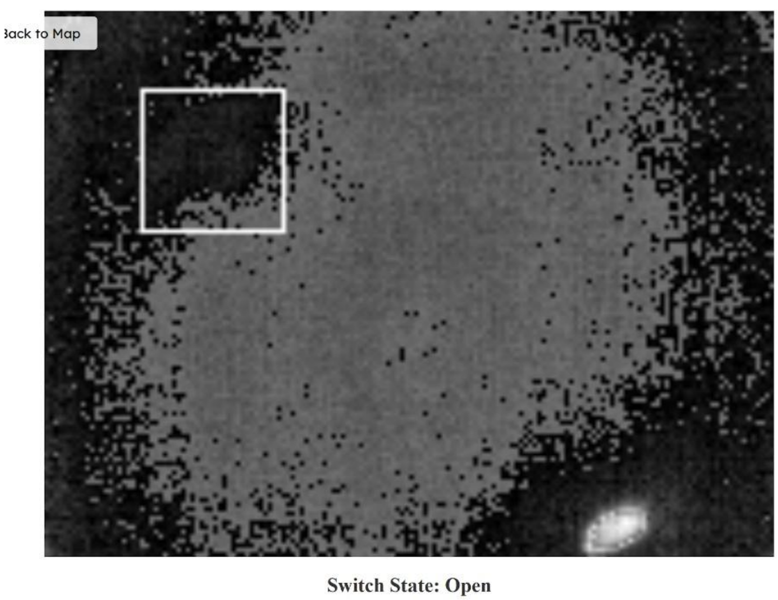

Figure 26: Switch State Test (Open)

To validate that the microcontroller can send data to the website, we will send both image data and switch state data to the website and look for a message sent back to the microcontroller saying the information was sent correctly. The screenshot below shows that the microcontroller is sending data correctly because the website sent a message back saying “Image received and converted successfully” and tells the microcontroller the switch state that the website received. Below is also a screenshot from the website showing the image that was sent to the website properly.

```
I (5686) HTTP_CLIENT: HTTP_EVENT_ON_CONNECTED
I (5686) HTTP_CLIENT: HTTP_EVENT_HEADER_SENT
I (5716) HTTP_CLIENT: HTTP_EVENT_ON_HEADER, key=X-Powered-By, value=Express
I (5716) HTTP_CLIENT: HTTP_EVENT_ON_HEADER, key=Access-Control-Allow-Origin, value=*
I (5726) HTTP_CLIENT: HTTP_EVENT_ON_HEADER, key=Content-Type, value=application/json; charset=utf-8
I (5736) HTTP_CLIENT: HTTP_EVENT_ON_HEADER, key=Content-Length, value=76
I (5736) HTTP_CLIENT: HTTP_EVENT_ON_HEADER, key=ETag, value=W/"4c-Ey0/7MdQTLNRNVIiC6jIxpJys+E"
I (5746) HTTP_CLIENT: HTTP_EVENT_ON_HEADER, key=Date, value=Sat, 19 Apr 2025 19:31:38 GMT
I (5756) HTTP_CLIENT: HTTP_EVENT_ON_HEADER, key=Connection, value=keep-alive
I (5766) HTTP_CLIENT: HTTP_EVENT_ON_HEADER, key=Keep-Alive, value=timeout=5
I (5776) HTTP_CLIENT: HTTP_EVENT_ON_DATA: {"message":"Image received and converted successfully","switchState":"Open"}
I (5786) HTTP_CLIENT: HTTP_EVENT_ON_FINISH
I (5786) HTTP_CLIENT: HTTP_EVENT_DISCONNECTED
```

Figure 27: Website Communication Test (ESP_IDF)

Figure 28: Website Communication Test (Website)

18.4. Subsystem Conclusion

The subsystem works as expected by the testing that has been done in the section above. It shows that the microcontroller is able to make a connection with the website, correctly read and store the data coming from the camera, process that data to determine the state of a switch, and send that information to the website.

19. Web Interface Subsystem Report (Erica Mathew)

19.1. Subsystem Introduction

The web interface subsystem is designed to display a live image stream from a thermal sensor, allowing operators to monitor their switchgear setup more efficiently. The website includes a login/registration page, overview page, map builder page and video page. Below is a flowchart breaking down the website.

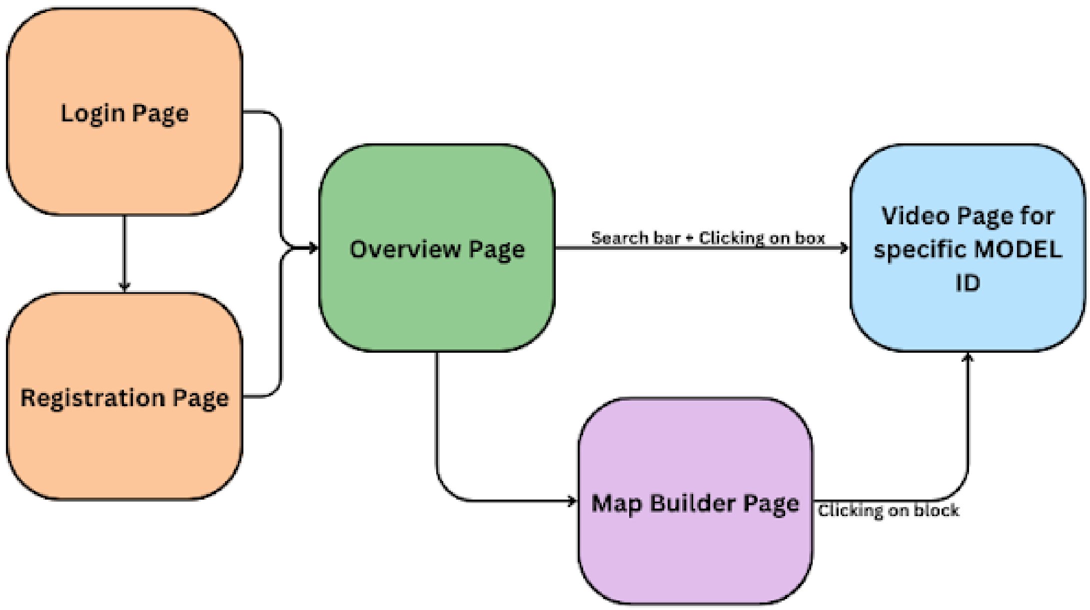

Figure 29: Subsystem Block Diagram

19.2. Subsystem Details

19.2.1 Login/Registration Page

The website opens to the Login Page, prompting users to enter their username and password. If they don't have a profile there is a link directing the user to a registration page. On the registration page the user must enter their email address, password, and confirmation of their password. The website then checks if the imputed password and password confirmation matches. There are also checks written to validate that the password created is longer than 7 characters and the user provided a valid email address. If all validations pass, an account is created using Firebase Authentication. Firebase stores the user credentials in its local database. After successfully creating a profile, the user is redirected to the overview page.

Figure 30: Login Page

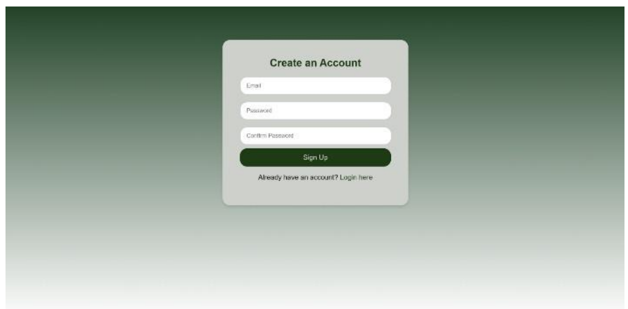

Figure 31: Registration Page

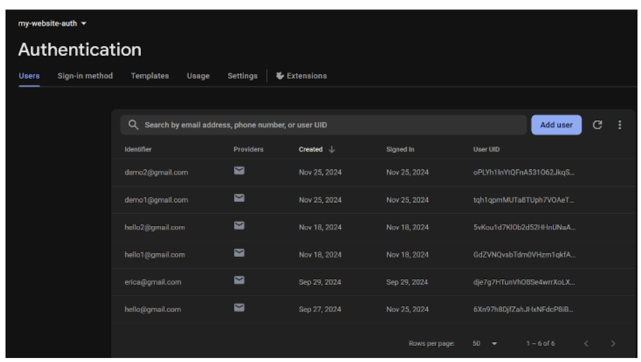

Figure 32: Firebase Authentication

If the user already has a profile they can sign in on the Login page with their email address and password. When the form is submitted, Firebase works to authenticate the user by checking the provided credentials against its database. If authentication fails, an error message is displayed. If authentication is successful, the user is redirected to the overview page.

19.2.2 Overview Page

The Overview page acts as a central hub of the website, allowing users to browse models, search for specific model IDs and navigate to the map builder page. At the top of the page there is a search bar to allow users to type a specific MODEL ID into the field and then press the magnifier icon to search. The search icon consists of a magnifier icon over an invisible search button; this was done to create a sleek appearance throughout the website. The search bar's event listener handles 'click' events from the search button. Then the user's input is trimmed and converted to uppercase. If the user's input matches an available model, the user is redirected to the MODEL ID's video page. If the input does not match, an error message is displayed. The overview page also includes a video grid that allows users to click on blocks that represent MODEL IDs. Clicking a MODEL ID block will direct the user to that specific image stream. At the bottom of the page is a link called 'Build Your Map' that will redirect users to the map builder page.

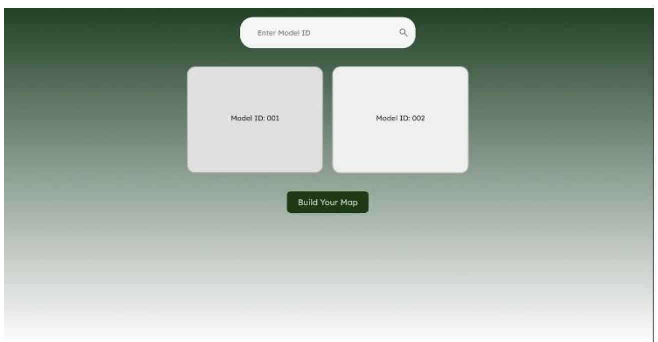

Figure 33: Overview Page

19.2.3 Map Builder Page

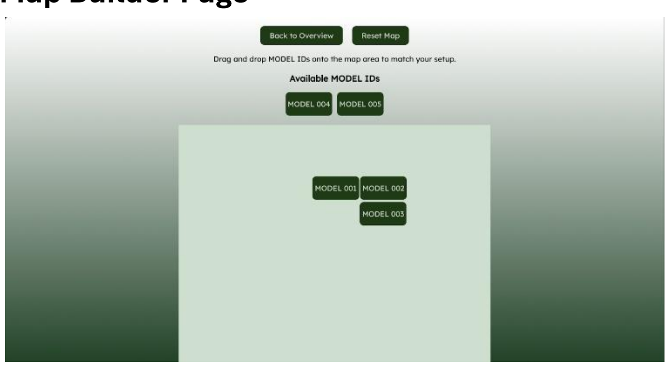

Figure 34: Map Builder Page

This feature was created to allow operators to mimic their physical switchgear setup by dragging and dropping blocks that represent MODEL IDs. By clicking on a block, it will direct the user to its specific image stream.

19.2.3.1. Drag and Drop

The drag and drop feature uses the interact.js library to enable smooth dragging. When a block is dragged the position is set to absolute (which allows the block to move freely), additionally the Z-index is changed to a high number that ensures it appears on top of any other element. When the block is dragged from the model-list (the available model IDs at the top) into the map area (the white box), the block's position is calculated relative to the new container. Once the block stops being dragged, the new position is calculated by finding the difference in the x coordinates (new position - old position) and the difference in the y coordinates to get a new (x, y) coordinate. The distance from the original position to the new position is calculated using the Pythagorean theorem and only if the distance is greater than 5 pixels is the movement registered. This is done to prevent unintentional movements and make the blocks move smoother.

19.2.3.2. Saving and Loading

Whenever a block located in the map-area is moved, its new location is saved to the browser's local storage. When the page is reloaded, there is a check to see if there is a saved layout; if there is then all blocks are moved to the saved position in the map area.

19.2.3.3. Resetting Map

On the map builder page there is a 'Reset' button that allows the user to clear the map area. Upon clicking the button, the user is asked for confirmation to clear the page. If confirmation is granted, the saved layout saved within local storage is removed. Additionally, all blocks in the map area are moved back into the model list and their position data is cleared.

19.2.3.4. Navigating to Video Page

The blocks have an event listener that detects clicks on a block. There is also a 'dragging' Boolean that is only set to 'True' when the block has been moved more than 5 pixels. When the event listener detects a click and the 'dragging' Boolean is set to false, the click is processed, and the user is redirected to that block's respective video page. This is done to prevent bugs while dragging blocks.

19.2.4 Video Page

The Video Page displays images sent from the microcontroller one by one to mimic a slow video stream.

19.2.4.1. Server

The server receives both raw 8-bit grayscale data and a binary switch state from the microcontroller. The microcontroller sends an HTTP POST with a body (containing the raw image data) and a header with the Switch-State being either open or closed. The server listens for these POSTs at /ping; the incoming image requests are parsed into a buffer, while the switch-state headers update with the latest switch position. Below is an image of the server console shows that the image data was successfully received from the microcontroller.

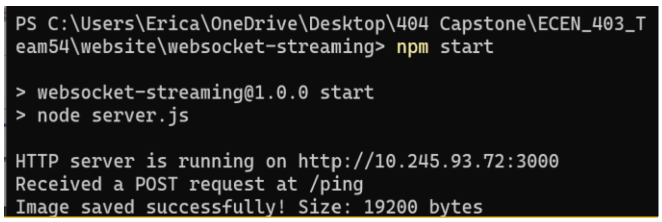

Figure 35: Image Received by Website

Then, using the sharp library, the buffer is interpreted as a single-channel grayscale image and converted to a PNG. The picture is then saved on disk. Every time a new image data comes; the new image replaces the old image. Below is an example of what the 8-bit grayscale data looked like and what the Output PNG looked like after it has been converted.

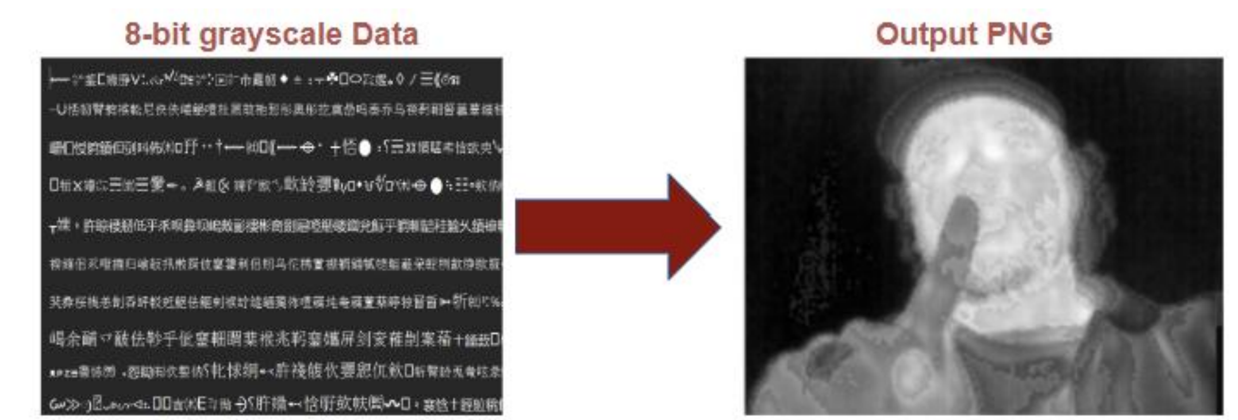

Figure 36: Raw Data to PNG

Simultaneously, the server caches the new switch state as an in-memory variable. This gives two endpoints: POST /ping for image updates and GET /switch state for the most recent state.

19.2.4.2. Video Page Front End

The front end of the video page has a big box at the center of the page displaying the image stream with the switch state written below it; the page also has two buttons at the top to navigate to the map and overview pages.

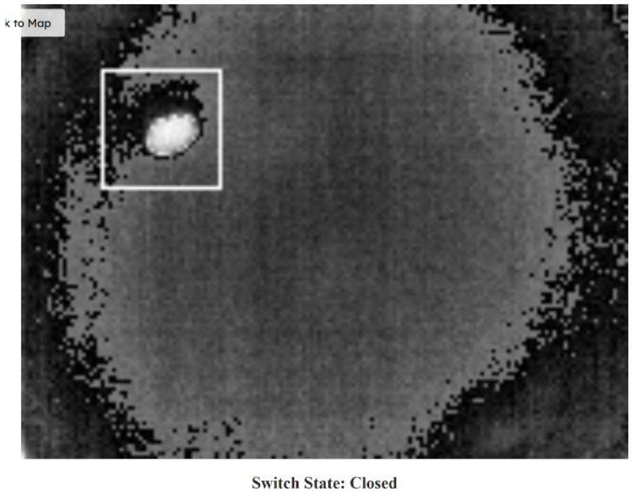

Figure 37: Video Page

This page has two elements: the <img> element for the image and the <span> element for the switch state. A timer is set to update both elements every 1.5 seconds. This forces the browser to fetch the newly saved PNG and the new switch state as either “Open”, “Closed” or “Unknown”. This allows the user to always see the most recent frame and switch state. As the image frames constantly update, a slow video stream is seen.

19.3. Subsystem Validation

19.3.1 Receiving Video

The website was validated to ensure the image stream was playing on the video page. This was confirmed by starting up the server and thermal camera and having the user navigate to the video page playing a live image stream.

19.3.2 Login System

The Login system was validated to ensure the login page would work with correct credentials and fail with incorrect credentials. This was confirmed by having the user register a new profile, confirm it can be found in Firebase, then log in with the new profile.

19.3.3 Search Bar

The search bar was validated to ensure it would redirect users to the proper image stream. This was tested by having a user type an available MODEL ID and then confirm that they were directed to the correct video page. Additionally, the user typed an incorrect MODEL ID and was given an error message.

19.3.4 Video Display Page

The video display page (overview page) was validated by clicking different MODEL ID blocks and ensuring that the user was directed to the correct image stream.

19.4. Subsystem Conclusion

The goal of the website is to create a simple solution that allows switchgear operators to remotely monitor the state of a physical ground switch within their switchgear. This website allows for simplified monitoring of multiple image streams. The website displayed image frames (along with their accompanied switch states) at a constant rate to mimic a slow video stream.

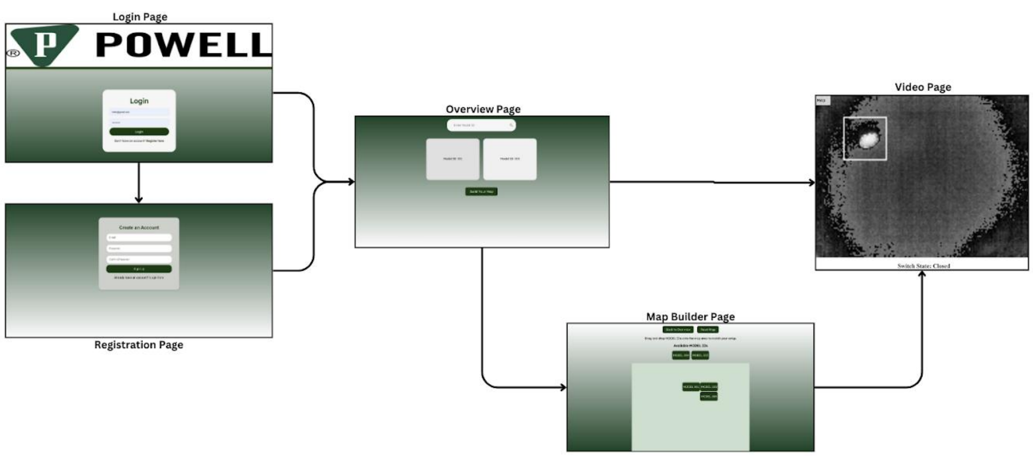

Figure 38: Website Overview

Remote Viewing Within High Voltage Apparatus

Blake Bagley

Julia Garcia

Erica Mathew

System Report

REVISION – 2
26 April 2025

System Report

FOR

Remote Viewing within High Voltage Apparatus

Team 54

Approved by:

Project Leader Date

Prof. Kalafatis Date

T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
1	4/2/2025	Julia Garcia		April Update
2	4/26/2025	Julia Garcia		Final Release

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20. Overview

The project sponsor, Powell Industries, requested a system that allows an operator to view the grounding switch inside a switchgear without opening the switchgear. The system is needed to protect operators in case of failure inside the switchgear. If the switchgear is open during failure, the operator could die. There were many proposed solutions, some non-electrical, but the solution chosen was a thermal image sensor mounted facing the switch. The sensor will send thermal images to the website via Wi-Fi.

The system is divided into three unique subsystems, the printed circuit board, the microcontroller, and the website. The printed circuit board subsystem encompasses all the hardware of the system. This system provides power to all components and houses all components. The main components of the printed circuit board are the microcontroller and the thermal image sensor. The microcontroller subsystem encompasses the image processing, and the code is used to send images to the website. The website subsystem encompasses the code needed to receive and display the images from the sensor. The website also has a database for login/registration information.

21. Development Plan and Execution

21.1. Design

The original design plan of the remote viewing system was a printed circuit board with four buck converters that housed and powered a thermal sensor and microcontroller. The microcontroller on the board communicates with both the thermal sensor and the website. The website displays the photos that the thermal sensor takes, along with the state of the switch that the sensor is viewing.

The design plan for the microcontroller mainly consisted of figuring out the best method for automatically determining the state of the switch. Analyzing photos from a thermal camera taken by Powell, we noticed that the switch contact has the highest heat in the entire photo. This realization is what helped to come up with the algorithm described in the subsystem report.

Once integration began the design changed due to hardware limitations, the thermal sensor is housed on a breakout board that connects to the main board. When integrating the microcontroller and website, we deemed sending post requests to the website as the solution to communicating to the website due to the limitations of the ESP32.

21.2. Execution

Sep 16: Brainstorm system ideas	**Sep 30:** Design basic website layout and PCB block diagram + Train image recognition	**Oct 6:** Simulate buck converters + Design video stream for website	**Oct 20:** Order PCB + Switch State Detection + Design website map builder	**Oct 27:** Soldered PCB + Image recognition + Finalize website video fetching	**Nov 11:** Test PCB + Finalize/ Validate Subsystems	**Nov 25:** Report and Demo

Figure 39: 403 Execution Timeline

Jan 22: Designed and ordered new PCB + Start integrating MCU/ website	**Feb 3:** Have PCB soldered and tested + website/ MCU connection	**Feb 17:** MCU can send image data to website + ESP32 on PCB able to download code	**Feb 24:** Have PCB working + program MCU + switch state comm.	**Mar 3:** All integration between subsystems complete	**Mar 17:** Encase prototype for dielectrics test + Practice demo	**Mar 24:** Practice demo + Completing final report + Prepping for showcase

Figure 40: 404 Execution Timeline

The development of the system was divided into two parts, subsystem implementation and integration. The subsystems were done individually with weekly communication and frequent updates between team members. All subsystem were completed before integration began. Multiple aspects of each subsystem changed during integration, but the foundations remained the same. The hardware was updated twice during integration, these updates are detailed in the subsystem report. The software for both the website and microcontroller were updated to ensure the smooth connection between the two. These updates are detailed in the subsystem report as well.

21.3. Validation

The validation was done systematically, each subsystem was validated before integration, then the integrated system was validated.

The PCB subsystem had three validation criteria, power, communication, and dielectric integrity. The PCB was required to provide specific power levels to the main components, facilitate communication between the main components, and maintain the dielectric integrity within the switchgear. These validations can be found in more detail in the subsystem report.

The microcontroller has three general validation criteria, receiving image data, processing that data to determine the switch's state, and sending that info to the website. The majority of the microcontroller was validated if the image results were coherent. For example, if the camera were aimed at the switch, the photo should look like the switch. We also validated the switch state determination through the use of controlled heat sources. These validations can be found in more detail in the subsystem report.

The website had three validation criteria. The first was to create a user-friendly UI that allows the operator to view the switch image stream. The second was to communicate with the microcontroller to receive both the raw image data and the switch state. The third was to convert the raw data into a PNG to display on the website. This was validated by walking through the components of the website to ensure the Login/Registration page, the Overview Page, the Map Builder Page and the Video Page were operating as expected. The image stream was validated by running the server and ensuring that both the image and switch state were properly displayed on the website. The subsystem report has more detail on the validation process.

The validation of the integrated system was complete once all subsystem validation was complete. The integrated system wouldn't work without all the criteria explained above being met, so once the integrated system was running successfully it was validated.

22. Conclusion

The system performed as intended, providing images mimicking a slow video stream for an operator to remotely view the grounding switch. Integration introduced challenges, but each subsystem was designed with integration at the forefront, so they were overcome without compromising any key functionality.

22.1. Sponsor Feedback

We met with our contact weekly and received feedback along the way, below is feedback given for the project and system as a whole.

"I enjoyed working with Erica, Julia and Blake this semester. From meeting them on the first day, they were inquisitive and enthusiastic about learning, not just about the information needed to complete the project, but about the power industry.

As Powell's R&D team grows, several R&D managers and I have conducted close to four hundred job interviews of various kinds in the past 36 months or so. In doing so, there are some core traits we tend to look for in the first initial contact with a potential hire. We tend to look for inquisitiveness, troubleshooting and problem-solving skills, organization, the desire to work with others, the ability to self-manage, an innate need to keep things moving forward technically and not just being happy with the status quo, and the ability to communicate with others especially when it comes to sharing technical ideas. Erica, Julia and Blake showed these qualities throughout the project and if they ever applied here at Powell, I have full confidence they would move to the top of the candidate list quickly.

The solution they presented to the problem is viable and Powell will be looking at both the schematics for the hardware as well as the coding and algorithms for the machine learning. It is very likely that some form of this solution will be implemented in the overall product development project it was intended for. After that it would be easy to take versions of the product and implement them in other applications." – Jay Yelvington, Research and Development Manager