Thermal Threat Detector

Critical Design Review

Photo Science Capstone 2023-24
April 2nd, 2024

Overview

- Design and develop a thermal imaging system that can detect a suspected threat in a room with no lighting.
- The device must be able to enter a room and return images to the operator.

Requirements

Size: The device should be around 14 in (d) x 4 in (h).

Sound: The device must be able to operate with minimal sound output.

Mobility: The system must be on the ground.

Operation: The device must be operative in manual mode, but if possible, it should be able to switch between manual and autonomous modes.

Power: The device should last at least 1 hour on a single charge.

Camera: The imaging system should have multiple thermal cameras able to detect a range of human body temperatures.

Requirements

Field of View: The imaging system should achieve 180 degrees.

Users View: Wireless live view, from a safe distance.

GUI: The GUI must have a button to allow the user to capture a picture.

Resolution: The system should be able to resolve a human being.

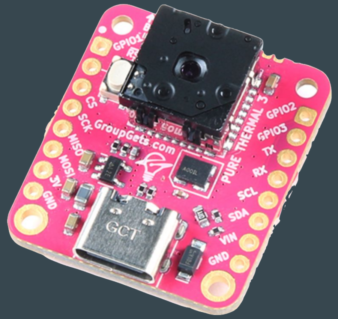
Lens: The lens should be a fixed focus lens.

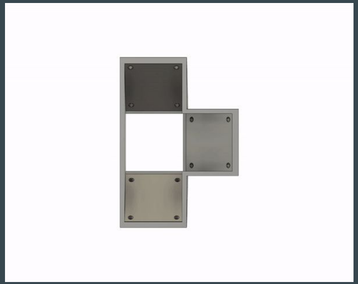
Budget: The budget is $3,000.

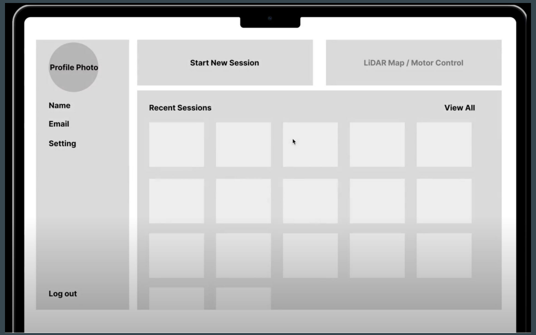
Completion date: The completion date is April 27, 2024 at Imagine RIT.

Where we left off

- Connecting to the Camera
- Programming GUI and Object Detection
- Designing camera mount and printing prototypes



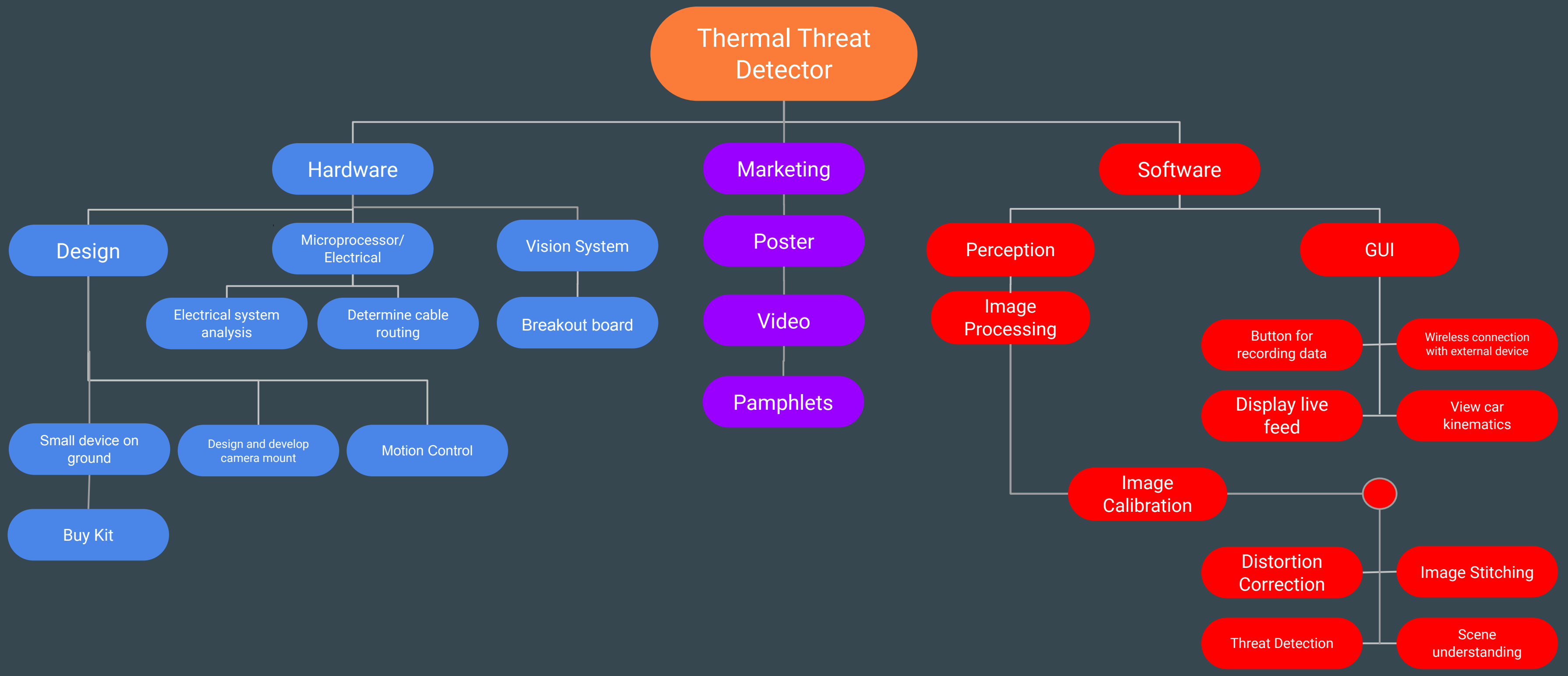




What we are working on

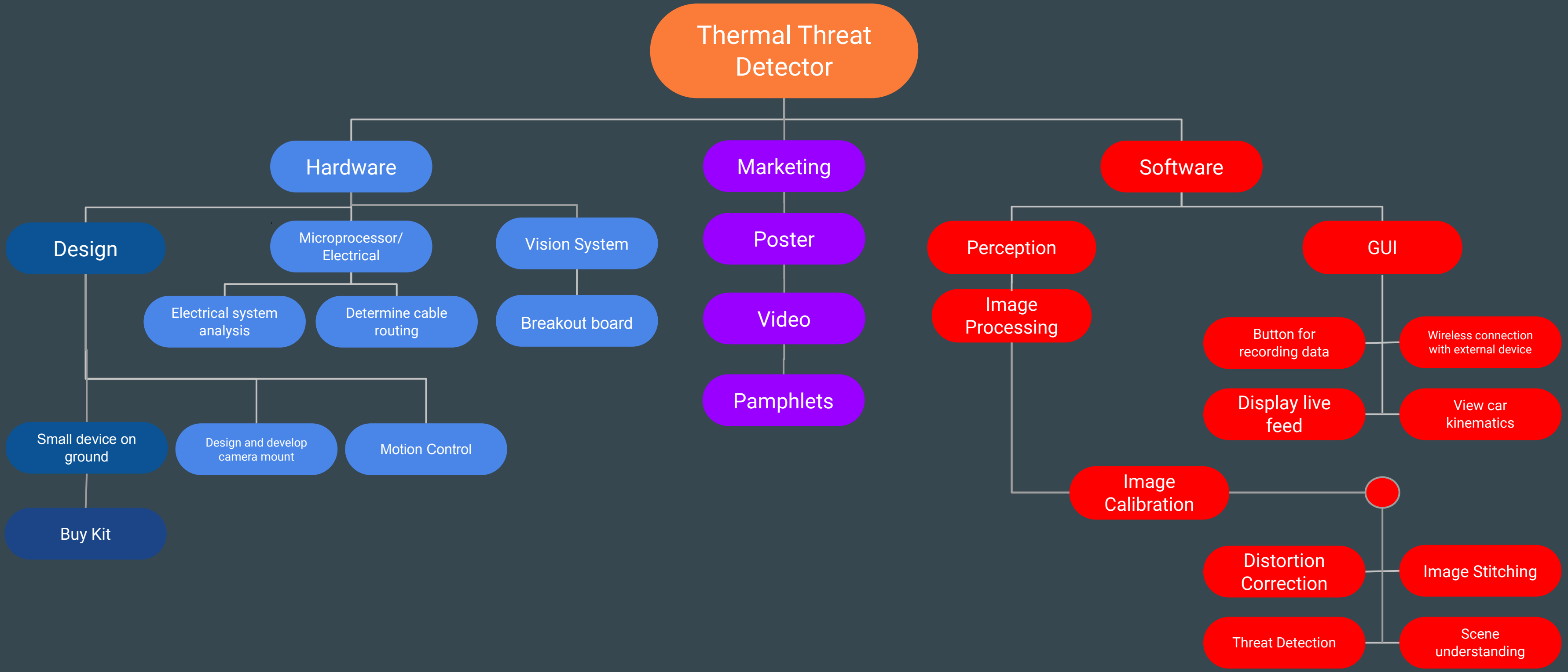
- Fine tuning camera mount
- Camera Calibration
- Image Stitching
- Vehicle control
- Finalizing GUI

Work Breakdown Structure



Hardware Updates

Work Breakdown Structure: Vehicle

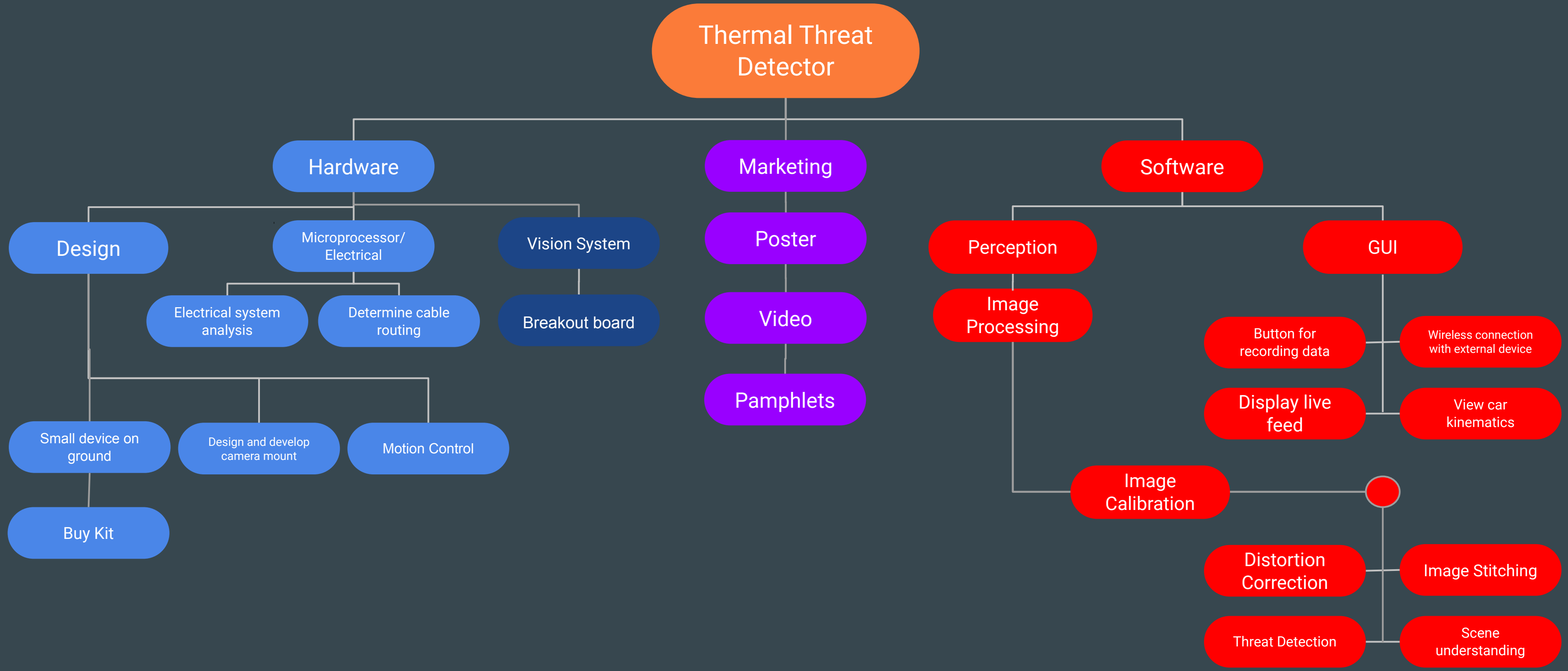


Vehicle

The vehicle chosen was the JetAcker with Jetson Nano.
Included features:
- LIDAR Mapping
- Multiple communication Methods (USB/ WiFi/ Ethernet)
- Compatible with python programming language

A series of test have been run:
- Sound output
- Manual control
- Trained Lidar
- Battery Testing

Work Breakdown Structure: Vision System



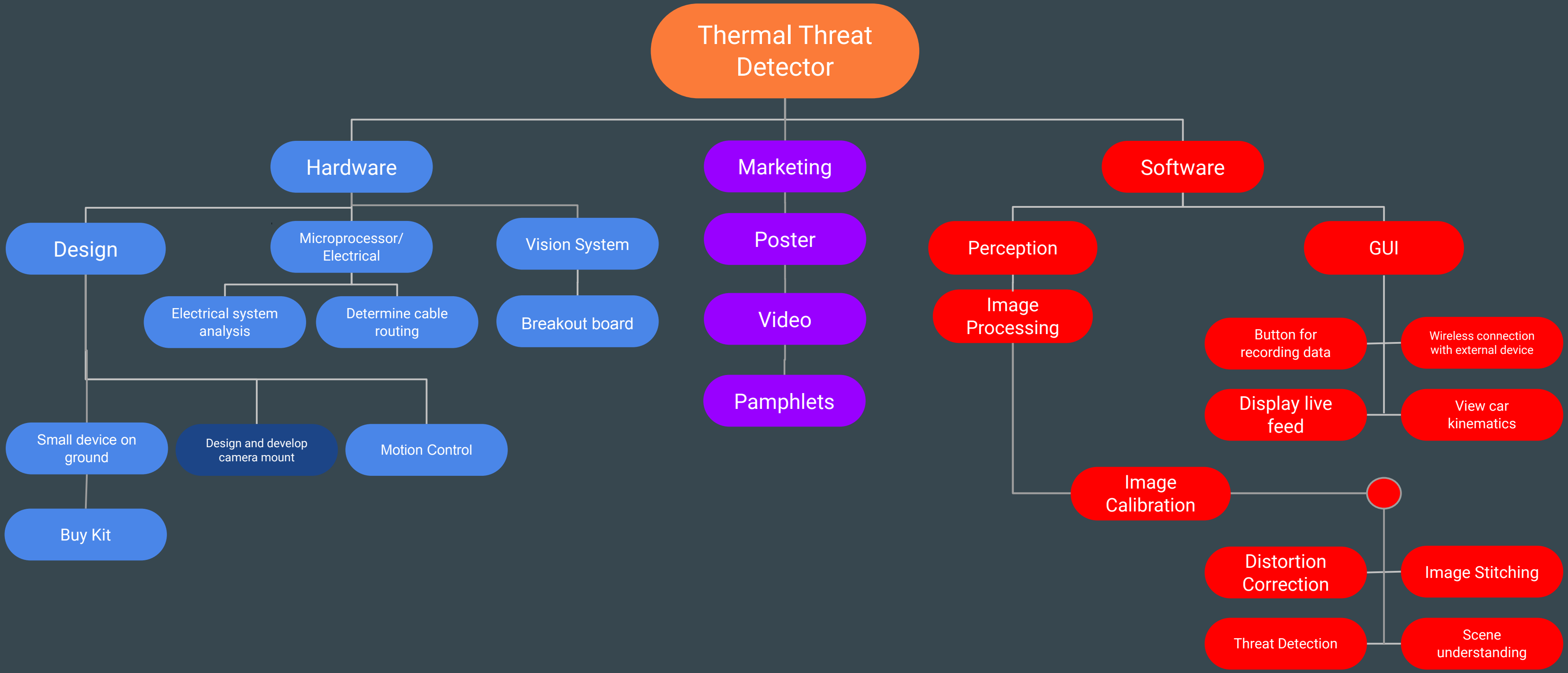
Pugh Analysis - Camera

			Camera					
Baseline	**Criteria**	**Weight**	Lepton 3.1R	FLIR K1	FLIR C3-X	SN-TPC4201VT-F (III)	Klein Tools Pro	HIK Vision
$2000 total	**Price**	5	Better	Same	Worse	Worse	Same	Worse
160x120 px	**Resolution**	5	Same	Same	Worse	Better	Better	Same
97.6-99.6	**Temperature Range**	5	Better	Better	Better	Better	Better	Better
50-60	**Field of View**	5	Better	Same	Same	Worse	Same	Worse
1 hour	**Power**	3	Better	Better	Better	Worse	Worse	Worse
Per user manual	**Easy-to-setup**	1	Worse	Better	Same	Worse	Same	Same
Yes/No	**Rotate**	2	Worse	Worse	Worse	Worse	Worse	Better
Per website and description	**Durability**	1	Same	Better	Better	Same	Better	Same
Based on year released	**Reasources/online info**	2	Worse	Same	Same	Same	Same	Same
Would it be easy to create a mount	**Camera size/shape**	3	Same	Worse	Better	Better	Better	Same
Yes/No	**Stream on it's own**	2	Worse	Worse	Worse	Better	Worse	Worse
	Better		4	4	4	4	4	2
	Same		3	4	3	2	4	5
	Worse		4	3	4	5	3	4
	Weighted Better		18	10	12	15	14	7
	Weighted Same		0	0	0	0	0	0
	Weighted Worse		-7	-7	-14	-16	-7	-15
	Overall Score		11	3	-2	-1	7	-8
	Best Decision	**Lepton 3.1R**						

Cameras - What we are using

- Lepton 3.1R
  - 95* HFOV & 71* VFOV allowing for 190* total HFOV and 156* VFOV
  - 160x120px frame size
  - $142 per camera x 3 cameras
    - $426 total
    - Price of all three Lepton cameras is less than the price of one camera for any of the other brands

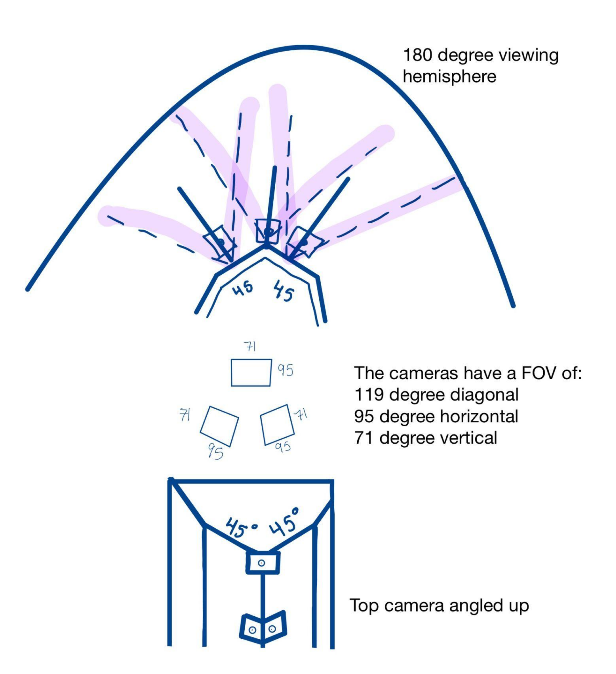
Work Breakdown Structure: Camera Mount



Initial Camera Mount Design

-Each Lepton Camera had:
- -119 degree diagonal
- -95 degree horizontal
- - 71 degree vertical

-The mount was designed to achieve a 180* horizontal field of view and a 156* vertical field of view

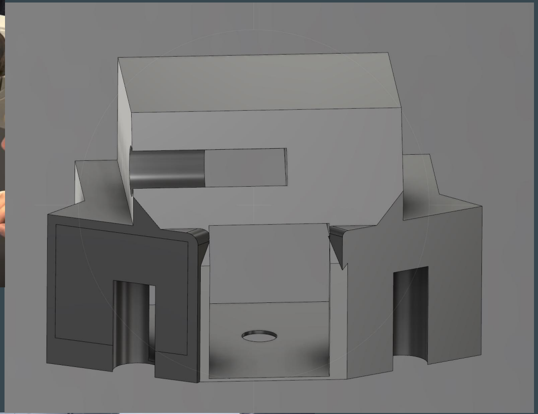


Camera Mount Testing

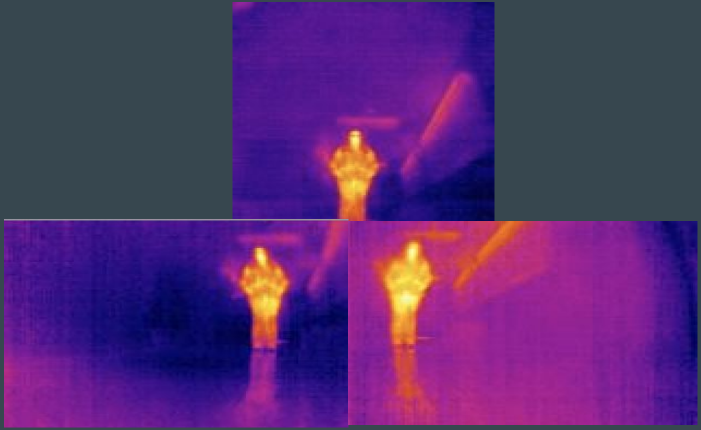
-When testing FOV, placements were marked on the floor where the edge of the frame was for each camera.

-The angle was measured from the outside marks

-Camera mount is being finalized with adjustments calculated from testing.



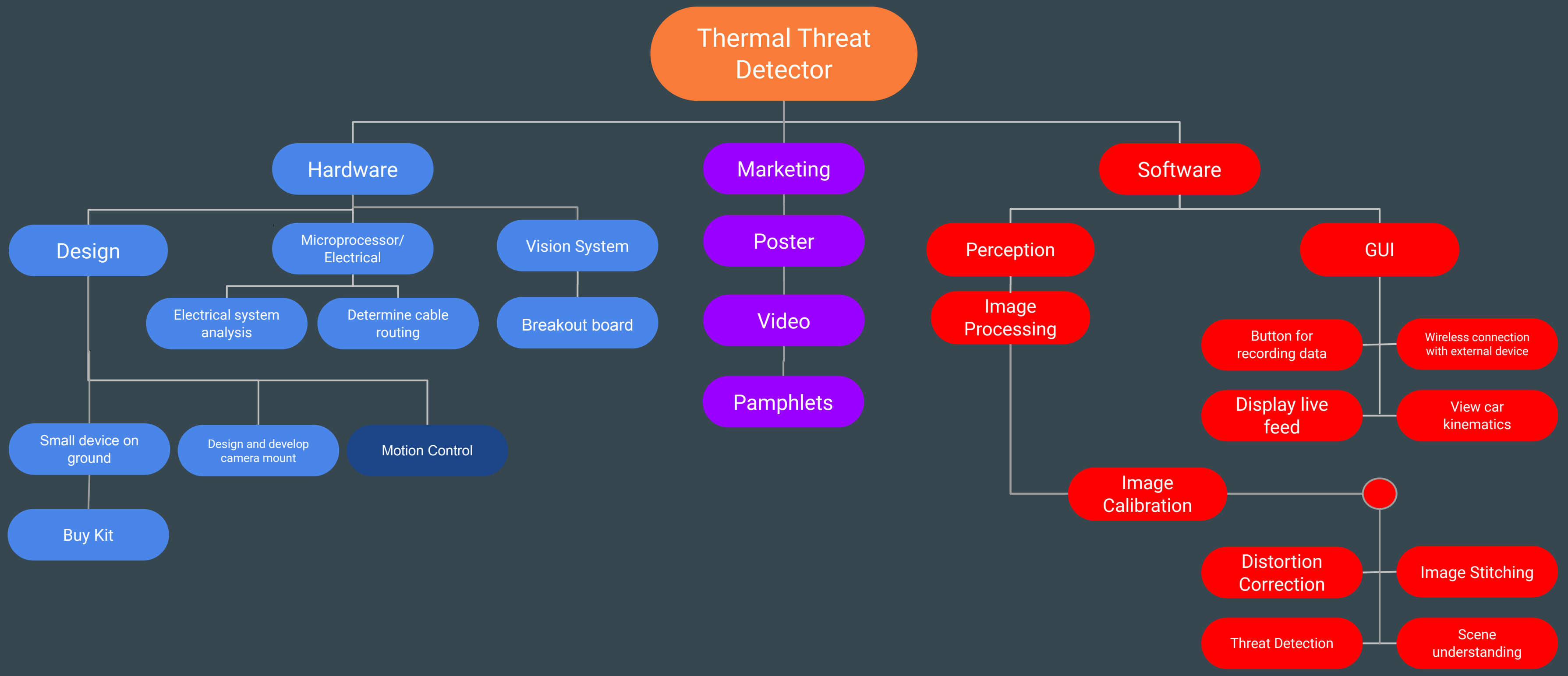
Current Mount FOV and Overlap



-Due to complications with original image stitching, the overlap on our reprint was overcompensated.

-With our new mount, the angle degree of outside cameras will be increased, decreasing overlap and focusing on obtaining our 180* FOV

Work Breakdown Structure: Motion Control

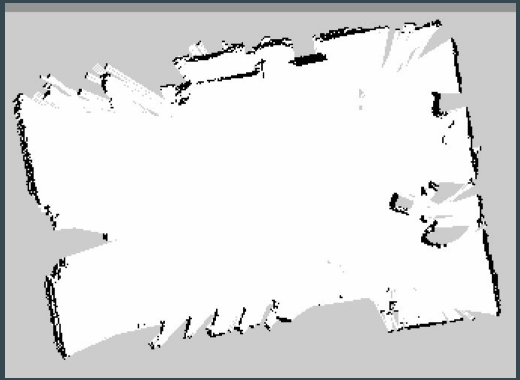


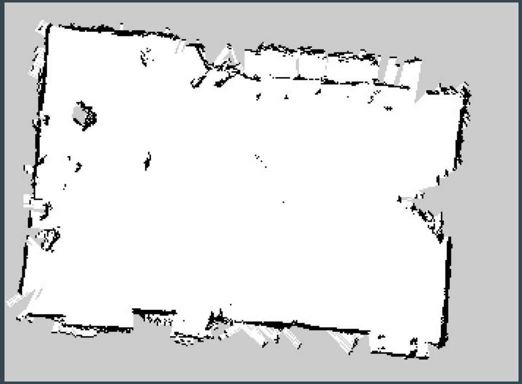
Motion Control

Lidar mapping

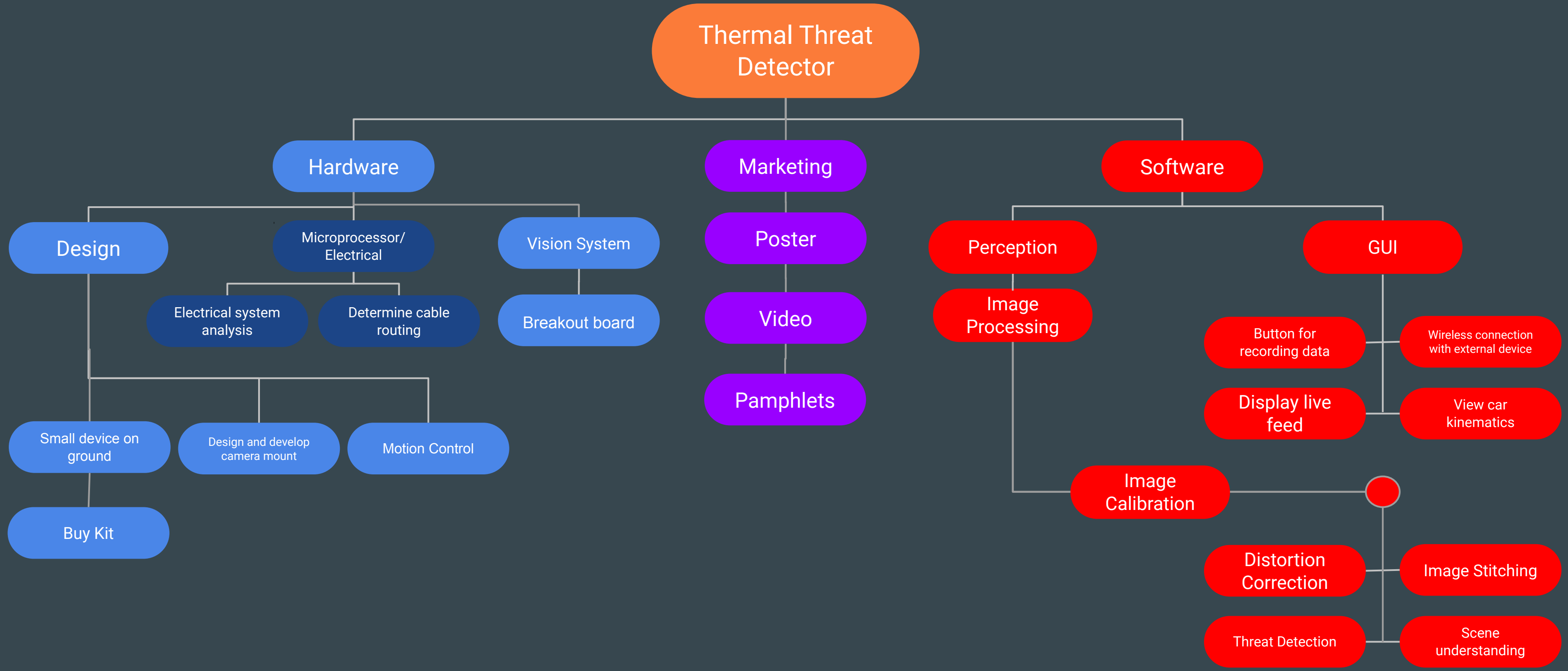
- Conducted SLAM mapping tests within the Gannett studios. Able to create the map with both manual and autonomous control
- Allowed for autonomous movement, and obstacle avoidance.

- Currently implementing vehicle control into the GUI





Work Breakdown Structure: Microprocessor



Microprocessor - Jetson Nano

Complimentary SDK:

- JetPack
- CUDA Toolkit
- cuDNN

Seamlessly integrates with frameworks for computer vision and robotics development like OpenCV and ROS

Because of the processing power, it gives developers a lot of headroom to design and debug while still aligning with the budget.

Topics	Criteria	Weight	Raspberry Pi	Jetson Nano	Jetson Orin Nano	Coral
Processing	GPU	4	Worse	Same	Better	Better
	CPU	1	Same	Same	Better	Same
	RAM	4	Better	Same	Better	Worse
Cost	Processor Cost	4	Better	Same	Worse	Same
Software	SDK	5	Worse	Better	Better	Worse
Hardware	Power Efficiency	4	Better	Worse	Worse	Better
Expandability	USB 3.0 Ports	3	Same	Better	Better	Worse
	Storage	3	Same	Same	Better	Same
Convenience	Vehicle Compatibility	5	Same	Better	Same	Same
	Better		3	3	6	2
	Same		4	5	1	4
	Worse		2	1	2	3
	Weighted Better		12	13	20	8
	Weighted Same		0	0	0	0
	Weighted Worse		-9	-4	-8	-12
	Overall Score		3	9	8	-4

Charging

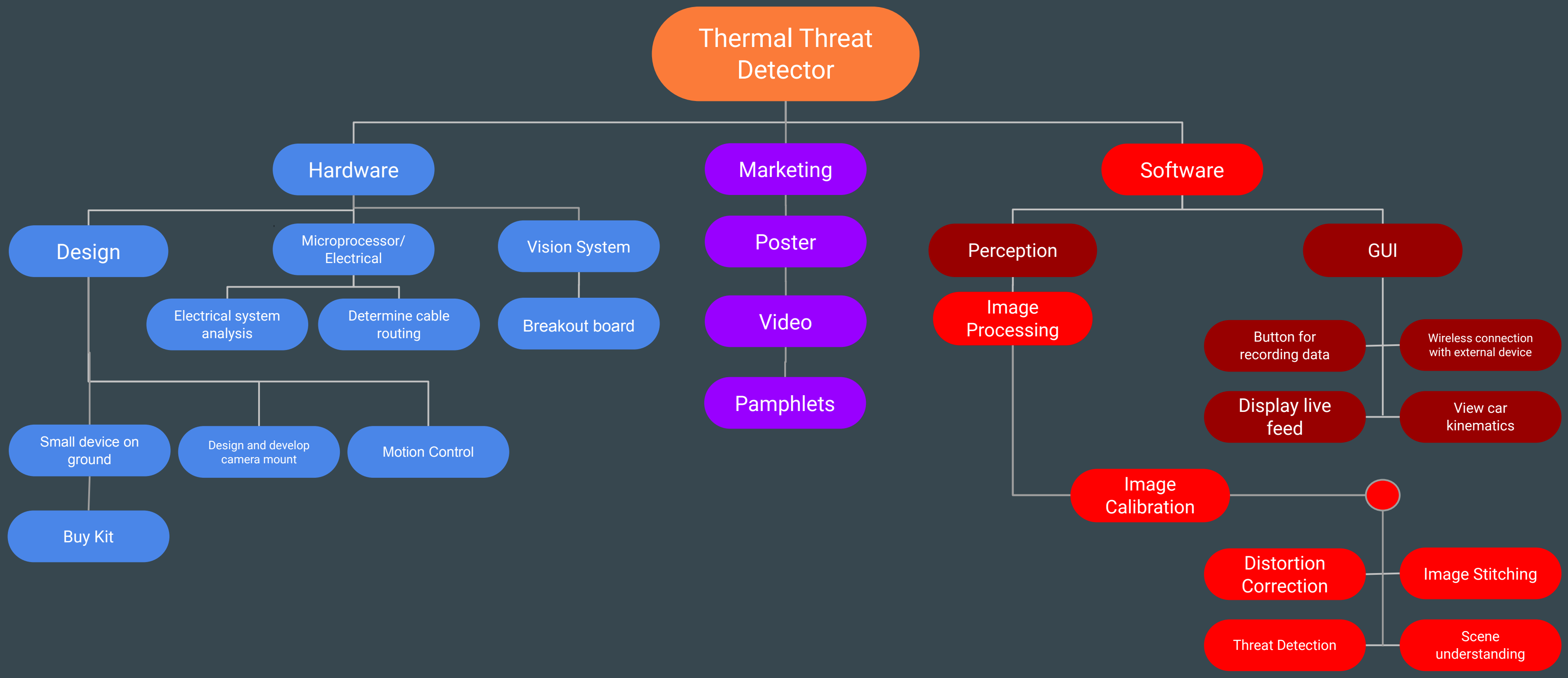
Initial Testing: 4hr Battery Life

- Ordered two additional batteries to change while the vehicle is operating so the system can last for all of Imagine RIT (8hrs)

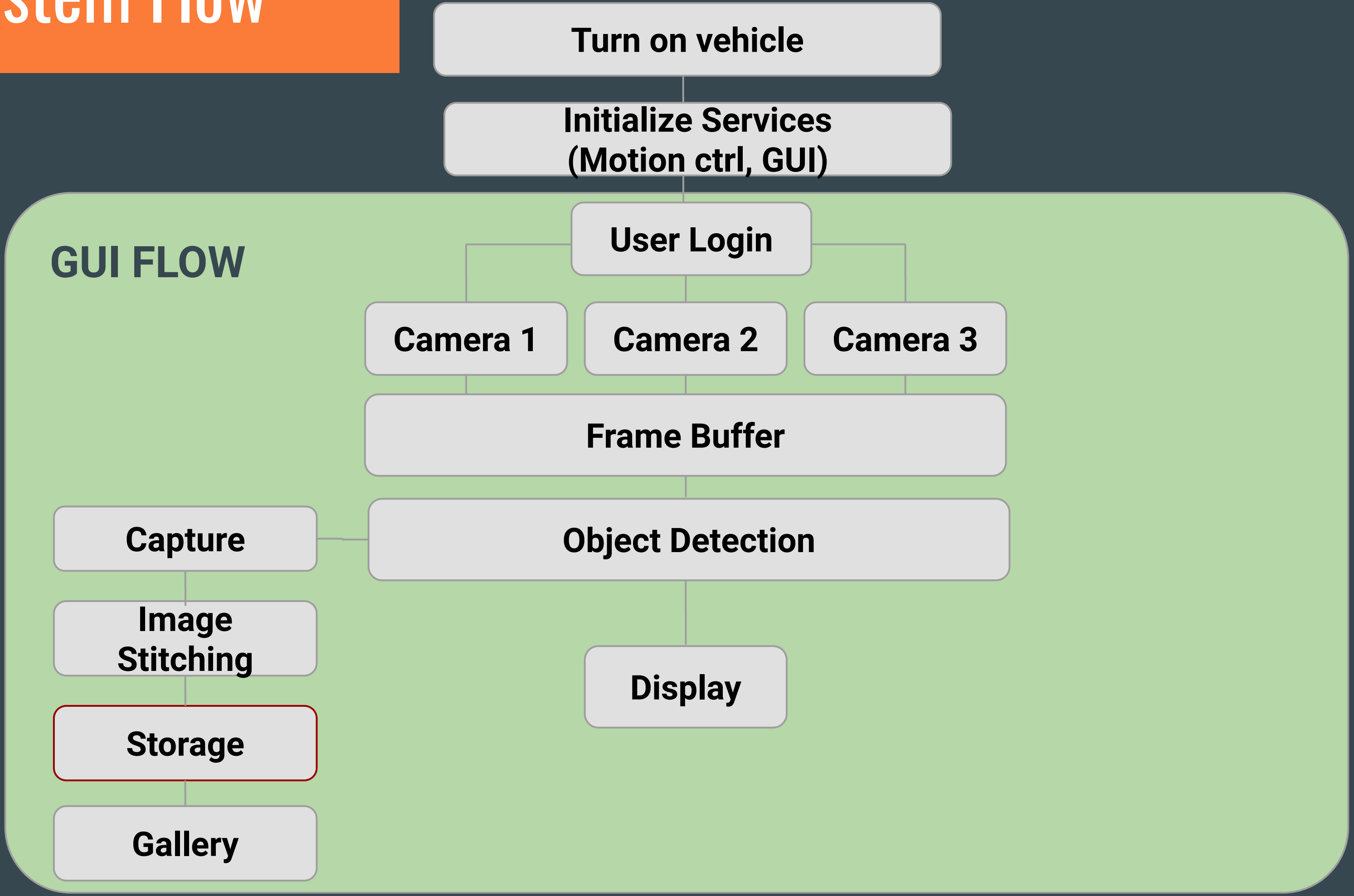
- Lastly have to solder the new wire connection and mount the new battery to the vehicle.

Software Updates

Work Breakdown Structure: GUI

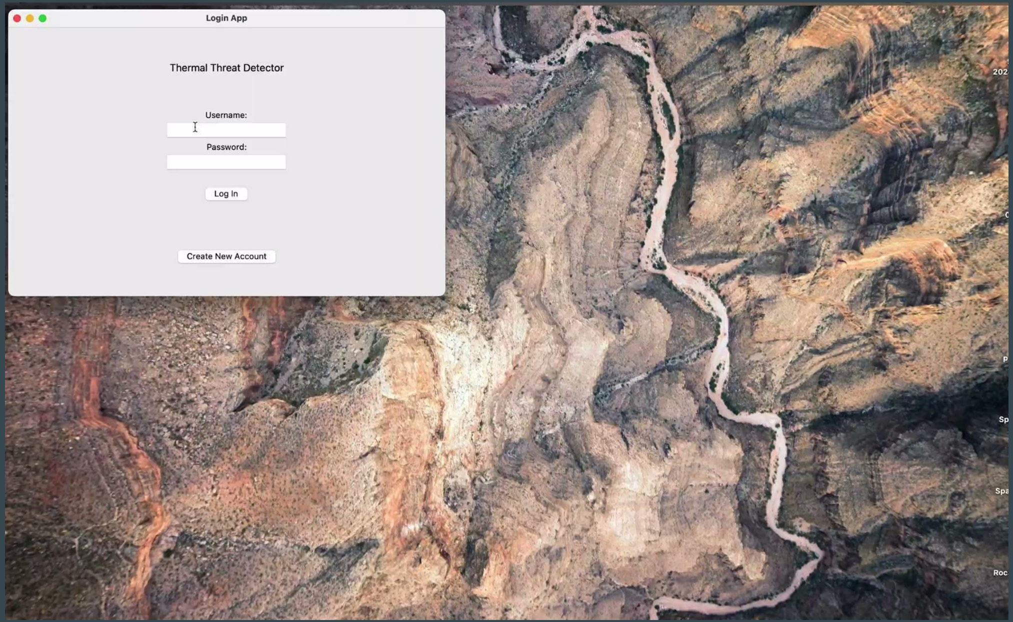


System Flow


Turn on vehicle
Initialize Services
(Motion ctrl, GUI)
GUI FLOW
User Login
Camera 1
Camera 2
Camera 3
Frame Buffer
Capture
Object Detection
Image
Stitching
Display
Storage
Gallery

GUI

- Python script for most functions are completed
- Utilize virtual database for user logins
- Camera's input for live feed
    - Object Detection
- Captured image saved in the Gallery
    - Image Stitching



Working on: syncing 3 cameras together

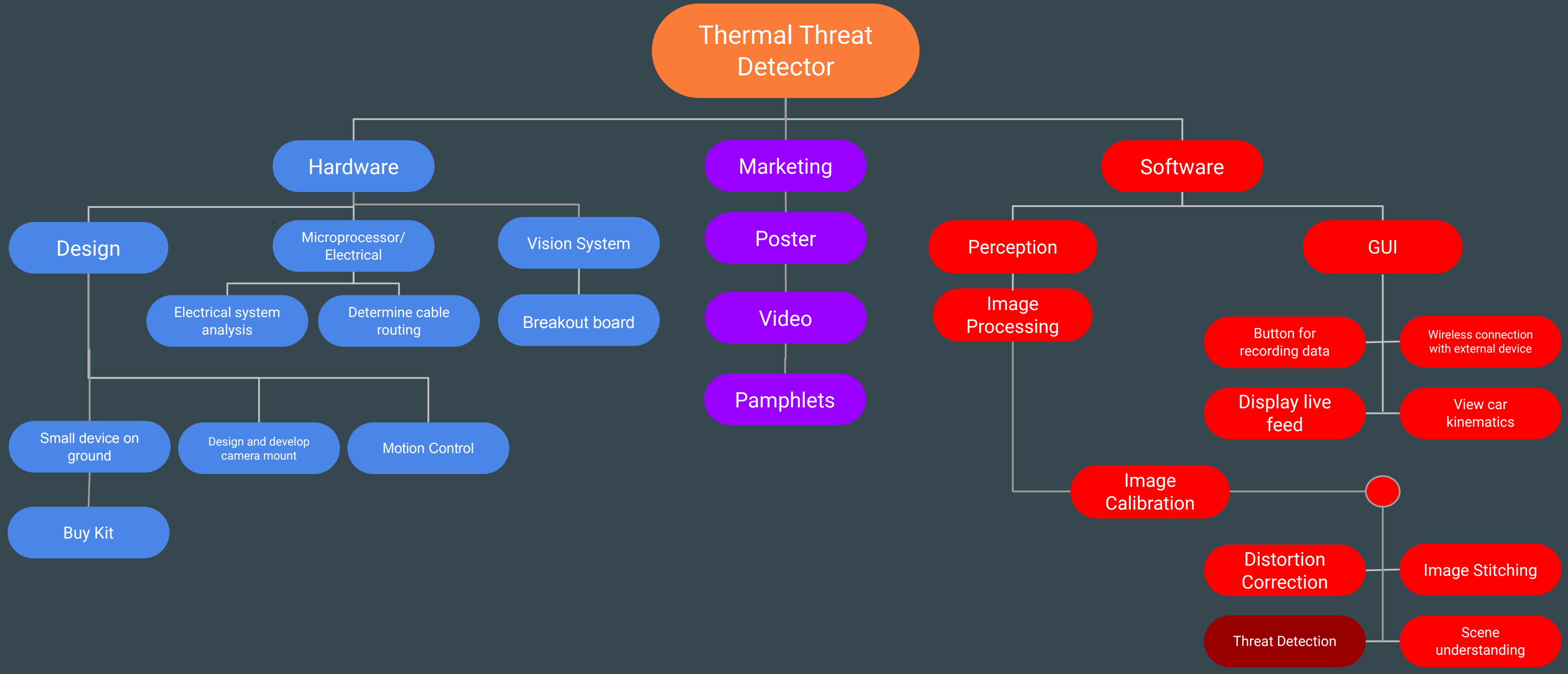
GUI

- Using HiWonder to connect with the vehicle
    - Bash script created to start GUI when vehicle turns on

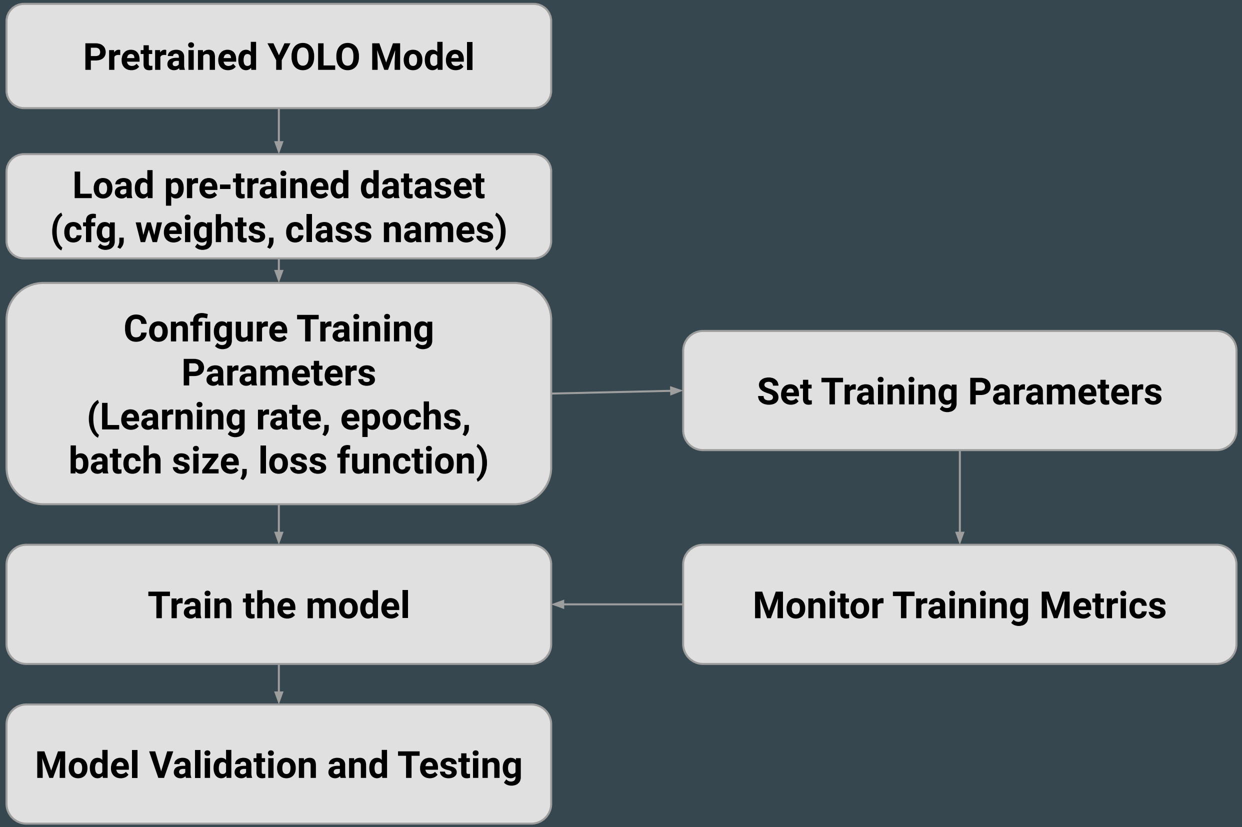
- Vehicle Control
    - Implemented in the GUI
    - User can use keyboard (w, a, s, and d) to control

```
#!/bin/bash

# Open new terminal - enable service
terminator -x bash -c './enable_service.sh'

# Wait for a bit to ensure the first command starts properly (optional, adjust as
needed)
sleep 2

# Open new terminal - start gui
terminator -x bash -c './start_gui.sh'

# Open new terminal - vehicle control
terminator -x bash -c './start_mapping.sh'

# Open new terminal - save map
terminator -x bash -c './save_map.sh'
```

Work Breakdown Structure: Threat Detection



Object Detection - Training

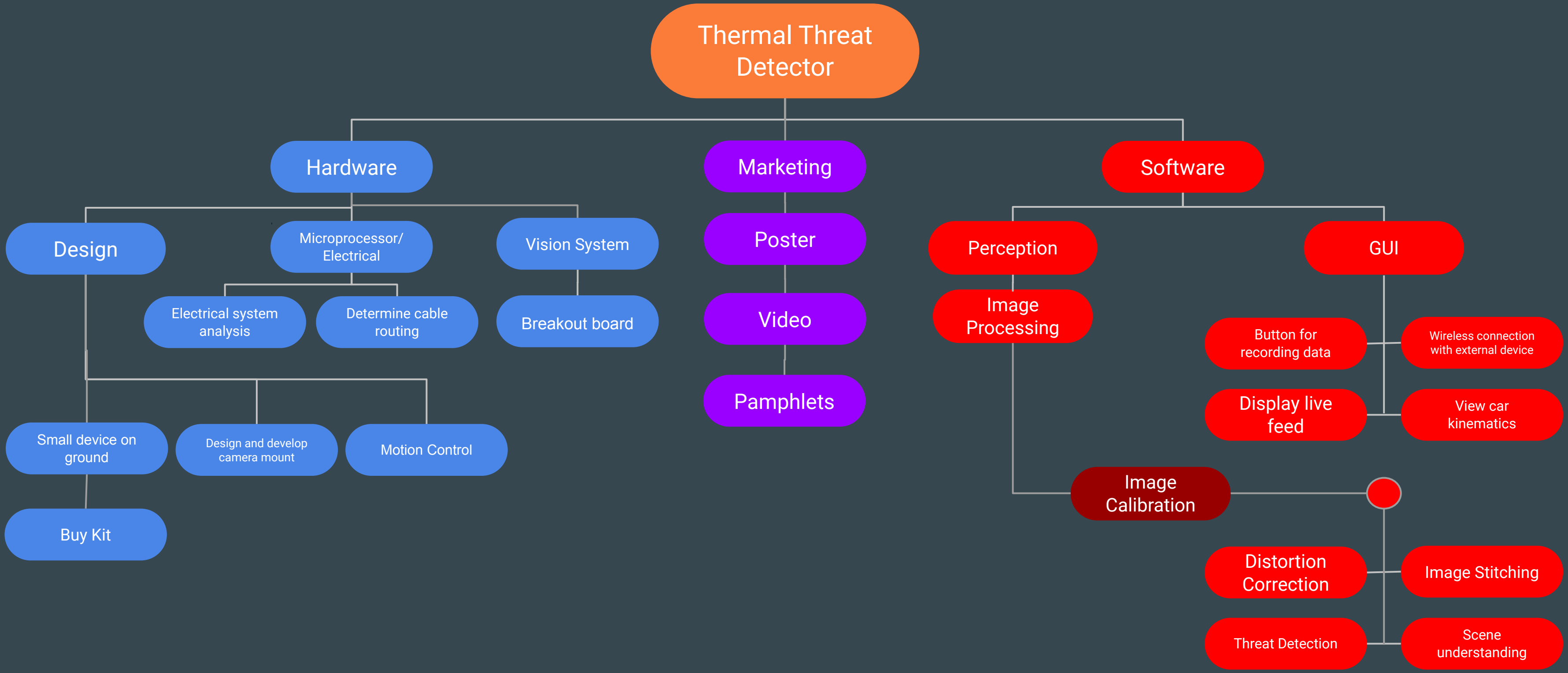


Object Detection - Results

Used Pre-trained YOLOv3 Model, trained with Flir ADASv2 Dataset

- Capable of detecting people and 14 other distinct objects
- Struggles to resolve people when they are far away from the camera
- Need to retest module with updated calibration

Work Breakdown Structure: Image Calibration



Benefits of Calibration

- To know what colors correspond to what temperature in a captured image after applying the color palette
- To know the pixel's response at each temperature
- This can help with image stitching as the three cameras will be able to display the same colors for the same temperatures

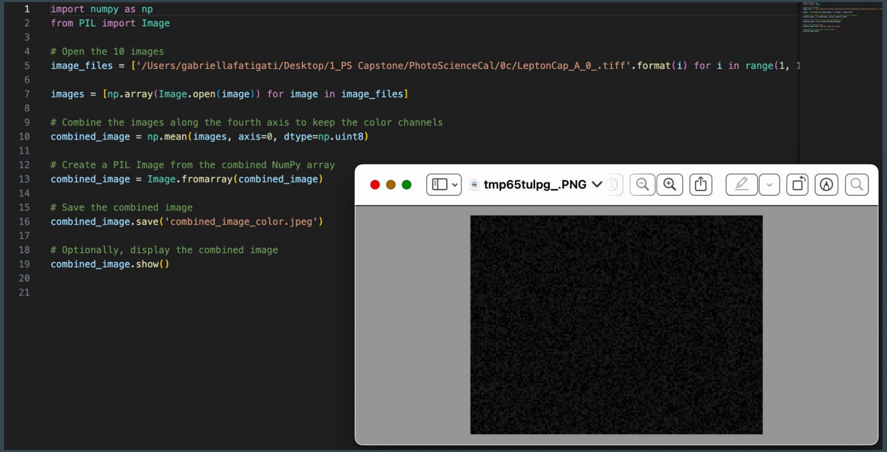
Calibration Process

- When you take images pointed at the blackbody radiator, you will know the pixel counts that correspond to that certain temperature (these pixel counts will be different for each camera because they are not calibrated the same)

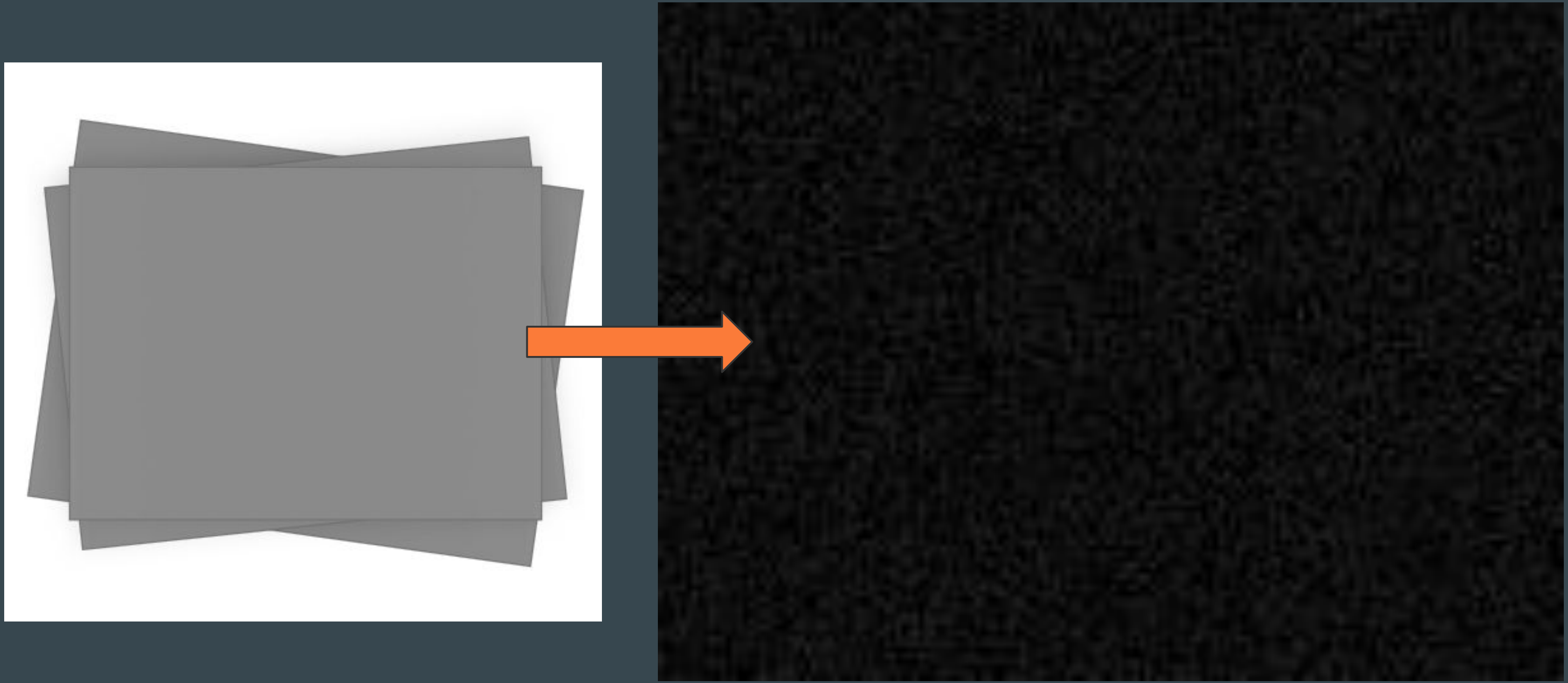
- Take 10 images and combine them to reduce noise to get “clean” images to work with

Calibration Results

- Gathered data from blackbody radiator, taking 10 images at
  - 10 , 20, 30 ,40 Celcius
- Step 1: Program successfully combined 10 tiff images into one tiff for each camera and temperature



Calibration - Step 1 Results



Calibration Final Steps

- Extract pixel values
- Calibrate the pixel values to the temperature we said it was

- Create a linear regression model showing what pixel values correspond to what temperatures
- Apply gain and offset to uncalibrated images
- Display a calibrated image

Calibration Issues

- Program is not handling tiff files (resizing and reshaping issue with newly collected data)

- Continuing troubleshooting to fix code

Users > gabriellafatigati > Desktop > 1_PS Capstone > PhotoScienceCal > linearRegress2 > ...

```python

    result = cv2.imwrite(os.path.join(resultsDir, 'slope.tif'), slope)
    result = cv2.imwrite(os.path.join(resultsDir, 'yIntercept.tif'), yIntercept)
    result = cv2.imwrite(os.path.join(resultsDir, 'rValue.tif'), rValue)
    if result:
        print('Files saved successfully.')
    else:
        print('Error in saving files.')

    return slope, yIntercept, rValue

if __name__ == "__main__":
    maxTemp = 50
    minTemp = 10
    steps = 2
    path = '/dirs/data/uas/uas_data/FLIR_calibration/Rec-000006/averagedImages/'
    resultsDir = '/dirs/data/uas/uas_data/FLIR_calibration/Rec-000006/statistics/'
    temps = np.flip(np.arange(minTemp, maxTemp + 1, steps))
    tiff_file = '/Users/gabriellafatigati/Desktop/1_PS Capstone/PhotoScienceCal/Camera C/combined_C_40.tiff'
    slope, yIntercept, rValue = linearRegress(path, temps, resultsDir, tiff_file)
```

PROBLEMS 2 OUTPUT DEBUG CONSOLE TERMINAL PORTS

```
Shape of c after reshaping: (1,)
Shape of c before reshaping: (1,)
Shape of c after reshaping: (1,)
Traceback (most recent call last):
  File "/Users/gabriellafatigati/Desktop/1_PS Capstone/PhotoScienceCal/linearRegress2", line 99, in <module>
    slope, yIntercept, rValue = linearRegress(path, temps, resultsDir, tiff_file)
  File "/Users/gabriellafatigati/Desktop/1_PS Capstone/PhotoScienceCal/linearRegress2", line 78, in linearRegress
    os.makedirs(resultsDir)
  File "/Library/Frameworks/Python.framework/Versions/3.10/lib/python3.10/os.py", line 215, in makedirs
    makedirs(head, exist_ok=exist_ok)
  File "/Library/Frameworks/Python.framework/Versions/3.10/lib/python3.10/os.py", line 215, in makedirs
    makedirs(head, exist_ok=exist_ok)
  File "/Library/Frameworks/Python.framework/Versions/3.10/lib/python3.10/os.py", line 215, in makedirs
    makedirs(head, exist_ok=exist_ok)
  [Previous line repeated 3 more times]
  File "/Library/Frameworks/Python.framework/Versions/3.10/lib/python3.10/os.py", line 225, in makedirs
    mkdir(name, mode)
OSError: [Errno 30] Read-only file system: '/dirs'

[Done] exited with code=1 in 1.12 seconds
```

Calibration Success in Real Time

- When shooting live, we can apply the gain and offset to each pixel after capturing an image (which is calculated from the program)
- Then the same temperature on all three cameras will show as the same color
- Can check this by selecting the pixel values and comparing

Work Breakdown Structure: Image Stitching

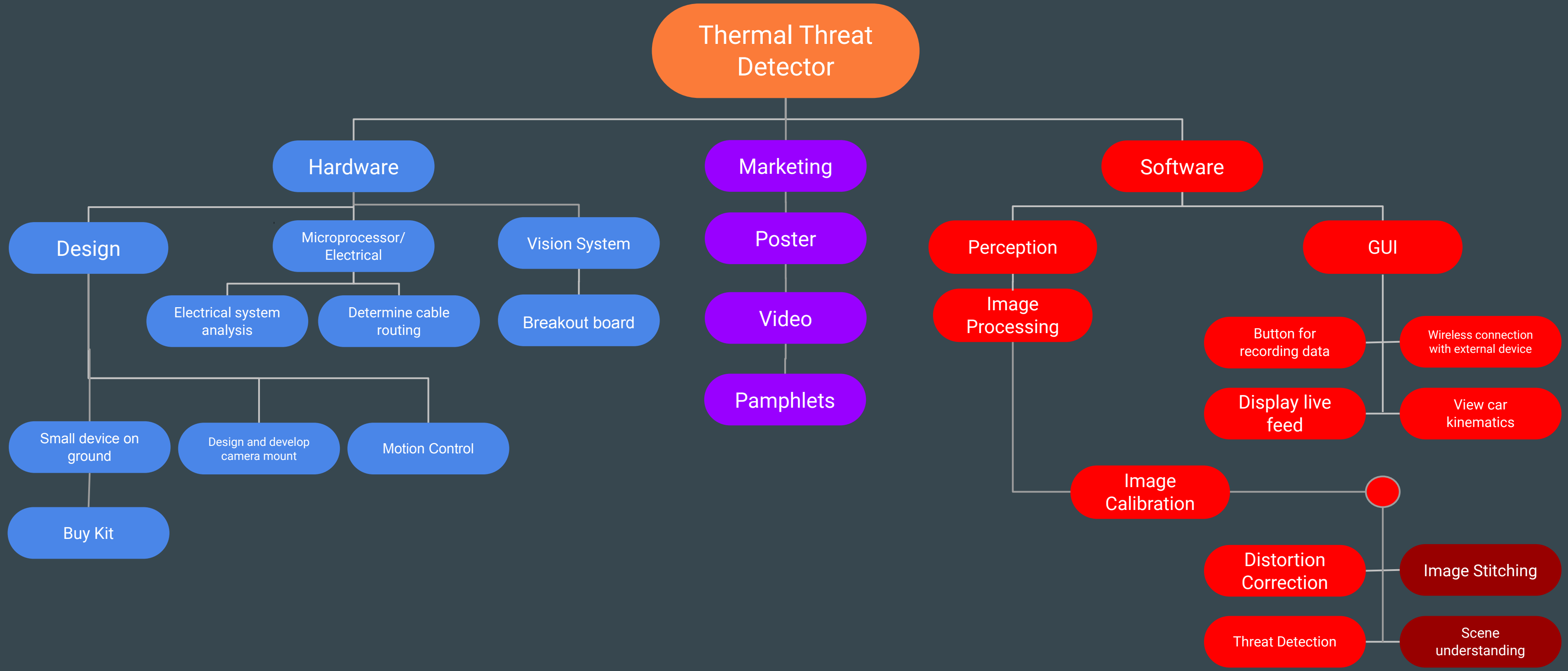


Image Stitching - How it works

Program written in python to stitch images together:

1. **Imports Images**

2. **Resizing Function**
   - Maximizes the size on each images (1000 pixels)

3. **Stitch Image**
   - Detects key points in images using SIFT (Scale-Invariant Feature Transform), to match key points.
   - Uses ratio test to determine if points are a good match.

4. **Homography Estimation**
   - Estimates the homography matrix using RANSAC (Random Sample Consensus) algorithm. Uses Brute Force (BFMatcher) to align points. (This uses the data points to determine if there are any outliers).

5. **Warping**
   - Warping the second image to first using the matrix.

6. **Blending**
   - Seamless integration

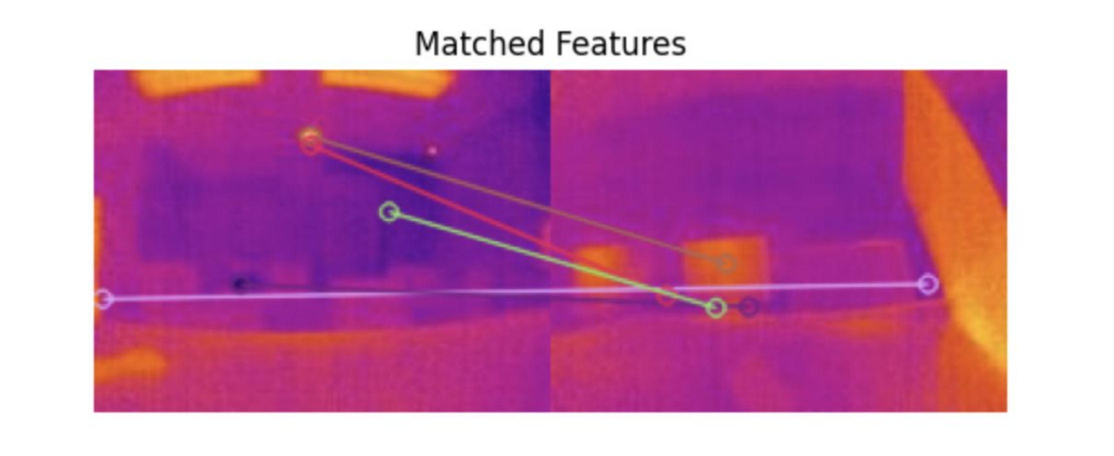
7. **Results/Output**

Image Stitching - Where we left off

- An error indicated there was not enough matches present to stitch the images.

- To address this issue various image sets were tested. Including black and white images to see if the thermal was impacting the results.

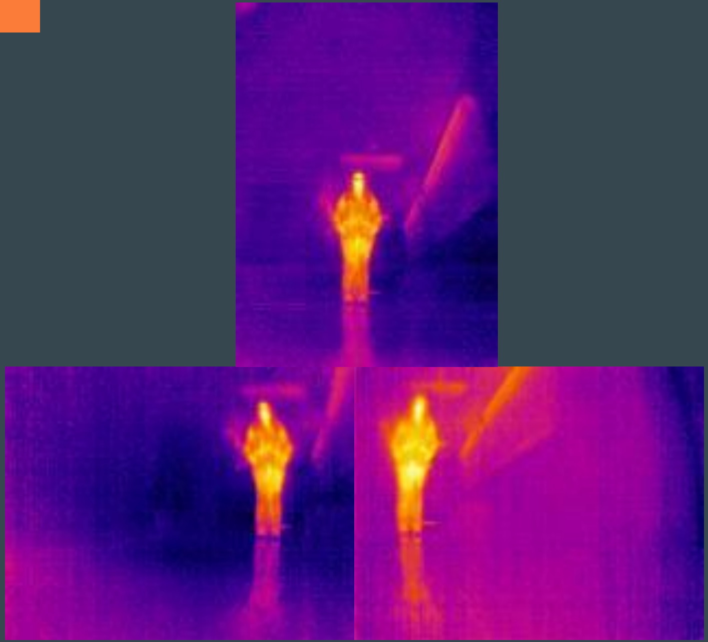
- Same error remained determining more overlap was needed as well camera calibration.



Imaging Stitching - Moving forward

We know how to complete the images stitching using:

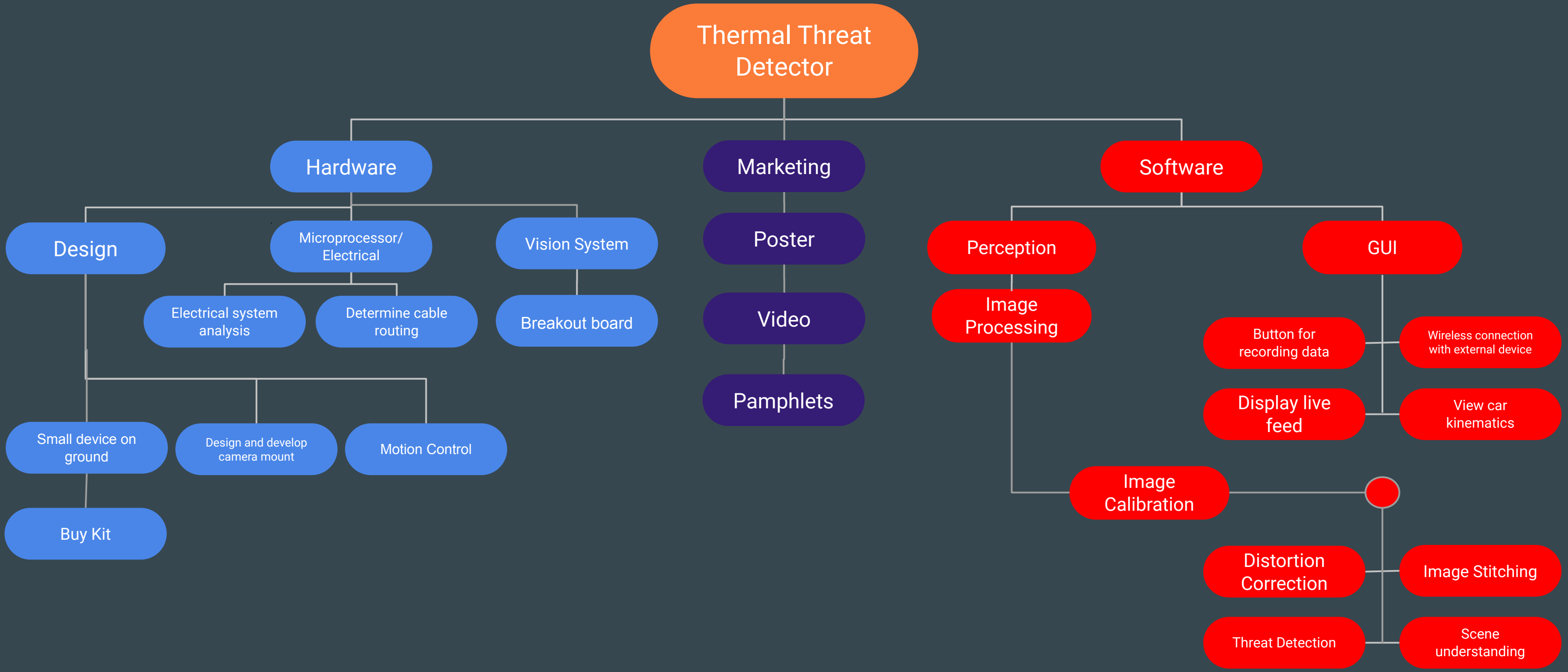
- The new RAW calibrated images.
- Completed matrix will be applied to every stitched image as cameras are in a fixed position.
- Once complete, can be implemented into the image processing pipeline.



Once calibration is complete colors will be standardized allowing the images to be stitched.

Marketing Updates

Work Breakdown Structure: Camera Mount



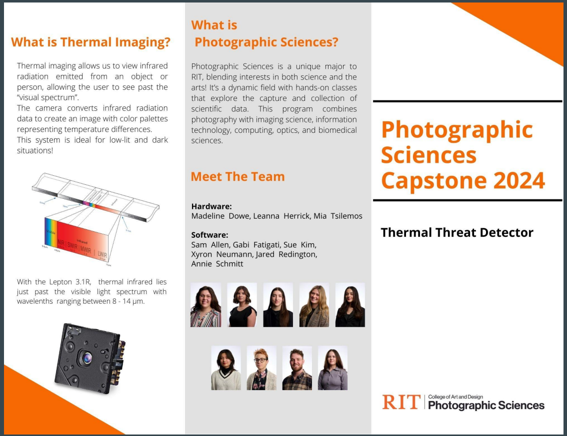
Marketing/Imagine RIT Updates

- Poster: **Finished**
  - Headshots
  - QR Code
  - Image of Device

- Video: **Filmed & Now Editing**
  - Interviews
  - Overview of Class
  - B Roll
  - Demonstration

- Pamphlets and Brochures: **In Process**
  - 'What is Thermal Imaging?'
  - 'What is Capstone?'
  - Hardware and Software Page

Marketing/Imagine RIT Updates



PROJECT: Thermal Threat Detector

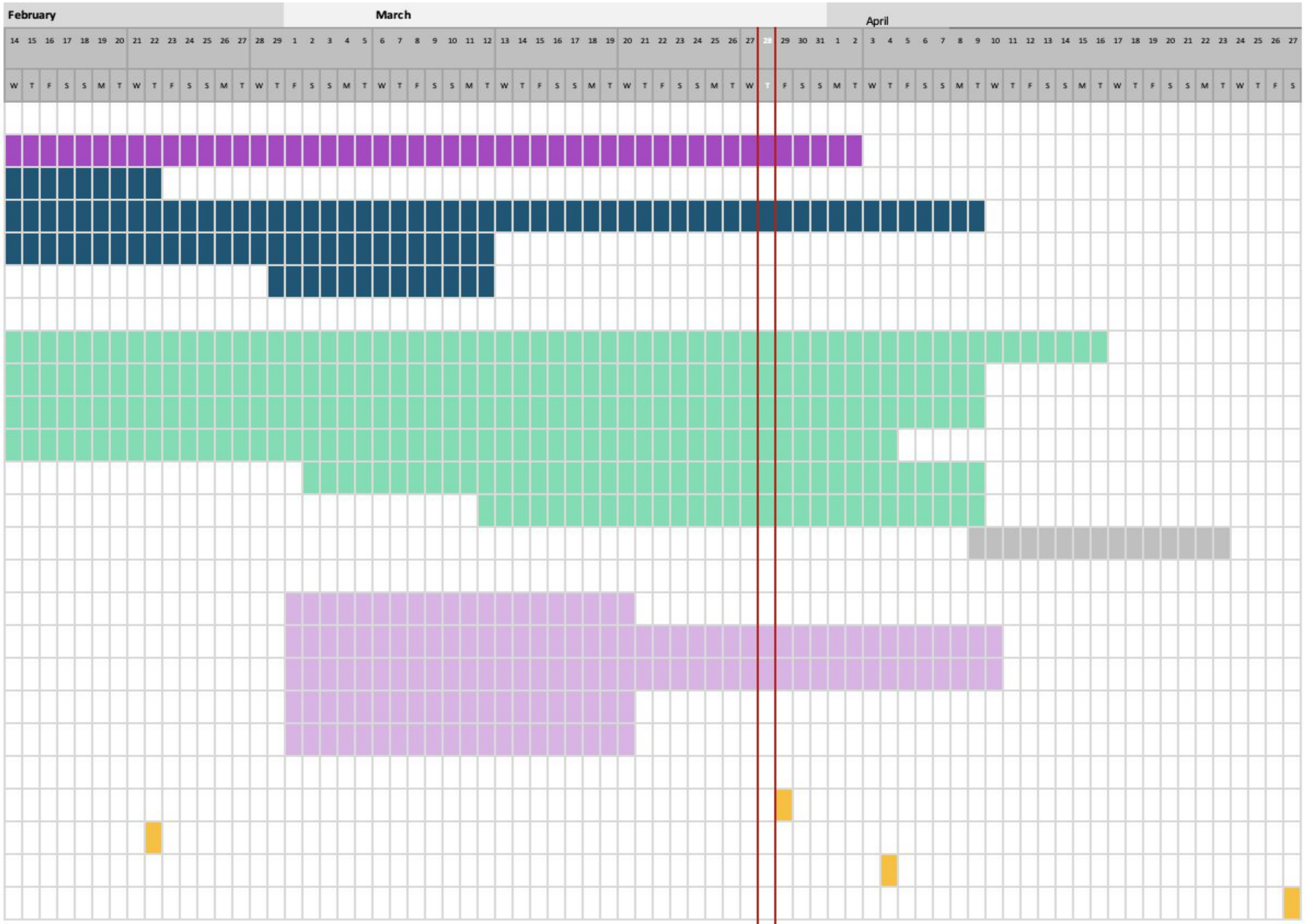
Photo Science Capstone 2024

Project start date: 2/9/24

Scrolling increment: 5

Legend: On track | Low Risk | Med Risk | Late/Behind | Unassigned

Milestone description	Category	Assigned to	Progress	Start	End Goal
Hardware Team					
Print camera mount	Goal	Leanna	90%	2/1/24	
vehicle testing	Med Risk	.eanna, Maddie, and Mi	50%	2/2/24	
Vehicle Control	High Risk	All software Team	30%	7/16/29	
Battery Life	Low Risk	.eanna, Maddie, and Mi	100%	1/30/24	
Train LiDAR	Med Risk	All software Team	10%	2/13/24	
Software Team					
GUI Design	On Track	Annie and Sue	60%	1/1/24	
Image Stitching	On Track	Sam	70%	1/3/24	
Camera Control	High Risk	Jared, Gabi, Xyron	33%	1/8/24	
Calibration	Med Risk	Gabi	70%	3/1/24	
Object Detection		Jared	50%		
Intergration	Milestone	All software Team	0%		
Finalize	Milestone	All software Team	0%		
Marketing/Papers					
Imagine RIT Poster		Gabi	50%		
Video		NBD	0%		
Report		Sam And Annie	0%		
Pamphlet		Gabi	100%		
Technical Manual		NBD	0%		
Presentations					
Critical Design Review Dry Run		Sam, Annie, and Jared		3/29/24	
Faculty Meeting		Maddie, Mia, and Sue		2/22/24	
Critical Design Review		Leanna, Gabi, and Xyron		4/4/24	
Imagine RIT				4/27/24	



Requirements Checklist

Requirement	**Requirement Minimum**	**Thermal Threat Detector**
Transportation	Manual	Manual
Power	1 hr	**4 hr**
Field of View	180*	~177*
Resolution	Capable of resolving a human	Capable of resolving a human in near distance
GUI	Allows user to capture image	Allows user to capture image

Remaining Work

- Retest image stitching and object detection modules (post calibration)
- Integrate three cameras with GUI
- Documentation
- User manual, technical manual, and research paper
- Marketing for Imagine RIT

Questions?