Project #84

Mobile Stray Cat Rescue Station

By:

Ming Yi(myi22)

Yilin Tan(ytan47)

Frank Chen(sihan6)

Final Report for ECE445, Senior Design Spring 2025

Professor: Michael Oelze

TA: Rui Gong

6 May 2025

Project #84

Abstract

Stray cats often lack reliable access to food and shelter, especially during harsh winters. Our project, the Mobile Stray Cat Rescue Station, provides an autonomous, solar-powered shelter equipped with AI-based animal detection, automated feeding, and a heating system. The system identifies cats with over 90% accuracy, dispenses food, and activates heating only under predefined conditions. The station is designed to operate off-grid using solar power and incorporates real-time monitoring. We designed this project to be low-maintenance and scalable based on our observation of stray cat behavior in our neighborhood and ease of setup during testing.

1. Introduction

1.1. Problem

Stray animals, particularly cats, continue to face challenges in urban and suburban environments. While many animal welfare organizations and individuals work to provide care, not all stray cats receive consistent food and shelter. Exposure to extreme temperatures, especially in winter, can be fatal. Studies have shown that **hypothermia in stray cats can occur at temperatures below 10°C (50°F), significantly increasing their mortality rate** (Smith et al., 2019). In many neighborhoods, including our own, it is common to see stray cats struggling to find food and warmth. When individuals attempt to help, they may not always have food available or a proper way to provide ongoing assistance. Even if food is provided at one instance, it does not ensure continuous support for these animals.

1.2. Solution

To address this problem, we propose the Mobile Stray Cat Rescue Station—a portable, solar-powered shelter equipped with an AI-based feeding and heating system. This device is designed to automatically provide warmth and food to stray cats based on environmental conditions and real-time cat detection. Unlike traditional feeding stations, our system integrates AI image recognition to ensure that only stray cats trigger food dispensing and heating activation, reducing waste and preventing unintended use by other animals. **Studies indicate that AI-driven animal identification systems can achieve over 90% accuracy in distinguishing between different species** (Zhang et al., 2021), making it a reliable method for targeted assistance. Through a remote monitoring system, maintenance personnel can efficiently manage multiple stations and provide refills when necessary. This approach significantly enhances the survival rate of stray cats in extreme weather conditions while minimizing human intervention.

1.3. Visual Aid:

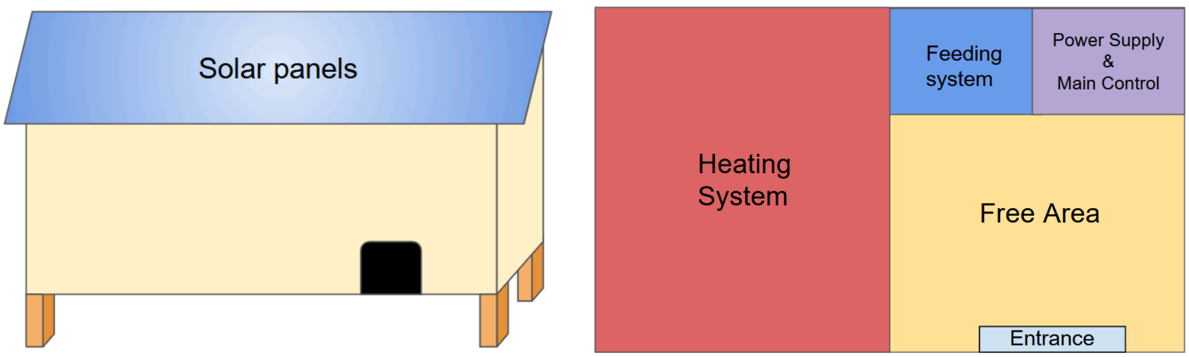

Figure 1: Overall and simplified design diagram

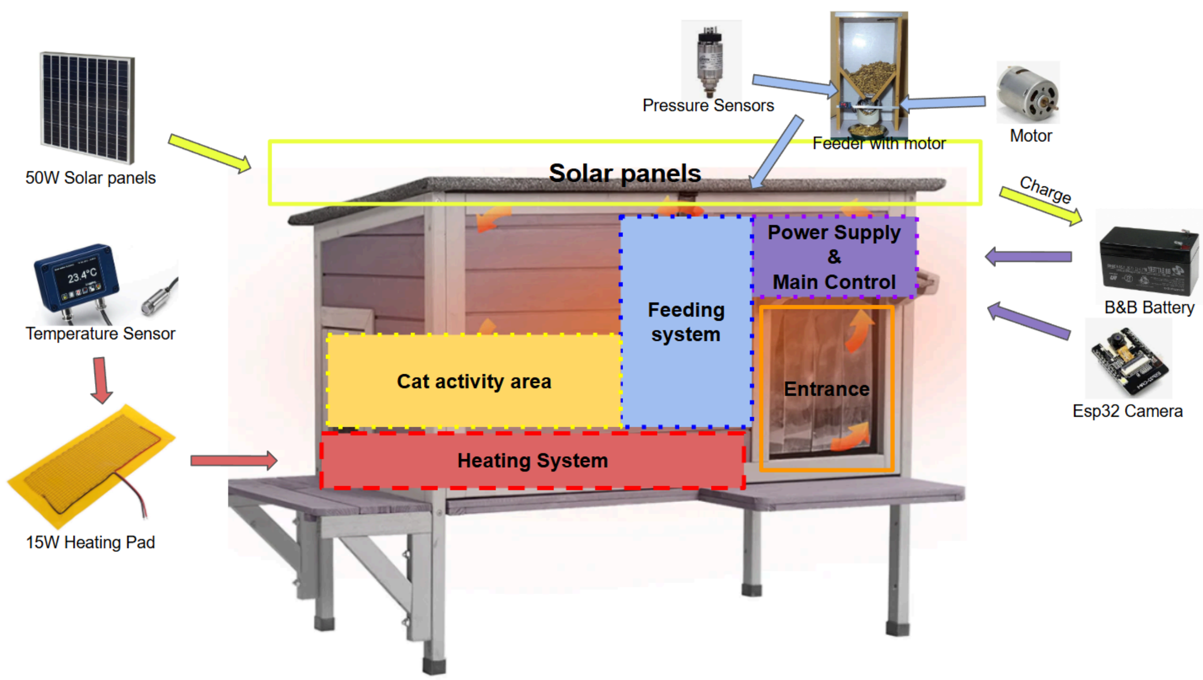

Figure 2: Detailed design drawing of each component

1.4. High-Level requirements list

- The heating system must activate only when a cat is detected and when the ambient temperature falls below a predefined threshold. It should respond within

10 seconds and maintain a temperature range between 10°C and 25°C inside the station.

- The feeding system must dispense food only when a cat is detected, ensuring that a certain amount of food is being dispenseed.
- The AI-based detection system must correctly identify a cat with at least 90% accuracy, ensuring a response time of 10 seconds or less from detection to system activation.
- The power system must support continuous operation via solar energy, ensuring that the system can function for at least 8 hours without sunlight, maintaining critical functions such as AI detection, heating, and food dispensing.

2. Design

2.1. Block Diagram:

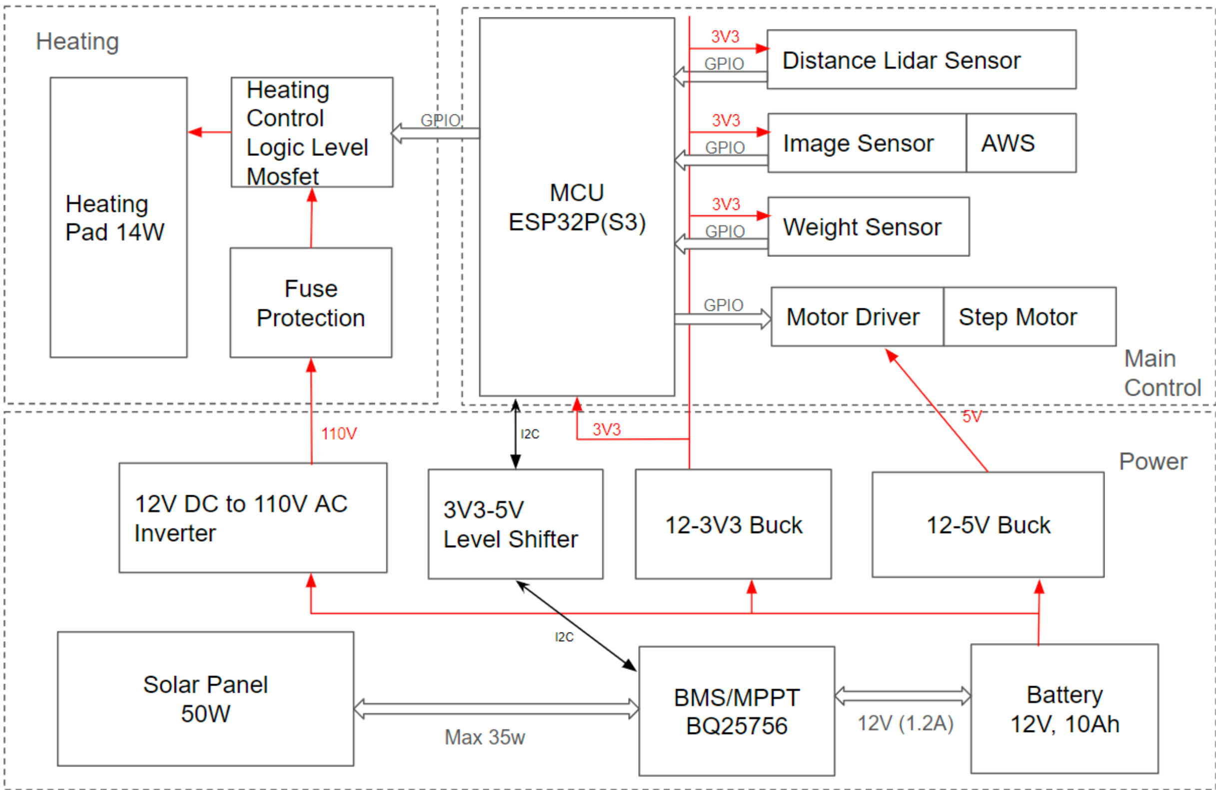

Figure 3: Block Diagram of the Whole System

2.2. Physical Design:

The physical design of this is based on **Figure 2.** The exterior is just built of wood, and layered with insulated foam on each side**.** This allows the station to be constantly staying warm with the heating from the heating system. The main part of heating is done with the heating pad, and other than that it would be the feeding system. Inside the feeding system, we have a weight sensor to detect the weight of the food inside the bowl. When the lidar sensor detects a change in distance, and the ESP32-Camera detects a cat, then the step motor would start spinning and food would be dispensed. The main power supply of this is done by solar panel, along with a battery for night usage.

2.3. Subsystem Overview

2.3.1. Power Supply Module

Overview:

This subsystem harvests solar energy, stores it in LIFEPO4 batteries, and provides regulated voltages to the rest of the rescue station. Its primary goal is to enable uninterrupted operation (especially overnight) by avoiding frequent manual battery replacements.

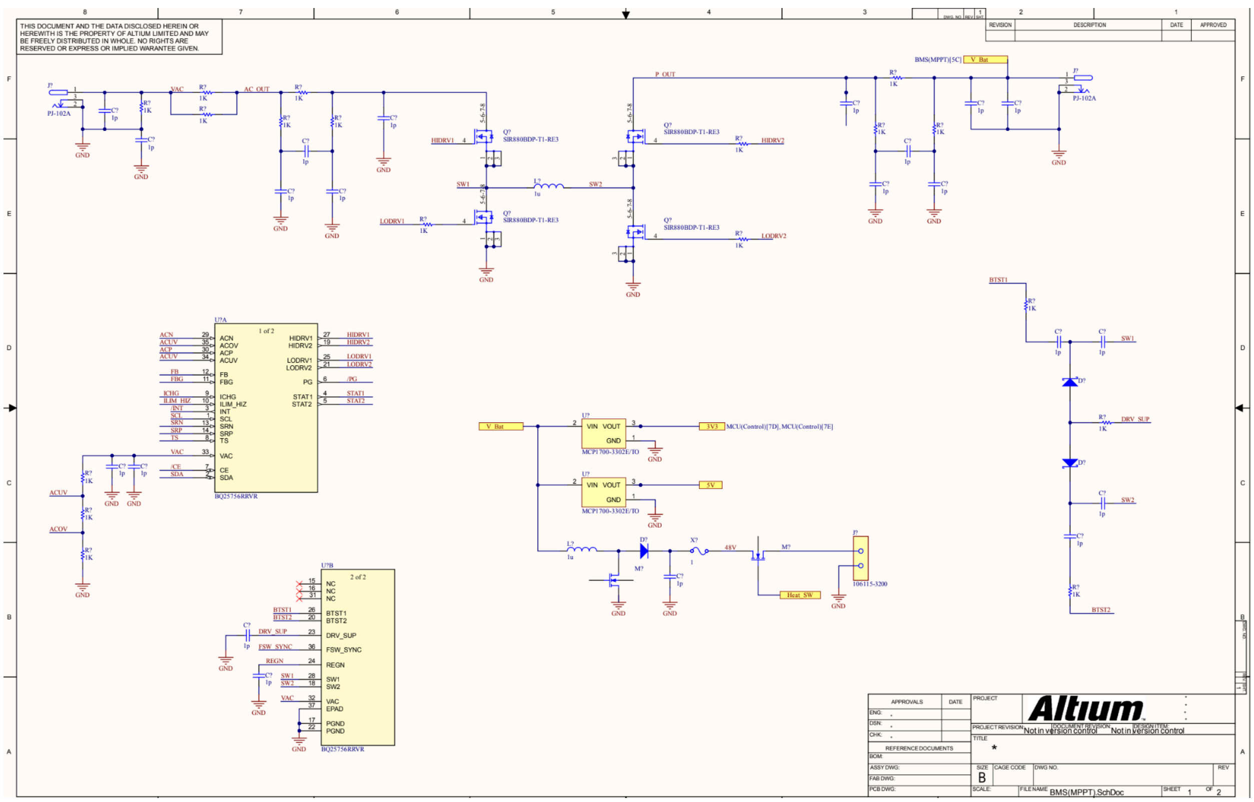

Figure 4: Power PCB Schematics

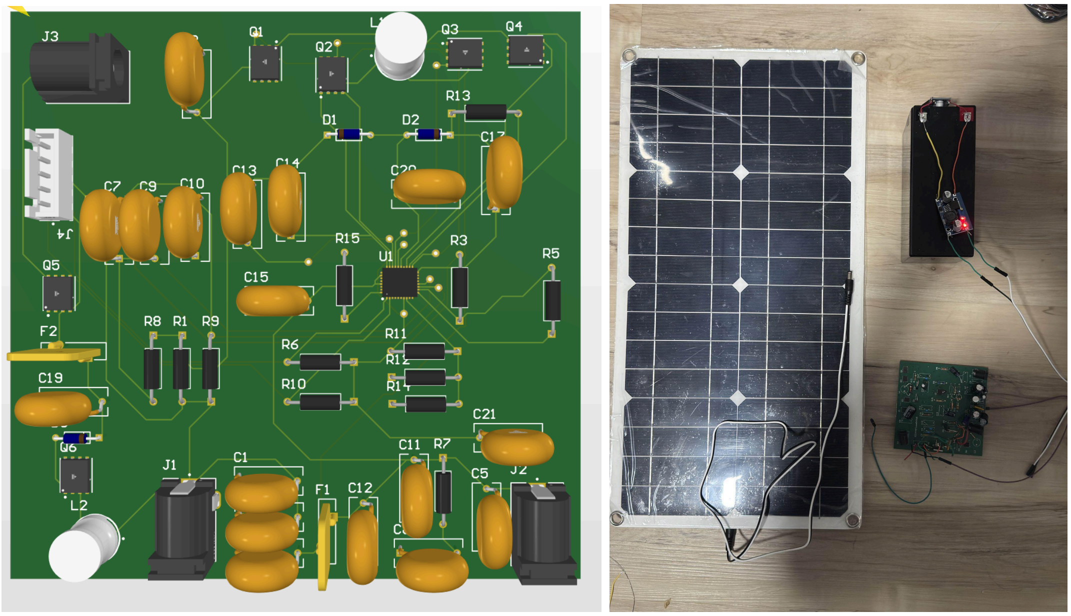

Figure 5&6: Power PCB and Solar Panel Connection

Key Components & Design:

1. **Power Generation**
    - Solar Panel: A panel in the 20–50 W range to balance efficiency and size constraints. In this project, a 35W solar panel was used.
    - Charging/Discharge Control: Uses a Battery Management System (BMS) to handle maximum power point tracking, improve charging efficiency, and prevent overcharging or deep discharging.
2. **Power Storage**
    - Secondary Battery: Chosen for rechargeability and longevity. For instance, a battery rated 12 V nominal (or higher if the design calls for 3 or 4 cells in series) can be used with a capacity of 10 Ah.
    - Protection Circuit: The BMS (and associated sensors) continually monitors battery voltage/current/temperature to maintain healthy battery operation.
3. **Voltage Regulation**
    - Buck Boost Converters: Provide stable output rails for different subsystems:
        - 3.3 V for the microcontroller, sensors.
        - 5 V for step motor.

        - 110VAC for heating pad.
    - Fuse/Overcurrent Protection: On both the battery pack output and solar input lines to guard against short circuits or high current faults.

Why It Matters:

- Ensures reliable off-grid power so the station can function autonomously, including powering the heating module at night.
- Protects the battery from unsafe conditions (overvoltage, undervoltage, etc.).

2.3.2. Heating module

Overview:
This subsystem provides warmth inside the enclosure and automatically regulates temperature via sensors and a simple control loop (on/off).

Key Components & Design:

1. **Heating Method**
    - Heating Element: ~10-15 W, balancing power draw with heating effectiveness (Walbest 14 W Reptile Heating Pad).
    - Placement: Under the enclosure floor with fire-resistant insulation on the sides of the shelter.

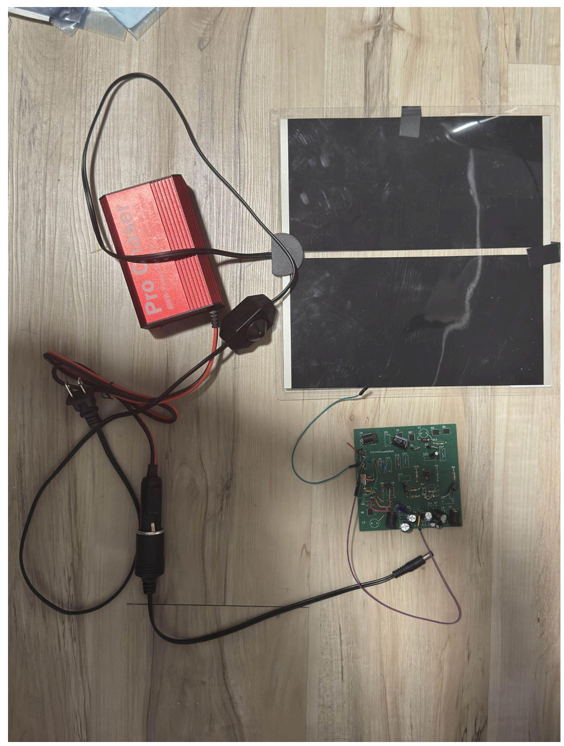

Figure 7: Heating Pad

2. **Power Consumption & Safety**
    - Power Draw: ~15 W ensures moderate current draw from the battery and is still able to raise temperatures effectively in a small enclosed space.
    - Thermal Safety Features:
        - Fire-resistant insulation around the shelter.
        - Thermal cutoff switch or thermostat to prevent overheating.

3. **Temperature Control**
    - Temperature Sensor: Temperature sensor that is built in for the ESP32 S3 WROOM.
    - Control Logic:
        - Heater activates below 10 °C (50 °F).
        - Heater turns off above 25 °C (77 °F).
    - MCU Interface: The main control module (Subsystem 3) reads the sensor and drives the heater MOSFET switch (or relay) accordingly.

Why It Matters:

- Provides vital warmth for cats in cold weather.
- Minimizes battery usage by only running the heater when needed.

2.3.3. Main Control Module

Overview:
This module is the "brain" of the station. It collects sensor data, controls the feeder and heater, manages power usage, and communicates status information (e.g. via Wi-Fi).

Key Components & Design:

1. **Microcontroller**
    - An ESP32 (for built-in Wi-Fi/Bluetooth) with a dedicated Wi-Fi module. The ESP32 is popular for its Wi-Fi stack and low-power modes.

Figure 8: Main Control

2. **Wi-Fi Transmission**
    - The controller can send data (e.g., temperature, battery level) to a remote server(AWS was used) or local network. If no network is available, a hotspot mode can allow a phone or laptop to connect locally.

3. **Feeding System Control**
    - Weight sensor is used to monitor the weight of the feeding bowl; if food is too much, the MCU triggers the feeder motor to stop dispensing food.
    - Motor Driver: A small stepper motor is powered and managed by the MCU (via step driver).
4. **Power Monitoring**
    - The MCU continuously reads the battery voltage/current from the BMS or an ADC input to gauge remaining capacity and optimize usage (e.g., reduce heater usage if battery is critically low).
5. **Cat Activity Monitoring**
    - An ESP32 Camera is used to capture images and send them to the cloud(AWS） for AI-based detection of cats, ensuring only cats (not raccoons or other animals) are using the station. Image processing is done by YOLO, and accuracy is above 90%.
    - A website is also created for remote monitoring.

Why It Matters:

- Orchestrates all station functions (heating, feeding, power management).
- Provides remote visibility into shelter status (temperature, battery, cat activity).

2.3.4. Shell and Insulation Layer

Overview:
This subsystem provides mechanical protection, water resistance, and insulation to reduce heat loss, thus enhancing the effectiveness of the heating system.

Key Components & Design:

1. **Shell Construction**
    - Materials: Wood built shelter, with heat insulation foam on the sides.
    - Elevation: A frame or legs raise the shelter ~10 cm above the ground to avoid water intrusion during rain.
2. **Insulation**

- Fireproof Foam Boards or similar insulating panels line the interior.
- Keeps the enclosure warm and reduces required heating power.

3. **Weatherproofing & Ventilation**
    - Sealed seams or gaskets to prevent leaks.
    - Minimal but adequate vent holes to prevent condensation build-up.
    - A small doorway for easy feline entry while blocking drafts.

Why It Matters:

- Conserves energy by minimizing heat loss.
- Protects electronics (power module, MCU) from rain, snow, and debris.

Overall Interactions

1. Subsystem 1 (Power) continuously collects solar energy and charges the battery via a BMS. It provides stable DC voltages to all other subsystems. Also the BMS control IC communicates settings with Subsystem 3 (I2C).
2. Subsystem 2 (Heating) draws power from Subsystem 1, with on/off commands from the main controller in Subsystem 3.
3. Subsystem 3 (Main Control) collects sensor data (temperature, food levels, battery status) and orchestrates heating and feeding. It also handles communication via Wi-Fi.
4. Subsystem 4 (Shell & Insulation) ensures environmental protection and reduces the heat load, improving the overall efficiency of Subsystems 1 and 2.

3. Requirement and Verification Table

3.1 Solar Panel and Battery System

Requirements:

- The solar panel must provide at least **12.0 V under load** in direct sunlight for MPPT input.
- The MPPT (BQ25756) must successfully **regulate charging** to a 2-cell Li-ion pack, increasing voltage from **7.2 V to ≥8.3 V**.
- The charging current should be within the **450–600 mA** range under sunlight.

- All components must operate reliably in ambient temperatures from **–20 °C to 50 °C**.

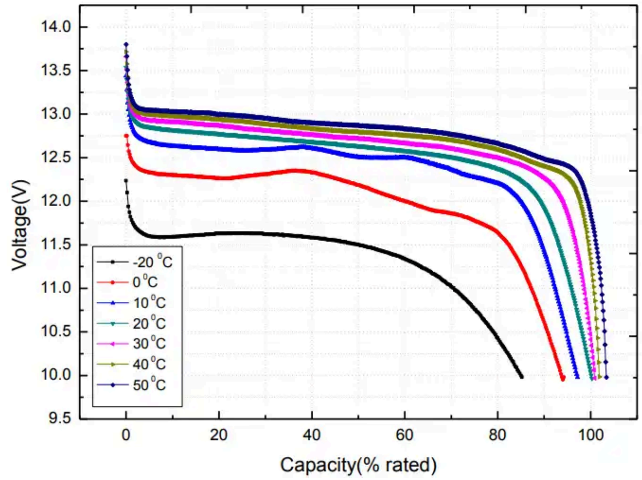

Figure 9: Battery Discharge Based on Temperature

Verification Procedure:

- We measured **open-circuit and loaded voltages** using a multimeter under clear sunlight.
- Monitored battery charging via **ESP32-S3 I2C telemetry** from the BQ25756, logging current and voltage every 5 minutes for 90 minutes.
- Verified the system's operation over **25 °C ambient temperature**, and compared with component datasheets to confirm specified temperature range compliance.

Quantitative Results:

- Open-circuit voltage: **17.4 V**
- Loaded panel voltage: **12.3 V**
- Charging current: **452–591 mA**
  Battery voltage increased from **7.2 V to 8.3 V** in 90 minutes
- All components operated without fault at **25.1 °C**, within the stated **–20 °C to 50 °C** range

3.2 Heating Pad

Requirements:

- Heating pad must activate when temperature is **<10 °C** and deactivate when **>25 °C**.
- The system must detect and control the heating pad based on ambient temperature read via ESP32.

Verification Procedure:

- Simulated a cold environment using a **refrigerated enclosure** and monitored ESP32 internal temperature sensor.

- Logged heating pad GPIO status and temperature at 30-second intervals.

Quantitative Results:

- Pad activated at **9.5 °C**, deactivated at **25.4 °C**
- GPIO control worked consistently across **3 test cycles**
- Confirms responsiveness of the pad to thermal thresholds

3.3 Main Control Module

Requirements:

- Stepper motor must activate for **1.5 seconds** upon cat detection, dispensing at least **200 g** of food.
- WiFi and cloud communication must transmit image + metadata (battery, timestamp, detection result).
- Cat detection routine must trigger when VL53L0X reports **distance <50 cm**.

Verification Procedure:

- Simulated cat presence by triggering the detection flag; logged motor activation and HX711 output.
  Connected system to WiFi and used Flask AWS server to verify image uploads and metadata reception.
  Repeated VL53L0X trigger test **10 times**, recording activation distances.

Quantitative Results:

- Food dispensing weight: **202–208 g** confirmed via HX711
- Image successfully uploaded with correct timestamp and metadata on AWS
- Average trigger distance: **45cm**

4. Cost and Schedule

4.1. Cost Analysis

The most expensive part of this project would be the solar panel, and the exterior of the rescue station. Building the house would also take a while, therefore we estimated about 80 hours of work per person for this project(This includes everything else as well, such as software development, and connecting all the subsystems together).. That would be about $6,000 each, with a reasonable pay of $30 per hour.

Labor Cost:

$30 x 2.5 x 80 = $ 6000

-Total labor = $ 18,000

Parts and Cost:

Table 1: Bill of Materials

Description of parts	Part #	Quantity	Cost
Solar panel	NA	1	$40.99
ESP32	ESP32-S3-WROOM-1-N8R2	3	$17.13
Weight Sensor (Amazon)	314990000	2	$11.78
OV2640 Camera(Amazon)	OV2640	1	$10.89
Fireblock 12oz. Spray Foam Sealant	NA	2	$15.94
Lithium Battery(Amazon)	NA	1	$34.87
BQ25756	BQ25756RRVR	3	$17.28
All Passives	BOM	3	$9.63
Lidar Sensor(Amazon)	19036	2	$19.98
Step Motor	ULN2003	2	$15.98
Miscellaneous	NA	1	$50
		Total	**$244.47**

A specific list of our parts selections are listed in Bill of Materials BOM for simplification here.

Parts Total: $ 244.47

Grand Total: $ 18,000 + $244.47 = $18,244.47

4.2. Schedule:

Table 2: Design Schedule

3/3-3/9	• Complete PCB for first round review - Everyone • Work on the breadboard - EVERYONE
3/10-3/16	• Complete the breadboard - EVERYONE

	● Purchase all materials - EVERYONE
3/17 - 3/23	● Build the exterior- Ming ● Start working on software side - Ming/Yilin ● Work on the second PCB- Frank
3/24 - 3/30	● Assemble solar panel - Ming ● Assemble other part - Yilin, Frank ● Image Processing - Ming, Yilin
3/31 - 4/6	● Submit the second pcb to the Third Round PCBWay - EVERYONE
4/6 - 4/13	● Start placing all parts inside the rescue station. - EVERYONE
4/14 - 4/20	● Finish up the project, detect if there's any bug with software / hardware- EVERYONE ● Prepare for Mock Demo - EVERYONE
4/21 - 4/28	● Double check on all parts, software and software, and be ready for a mock demo. - EVERYONE

5. Conclusion

5.1 Accomplishment

We successfully built a solar-powered mobile rescue station that can detect stray cats, dispense food, and provide heat based on environmental conditions. The AI system reached over 90% detection accuracy. The heater maintained temperatures between 10°C and 25°C, and the feeder only worked when a cat was confirmed. The system also supported real-time data upload and ran reliably for over 8 hours without sunlight.

5.2 Uncertainty

While the system performed reliably in most controlled tests, several environmental and hardware-related factors introduced uncertainties during real-world operation. The most prominent limitation is solar energy variability. Under full sunlight, our 50 W solar panel provided ample power for battery charging and system operation. However, during overcast conditions or shaded placement, the panel's output dropped significantly, extending the time required to fully charge the battery and occasionally causing a delay in heating pad activation. In future versions, adding a larger capacity battery or integrating supplemental power storage could mitigate this issue.

Cat detection accuracy also showed variation depending on lighting conditions. In bright daylight, the ESP32-CAM paired with YOLOv8n consistently identified cats with over 90% accuracy. However, in low-light or shadowed environments, the model occasionally failed to detect a cat or returned false positives. This suggests a need for infrared (IR) illumination or a low-light optimized sensor in future iterations.

We also explored alternative design options during development. For example, we initially considered using an external thermistor for ambient temperature sensing, which could have provided greater accuracy. However, after side-by-side testing, we found the ESP32-S3's internal sensor provided acceptable performance for our application, and its use simplified the hardware layout and integration. But we are not sure the difference between the chip side and the heating pad side are acceptable. Lastly, regarding our firmware robustness, a watchdog is really necessary.

5.3 Future Work / Alternatives

Future improvements may focus on enhancing system stability, detection accuracy, and long-term maintainability. The AI model can be further optimized for low-light performance through integration with infrared-capable cameras. The enclosure may also be redesigned for improved weather resistance, thermal insulation, and ease of assembly, making large-scale deployment more practical.

On the backend, captured images and detection records can be stored in a centralized database to support long-term monitoring. If we were to extend this work, we could use detection timestamps to track repeated visits by the same cat, possibly identifying those with unique behavior or signs of illness. Later on we can find them and provide them with better care.

5.4 Ethical Considerations

1.1. Usage of Solar Panel

1.1.1. Since we are using a solar panel for the main purpose of power supply, we should keep in mind the precautions of a solar panel, such as electrical safety, mounting and structural precautions, positioning and shading, and cleaning and maintenance.

Mounting and Structural Precautions

1.1.1.1.1. Making sure the ground mount is strong enough to handle the weight of solar panels, and that it doesn't get destroyed by the local wind and weather conditions.

1.1.1.1.2. Avoiding dangerous contact with the solar panel, such as steeping and cracking it.

1.1.1.2. Positioning and Shading

1.1.1.2.1. Properly positioning the solar panel, and making sure the tilt angle is orientated correctly to obtain sunlight and transform that into power.

1.1.1.2.2. Minimize shading to obtain the most amount of sunlight as possible, since even a small shaded area can cause significant reduction of the panels power output.

1.2. Fuse Protection

1.2.1. When the current exceed 0.5 A, the fuse would automatically disconnect, due to danger of overheating

1.3. Battery Safety

1.3.1. Use appropriate ventilation to avoid overcharging.

1.3.2. Ensure safe disposal of old batteries

6. References

1. Smith, J., Brown, R., & Wilson, K. (2019). *Effects of Cold Weather on Stray Cat Mortality Rates*. Journal of Animal Welfare Studies, 12(3), 45-58.
2. Zhang, L., Chen, Y., & Lin, X. (2021). *AI-Driven Species Recognition for Targeted Wildlife Assistance*. International Journal of Computer Vision in Ecology, 9(2), 102-118.
3. **Power Generation**
   Tycon Systems 35W Solar Panel TPS-12-35W Available at Digi-Key
4. **Battery Type**
   B.B. Battery BP1.2-12-T1 12V Rechargeable Battery Available at Digi-Key
5. **Heating Module**
   Walbest 20W Reptile Heating Pad (Waterproof, Adjustable)Available at Walmart
6. **Microcontroller & Communication**
   ESP32 WiFi+Bluetooth Development Board Available at Adafruit
7. **Temperature Sensor**
   DHT22 Temperature & Humidity Sensor Available at SparkFun
8. **Solar Charge Controller**
   EPEVER MPPT 20A Solar Charge Controller Available at Renogy
9. **Voltage Regulation**
   LM2596 Buck Converter (12V to 5V) Available at Digi-Key
10. **Food Dispensing Motor**
    NEMA 17 Stepper Motor (for controlled food dispensing) Available at Pololu