Firefighting Remote Exploration Device II

Justin Cheng (ECE/CS), Demi Karavoussianis (ME/CS), Augustus Moseley (CEE), Leif Sahyun (RBE/CS)
Advisors: Professor Carlo Pinciroli (RBE/CS), Professor Rajib Mallick(CEE),
Professor William Michalson (RBE/ECE), Professor Ahmet Sabuncu (ME), Professor Sarah Wodin-Schwartz (ME)

Abstract

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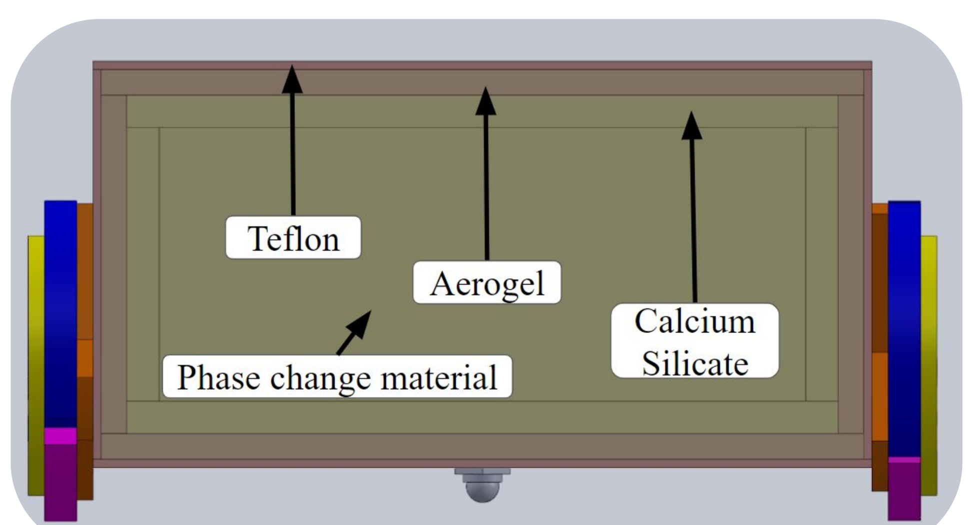
Material Layering System

We decided to use a composite material layering system in order to provide structural stability, impact resistance, and heat resistance from conduction, convection, and radiation. To further increase heat resistance, we implemented a phase change material inside the interior.



Requirement Metric:
Maintain an interior temperature of under 60 ℃:

- for 15 minutes in an 160 ℃ environment
- for 3 minutes in an 210 ℃ environment
- remain under 15 pounds

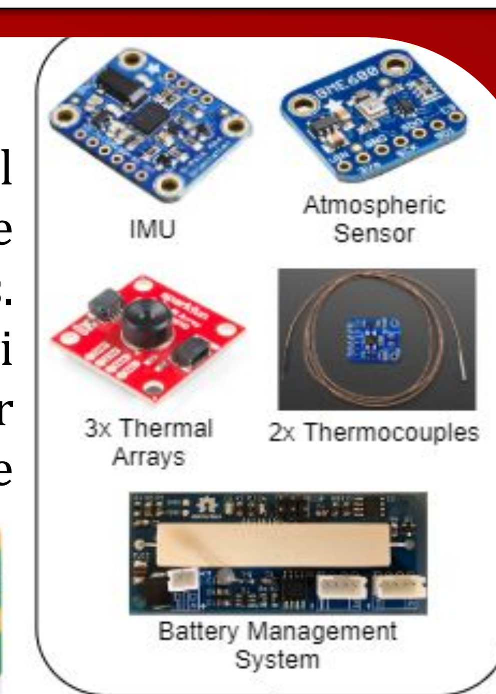
Whegs

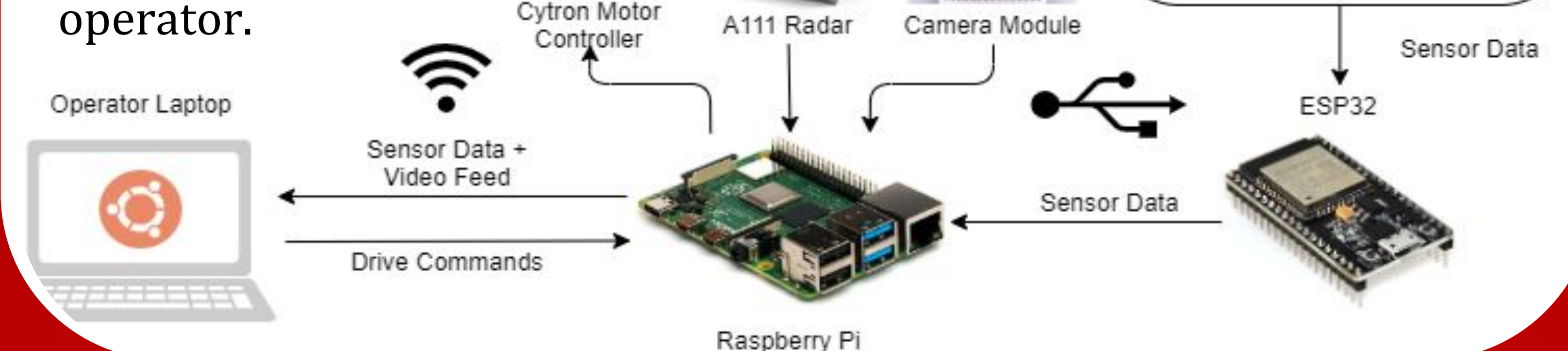
The wheel design selected is a transformable wheel to leg configuration.

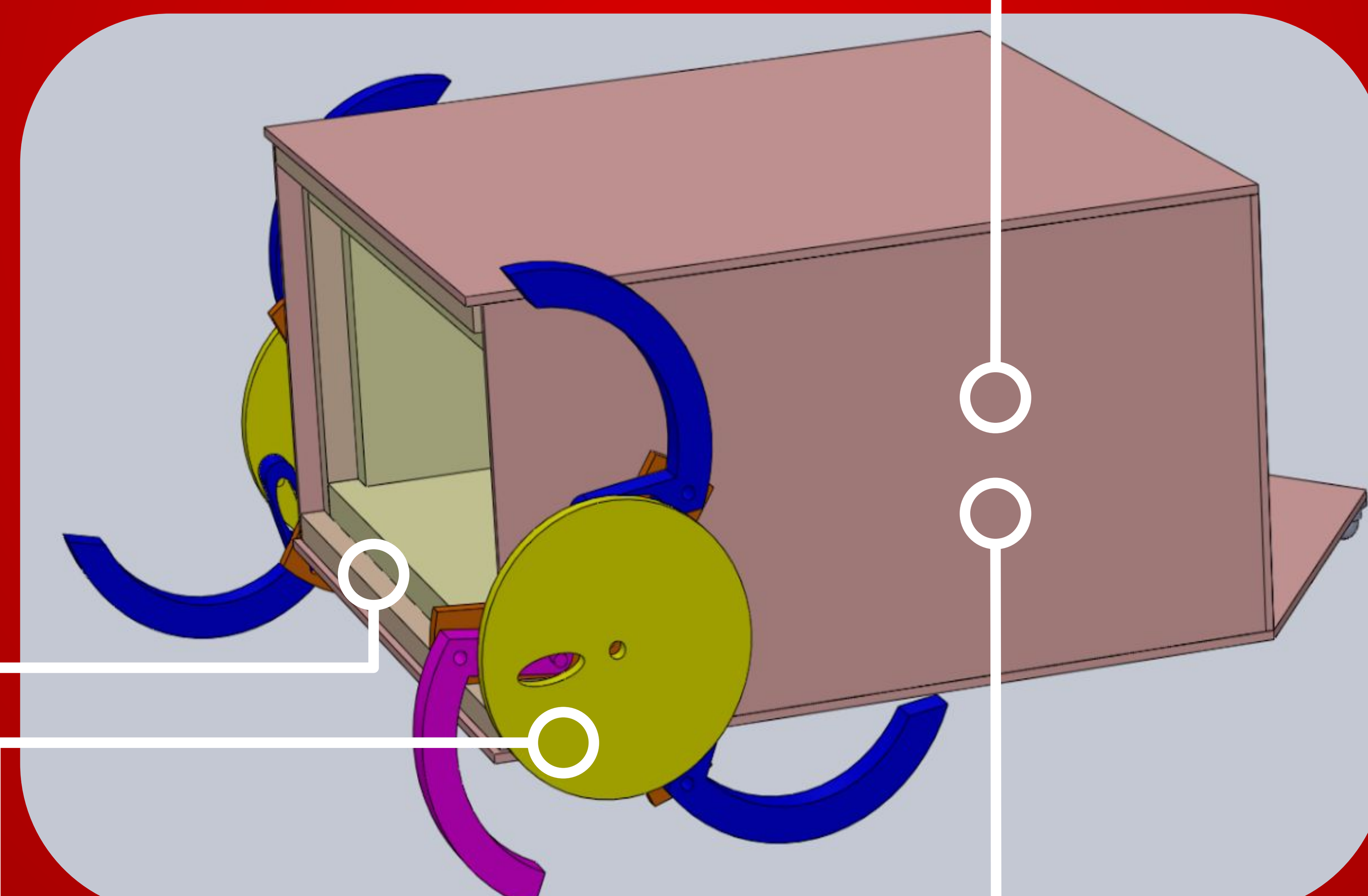
- Allows for a smooth and quick drive in wheel formation
- Ability to climb stairs in the expanded formation.
- The transformation is passive, and is triggered by external force applied to one of the legs
- Selected material is an aluminum alloy which can withstand high temperatures without deformation

Electronics

Sensors connected to the ESP32 gather internal & external data including temperature, pressure orientation, battery charge, and thermal images. Sensor data is processed on a Raspberry Pi running ROS along with a camera feed and radar data. Data gathered by the robot is sent to the operator laptop wirelessly where the robot can be controlled by an operator.



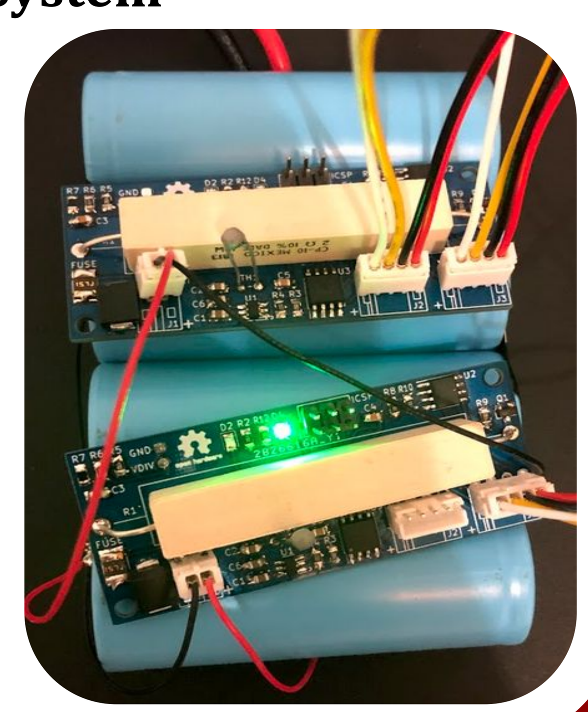




Battery Management System

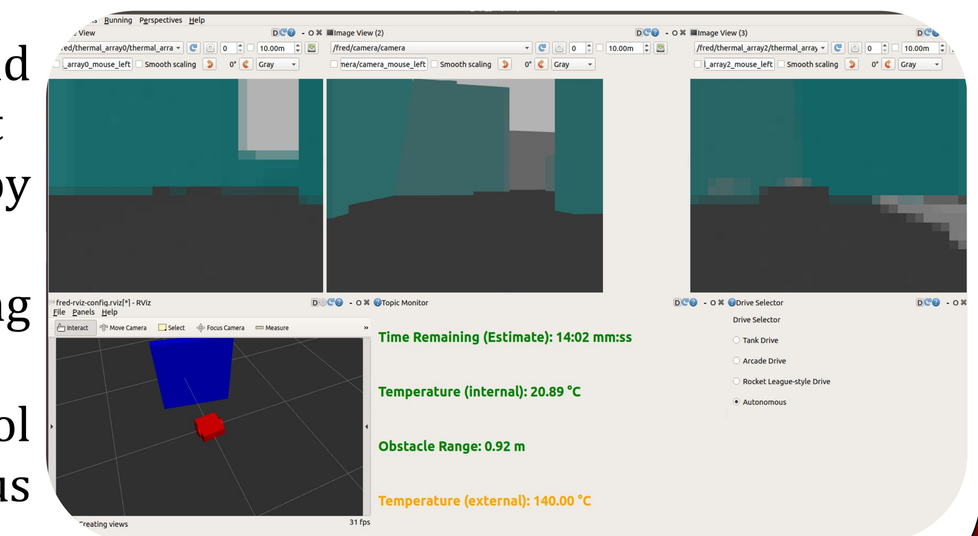
Our integration uses an open source Battery Management System (BMS) designed by Stuart Pittaway to help monitor the robot's battery. The benefits of having a BMS in this system are:

- Protecting the battery while charging
- Monitoring battery state:
  - Voltage
  - Current
  - Capacity
  - Temperature



Graphical User Interface

- Shows firefighters live visual and thermal video feeds from the robot
- Displays sensor data color-coded by how dangerous it is to the robot
- Displays an estimate of how long the robot can continue to operate
- Allows the user to change control schemes or enter autonomous mode.

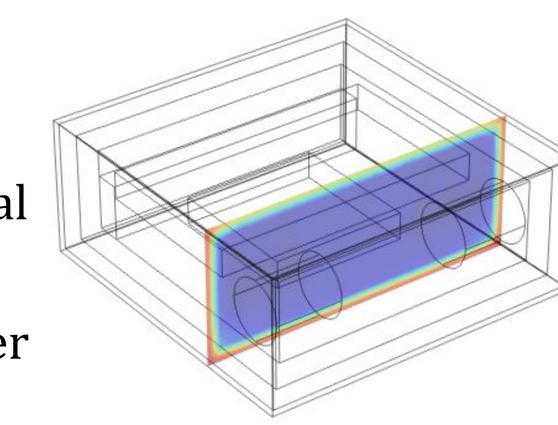


Autonomous Obstacle Avoidance

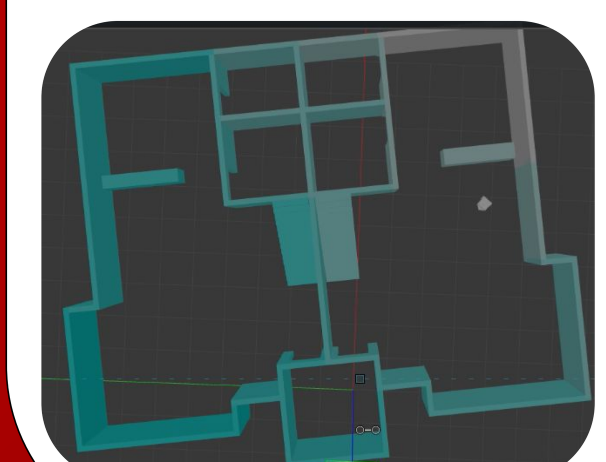
- Pulsed coherent radar detects obstacles within 1m in front of robot
- Robot turns in a random direction when near an obstacle
- Calculates turning radius that will avoid obstacle in front as well as known obstacles on the sides

Simulation & Testing.

For chassis testing, we modelled the robot in COMSOL



- Ran time-dependent studies at various external temperatures.
- At 160℃, the interior remained under 60 ℃ for over 15 minutes, passing the requirement metric



As a system test, the robot navigated through a virtual "fireground", created in Gazebo, for 15 minutes.

- The fire was modelled by the color on the walls
- The simulated temperature sensor would extract a color code to determine the temperature.
- The model included the following simulating components camera, IR thermal arrays, radar and battery.

Lessons Learned

In designing and simulating this robot, we learned about the intricacies of creating a fire resistant robot. Keeping the robot relatively lightweight, impact resistant, and maintaining a cool interior were some design metrics that tended to disagree, especially when selecting materials. In addition, we discovered that it is difficult to develop an effective autonomy specific to mapping and navigating a fireground, where the environment is constantly changing. Finally it is challenging to develop a comprehensive, easy to understand GUI when there is so much prominent information.

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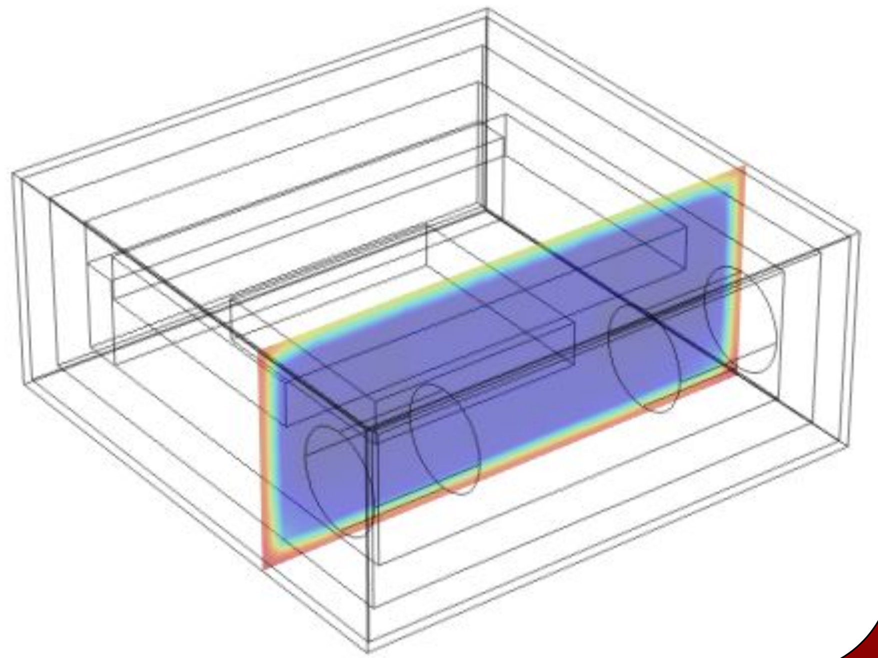
Project Requirements

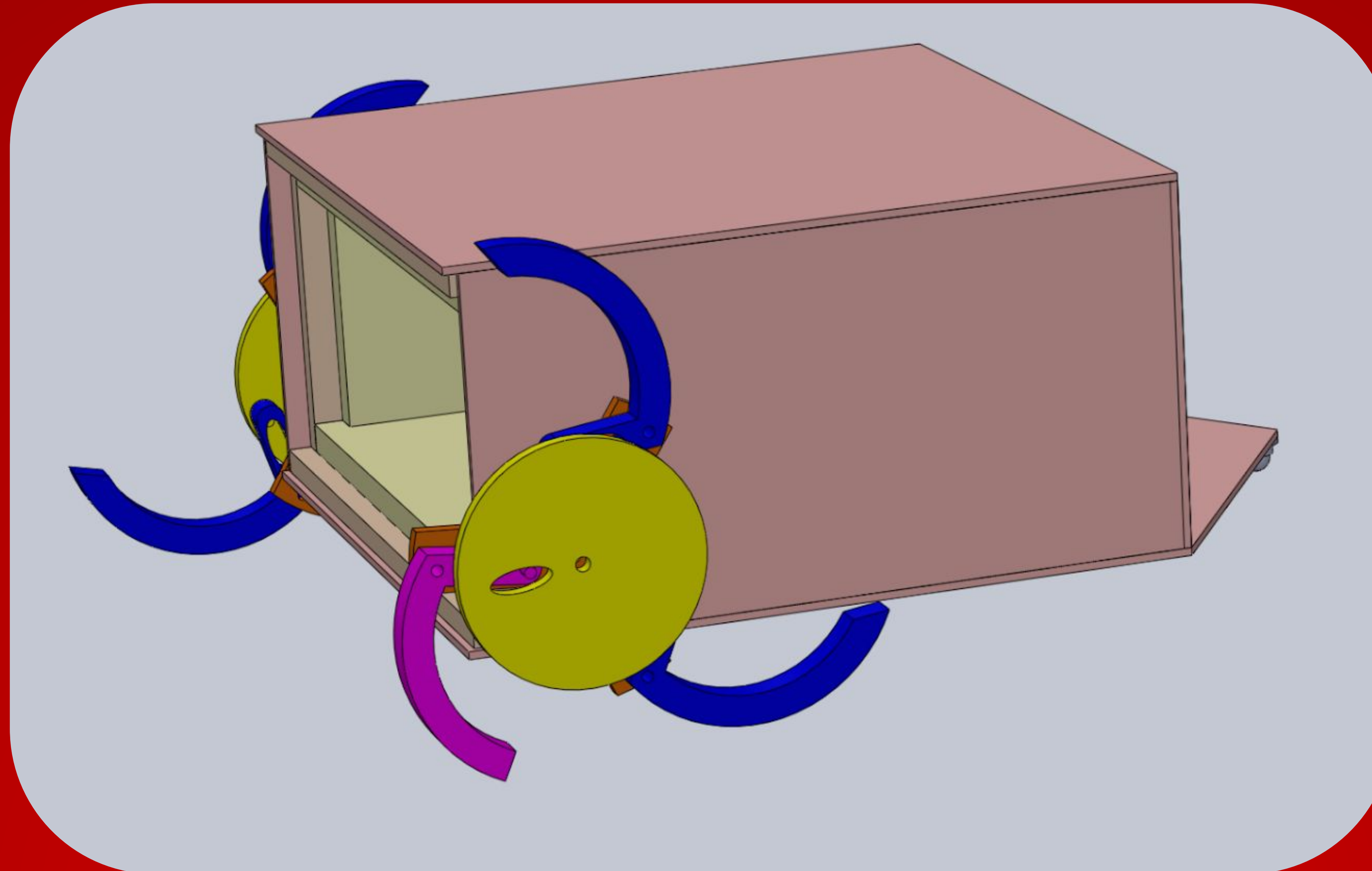
- maintain an internal temperature less than 60 ℃:
  - after 15 minutes in a 160 ℃ environment
  - after 3 minutes in a 210 ℃ environment
- Have heat resistant whegs capable of surviving 250 ℃
- Utilize a battery management system
- Have a comprehensible user interface with defined modules
- Estimate and relay time remaining before the internal temperature exceeds 60 ℃
- Perform autonomous exploration of a fireground, while avoiding obstacles
- Move at 0.5 m/s with heat and impact shielding on

Material Layering System

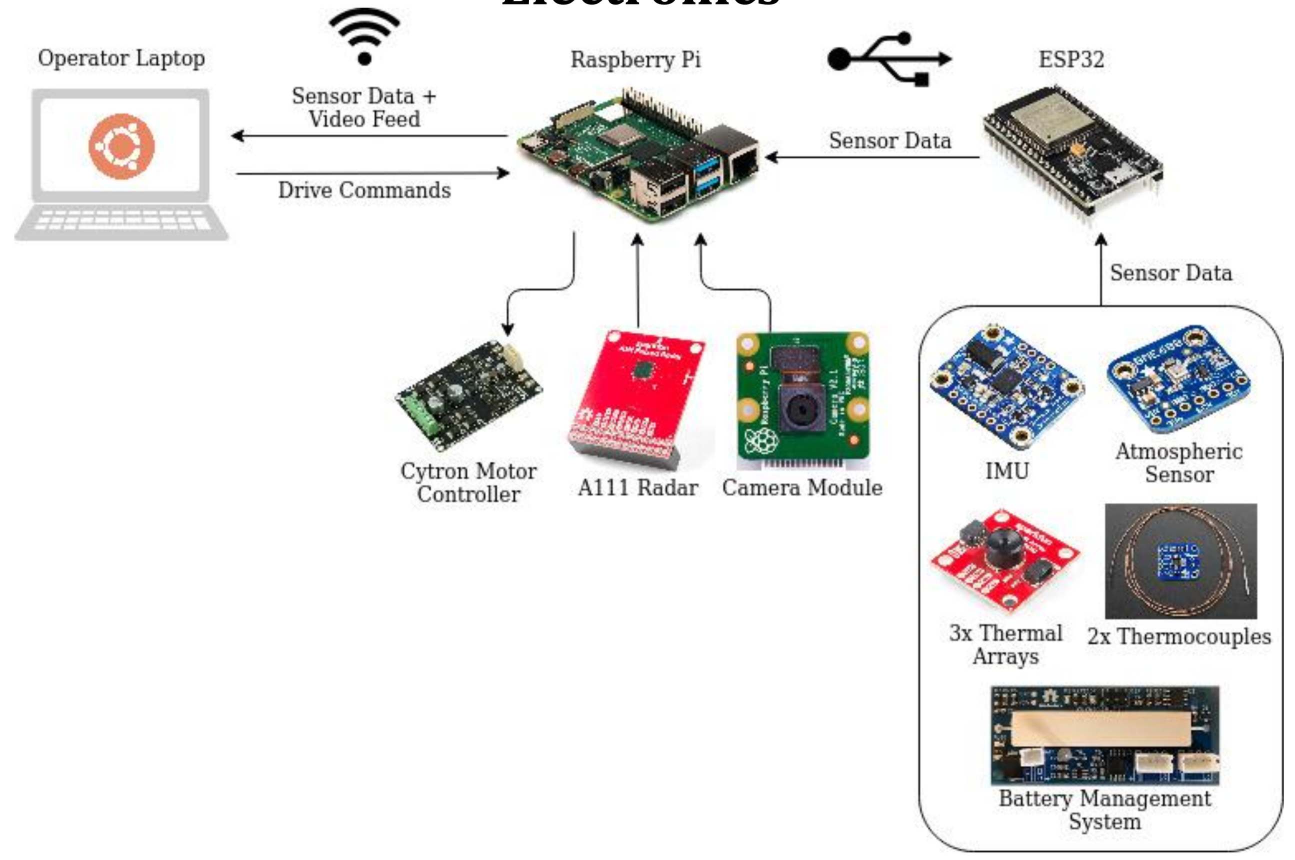
We decided to use a composite material layering system in order to provide structural stability, impact resistance, and heat resistance from conduction, convection, and radiation. The material layering system was simulated via the multiphysics software COMSOL

1. Adhesive Aluminum/Fiberglass
2. ⅛ inch teflon (PTFE)
3. ⅓ inch aerogel mat
4. ½ inch calcium silicate board
5. Phase change material





Electronics



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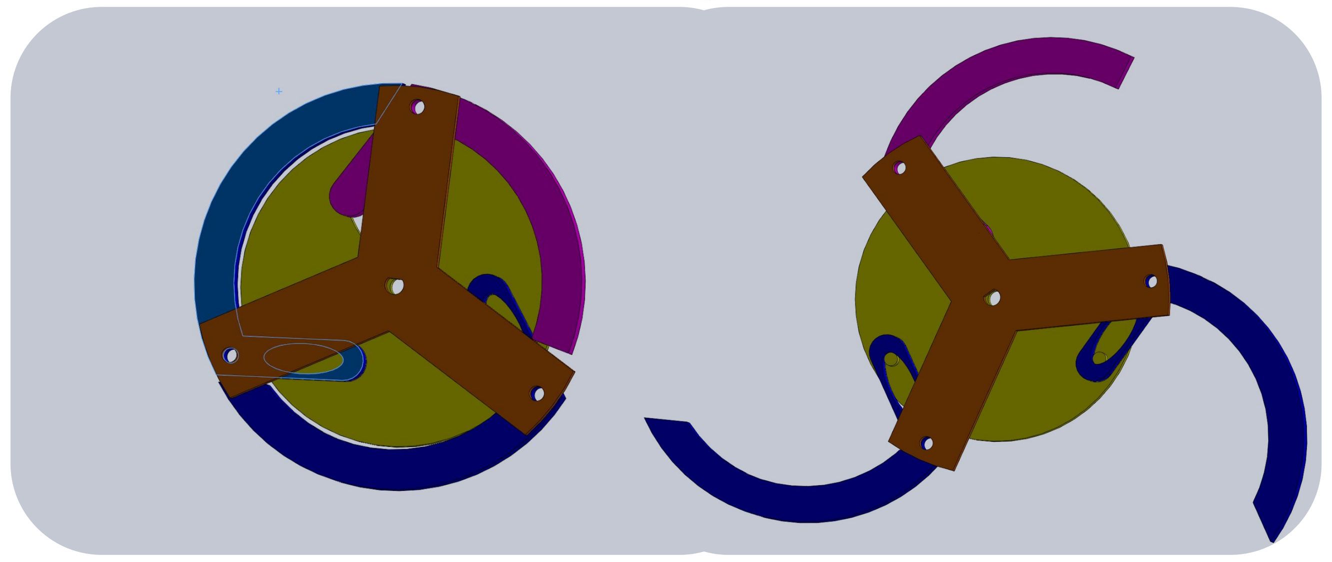

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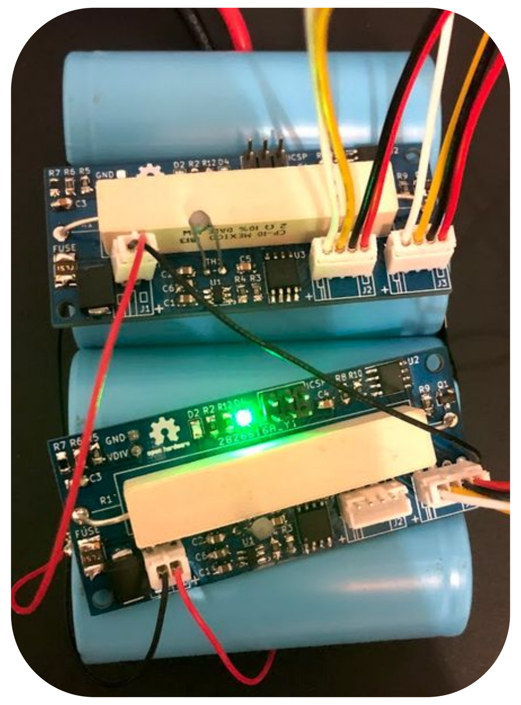
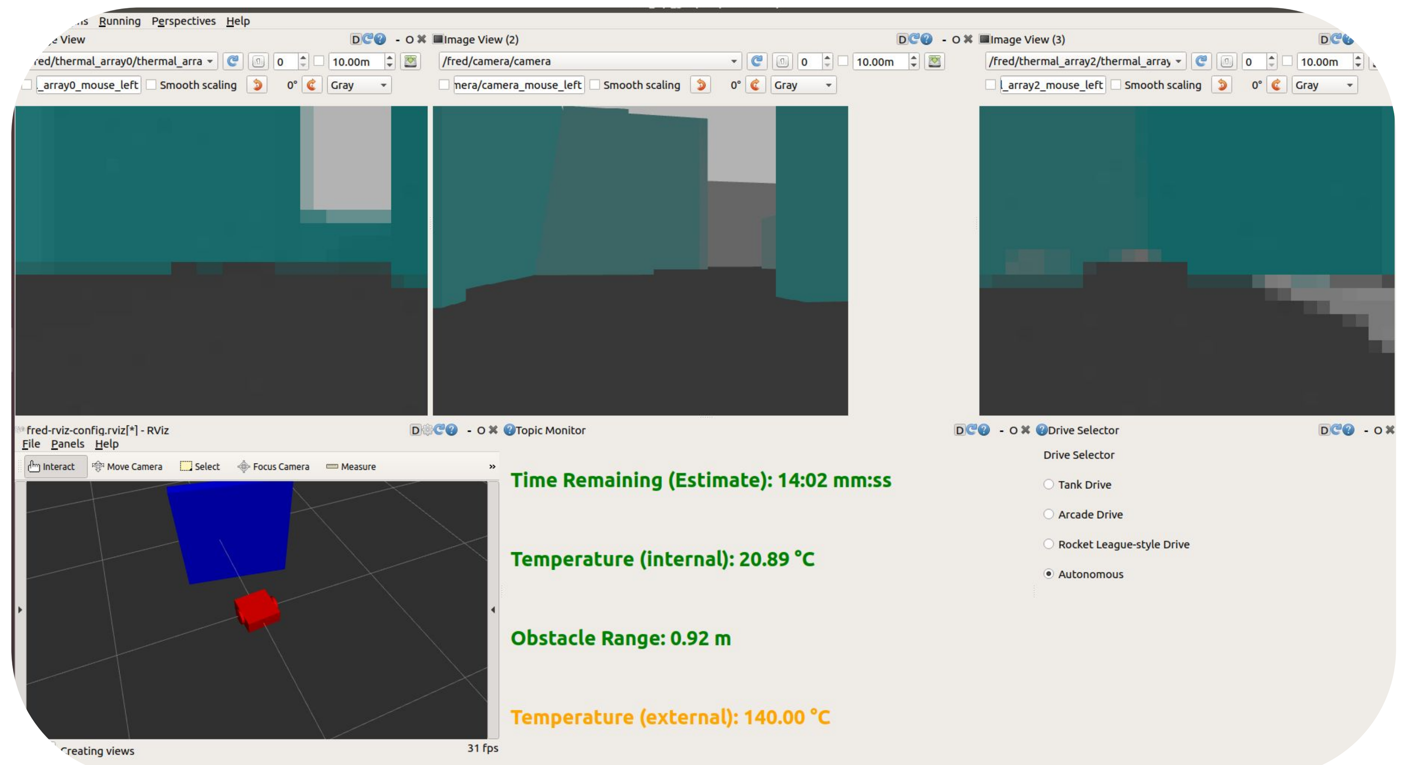


Graphical User Interface



Future Opportunities

The long term goal is to create an autonomous robot that can be deployed prior to the entrance of the firefighters and send data consisting of building integrity, persons, and temperature among other functions that could save the lives of the firefighters. Our team has developed recommendations for future work to help achieve this goal.

- Autonomous mapping of fireground
- Intelligent autonomous exploration
- Autonomous exit from building
- Ability to use multiple robots
- Working physical robot
- Ability to detect potential flashover and burnout

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Lessons Learned

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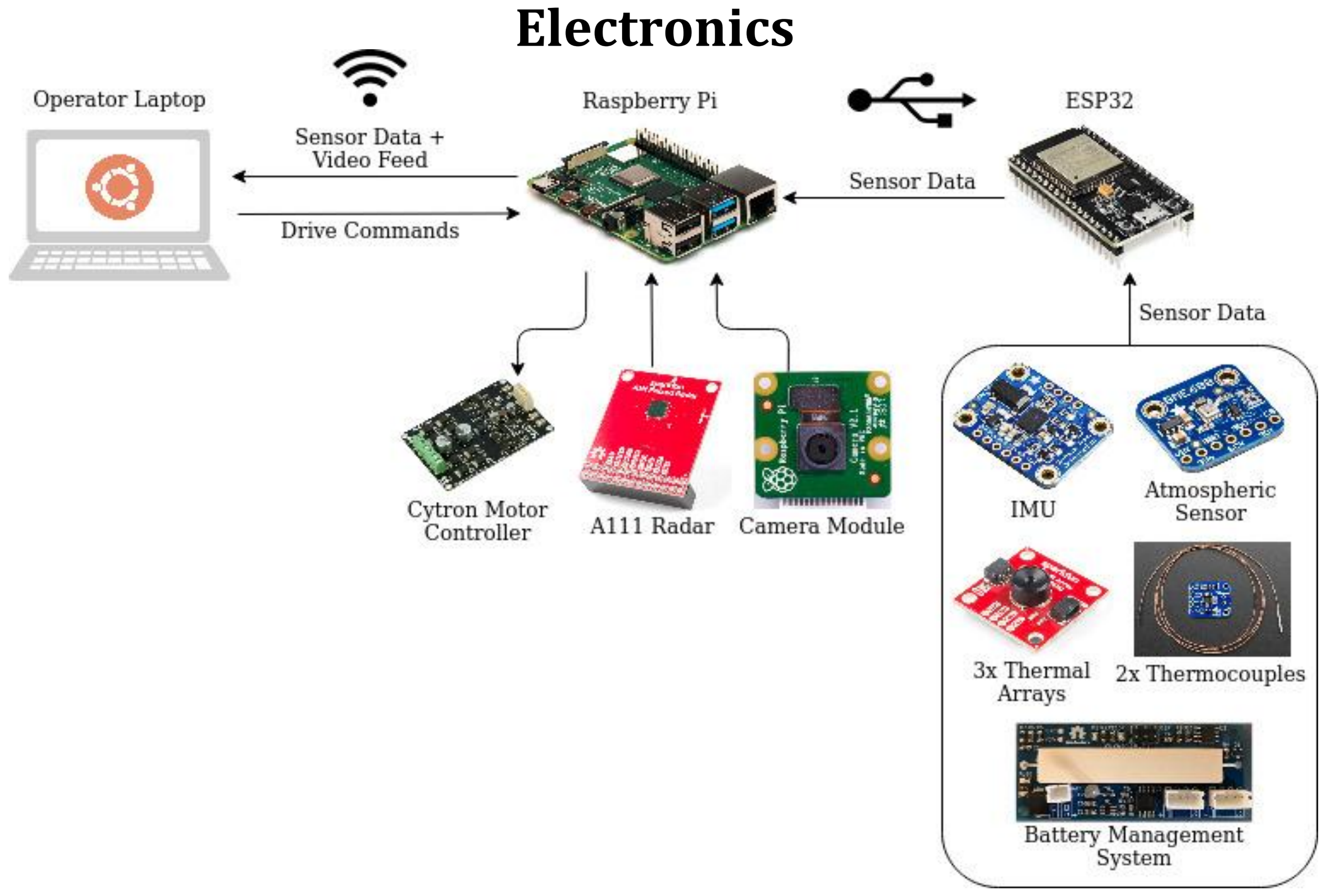
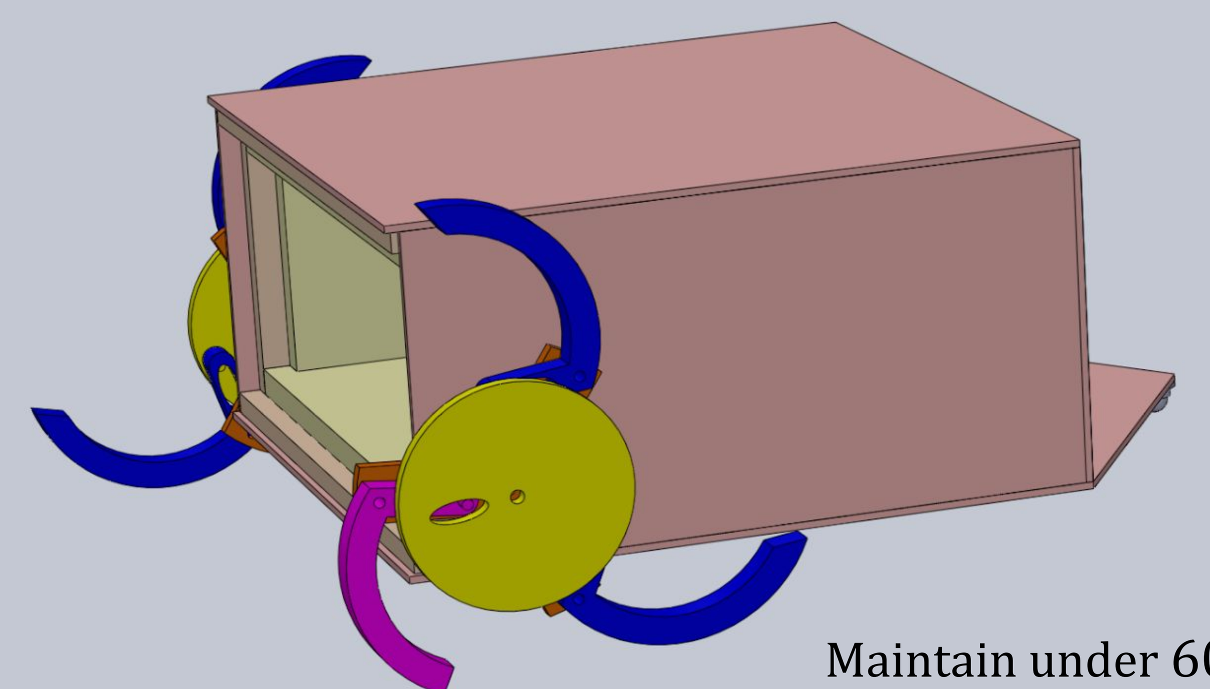
Electronics





Maintain under 60 ℃ inside:

- For 15 minutes in 160 ℃
- For 3 minutes in a 210 ℃

Whegs

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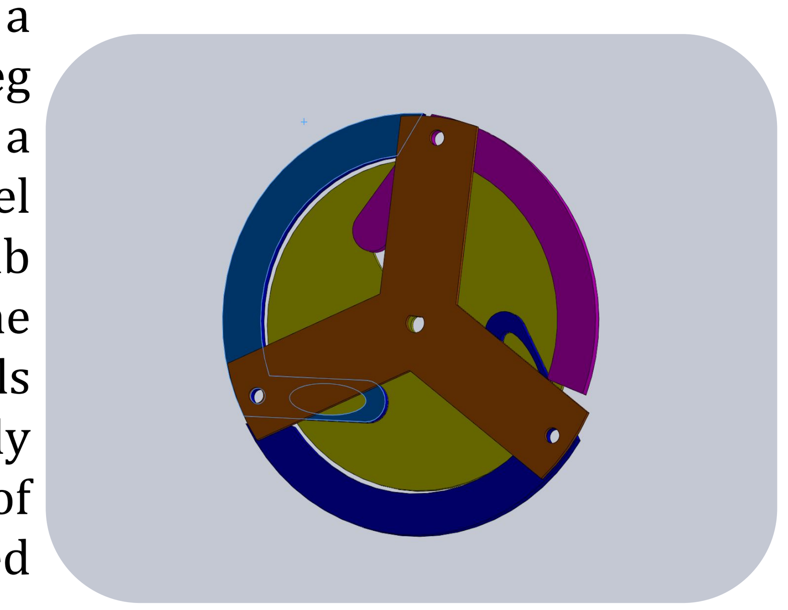

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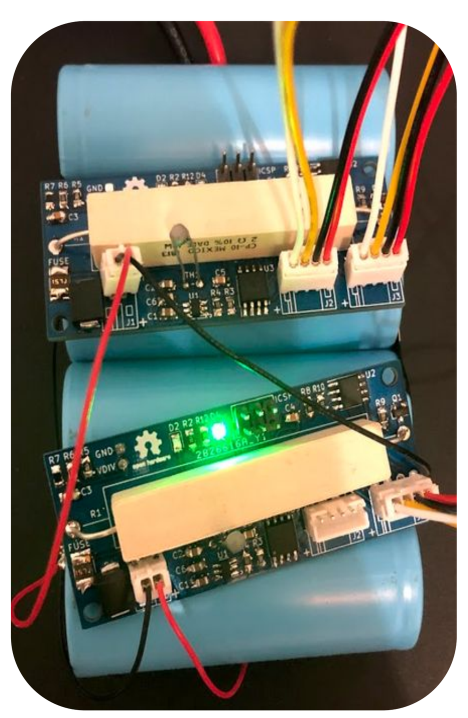

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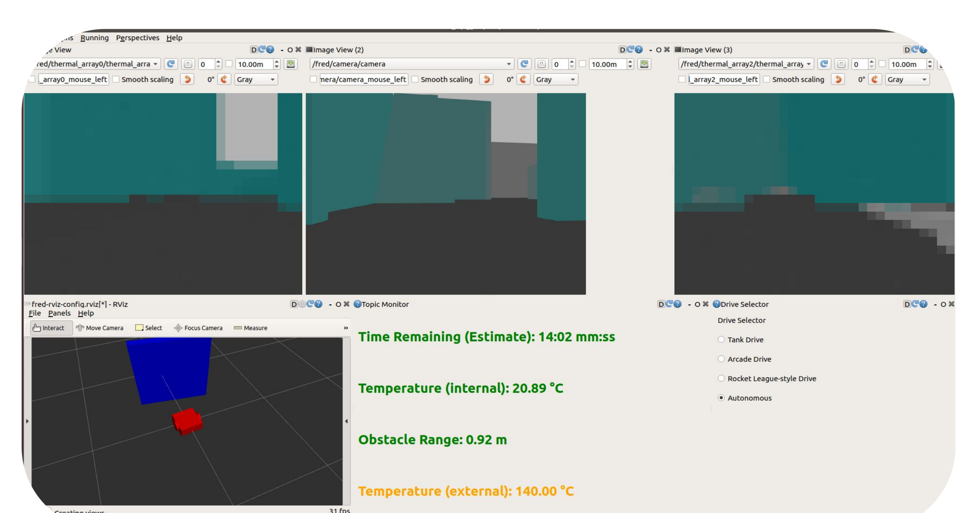

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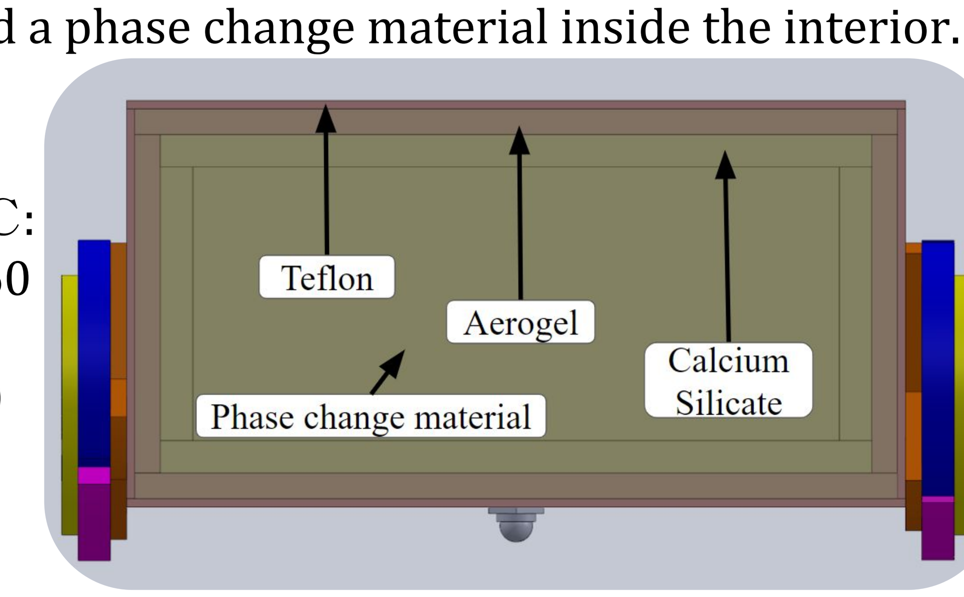

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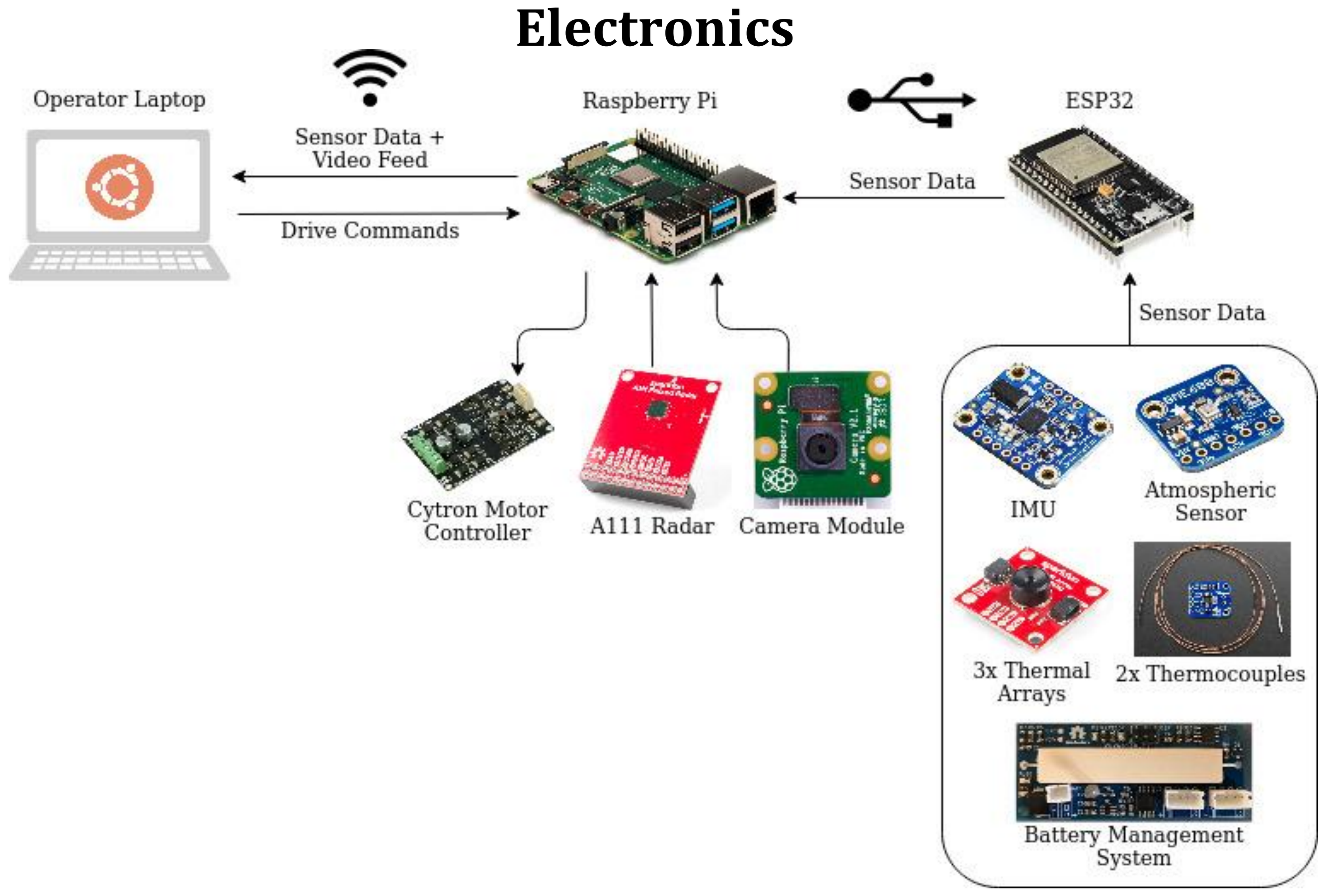

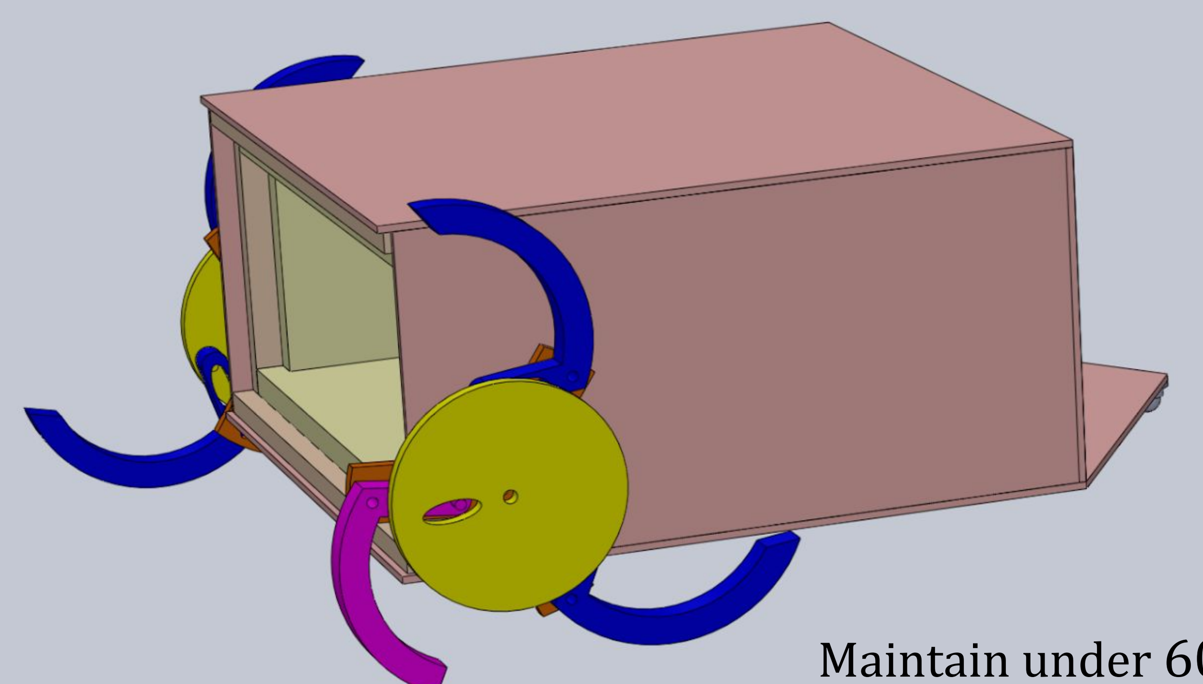

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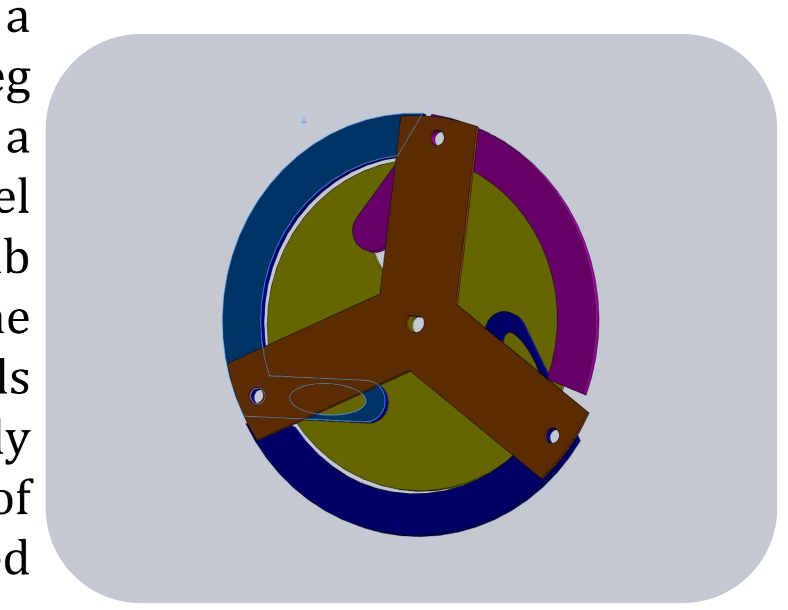

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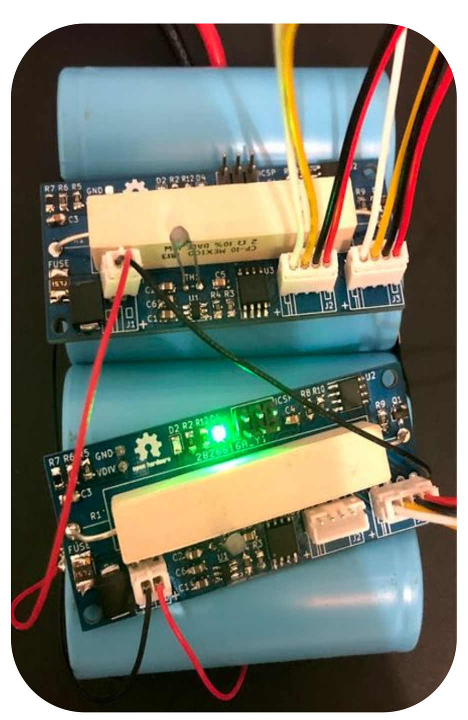

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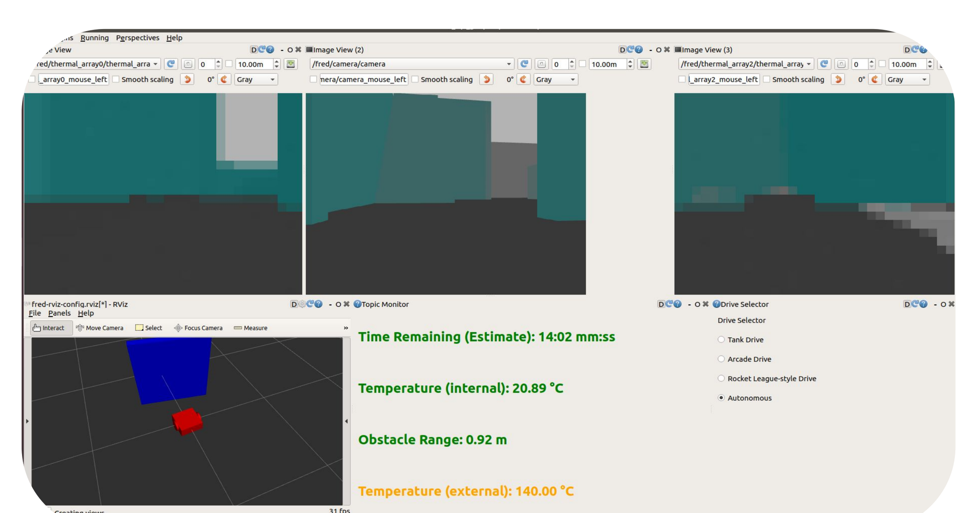

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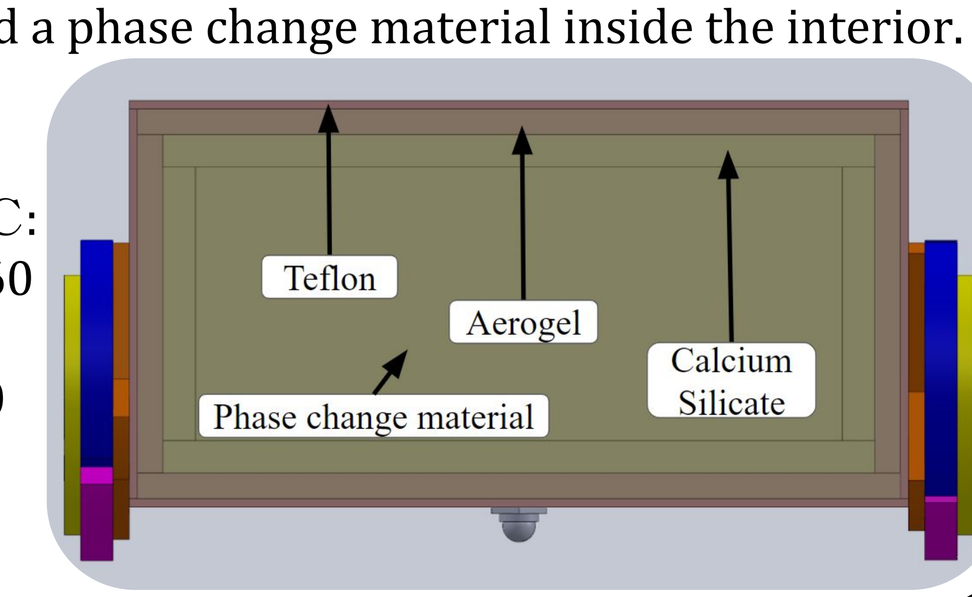

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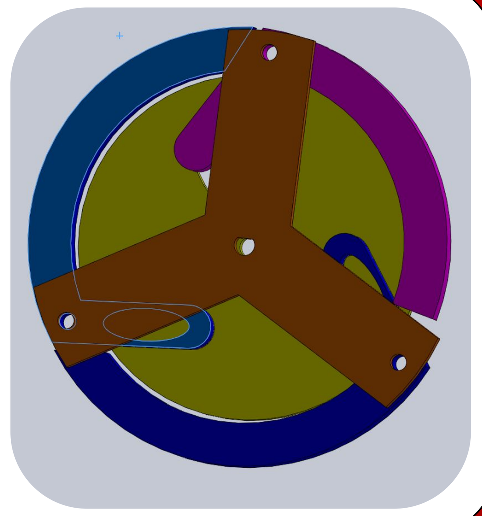

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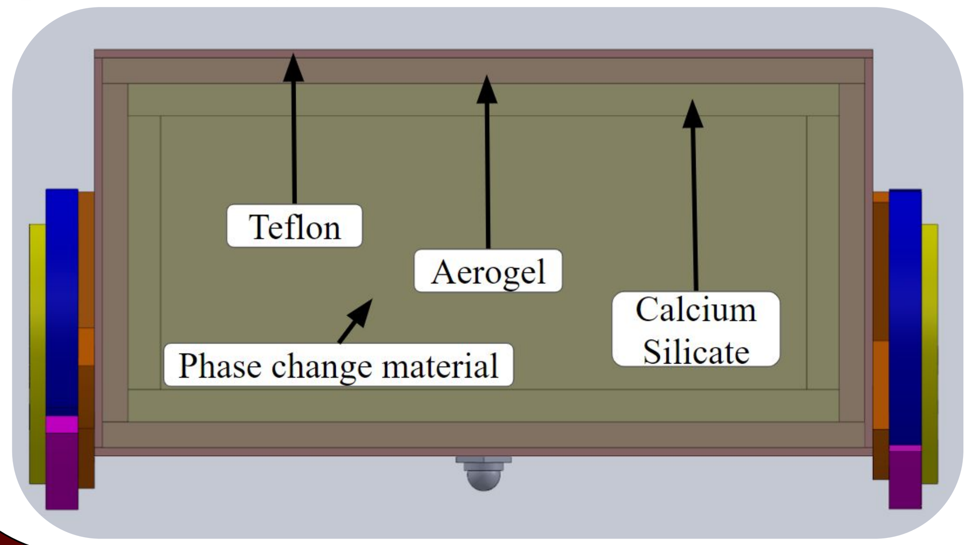

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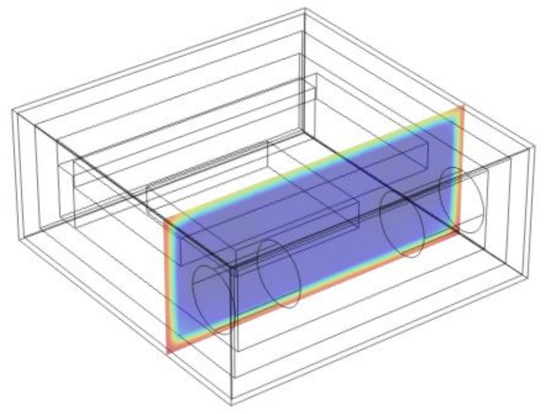
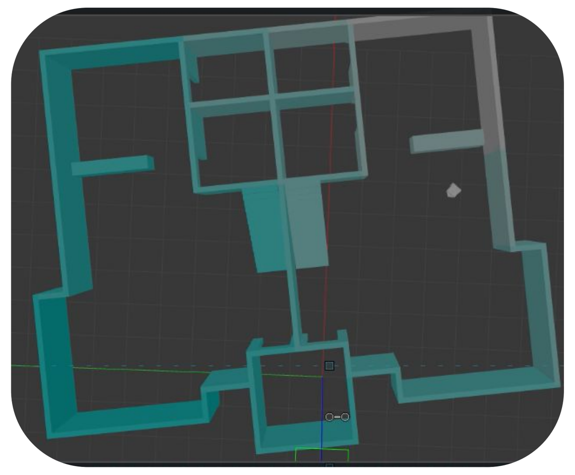
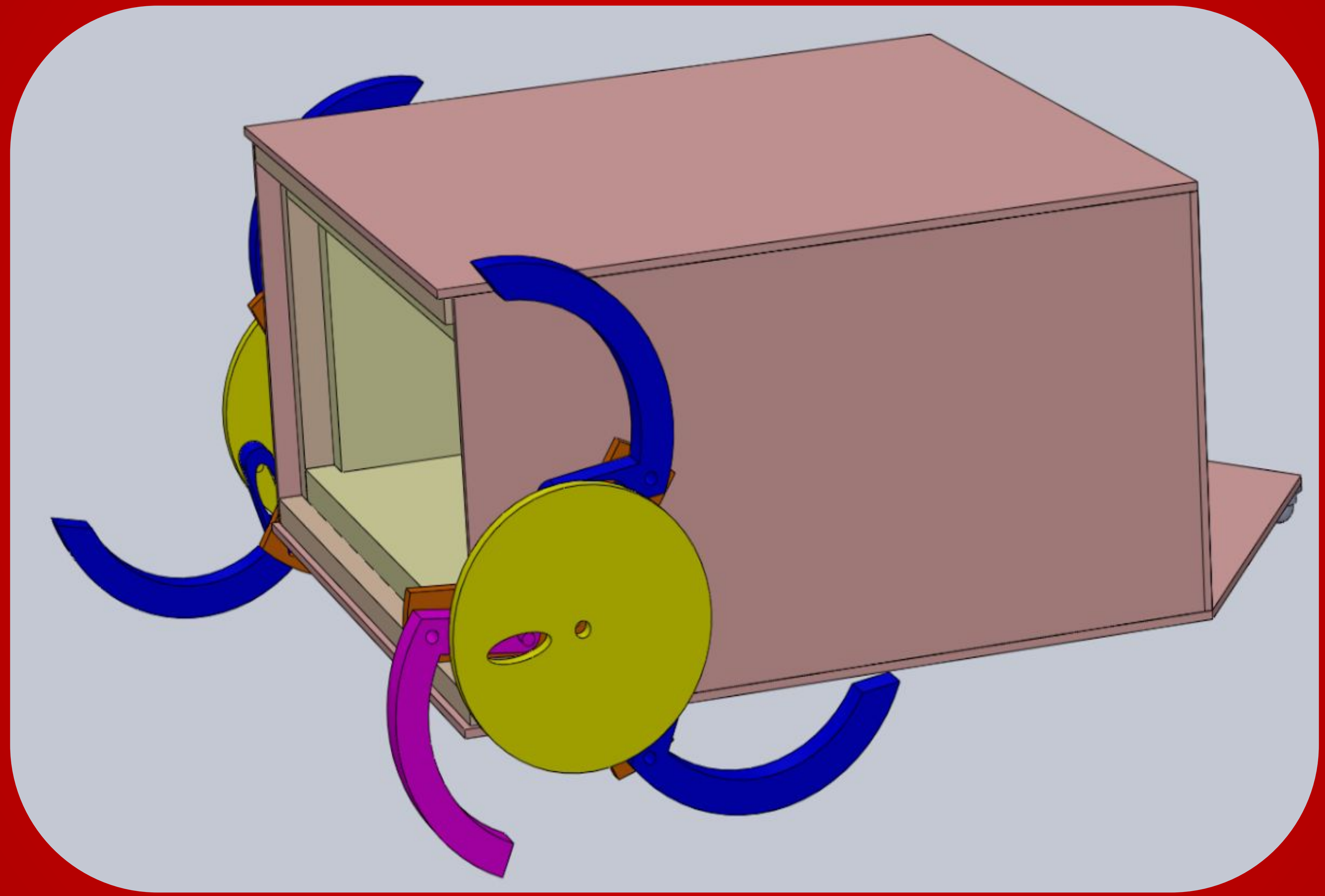
Simulation & Testing

For chassis testing, we modelled the robot in COMSOL and ran time-dependent studies at various external temperatures. At an external temperature of 160 ℃, the material layering successfully kept the interior under 60 ℃ for 15 minutes, passing the requirement metric in simulation.



As a system test, the robot navigated through a virtual “fireground”, created in Gazebo, for 15 minutes. The fire was modelled by the color on the walls, where the simulated temperature sensor would extract a color code to determine the temperature. The robotic model used included the following simulated components: camera, IR thermal arrays, radar, and battery.





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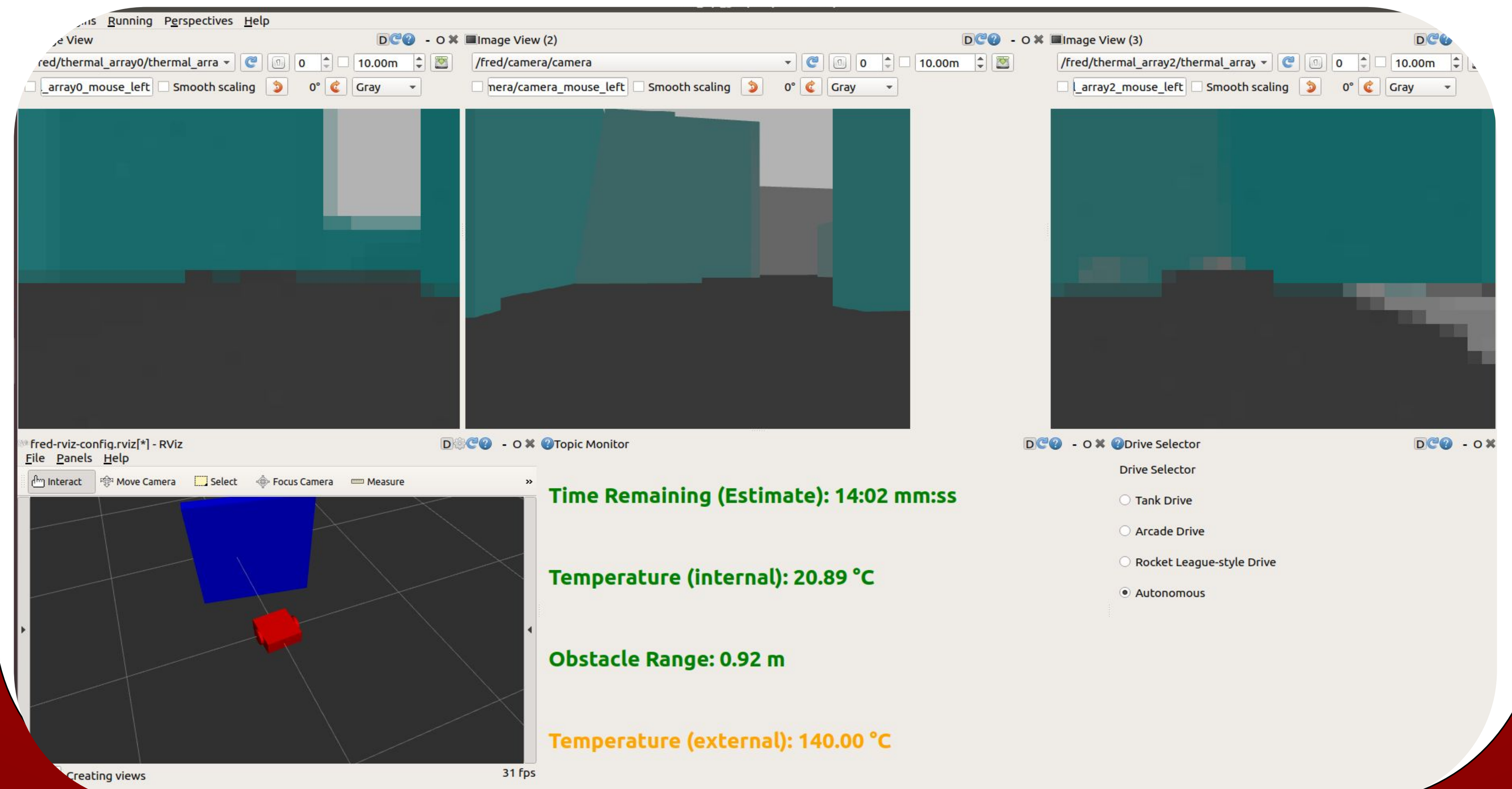

Electronics

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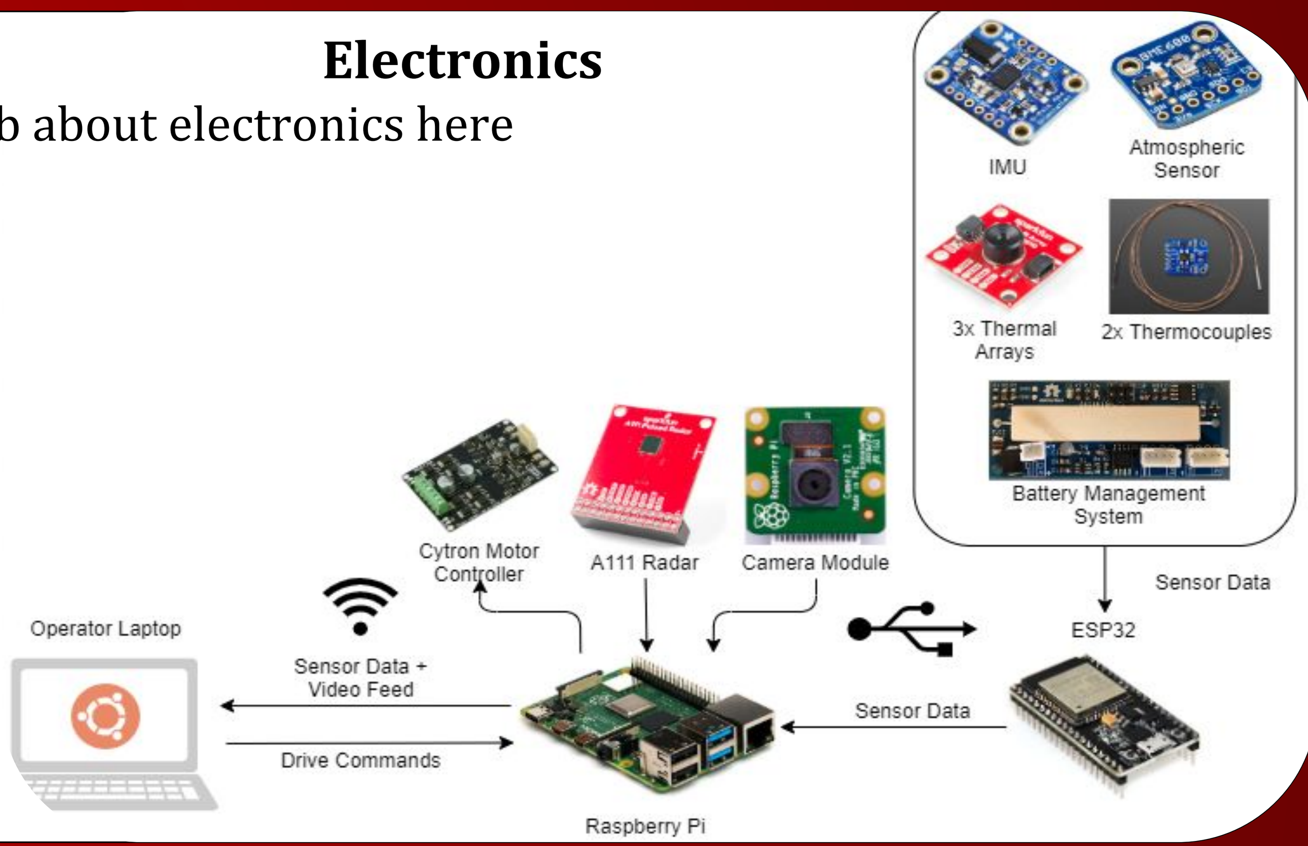

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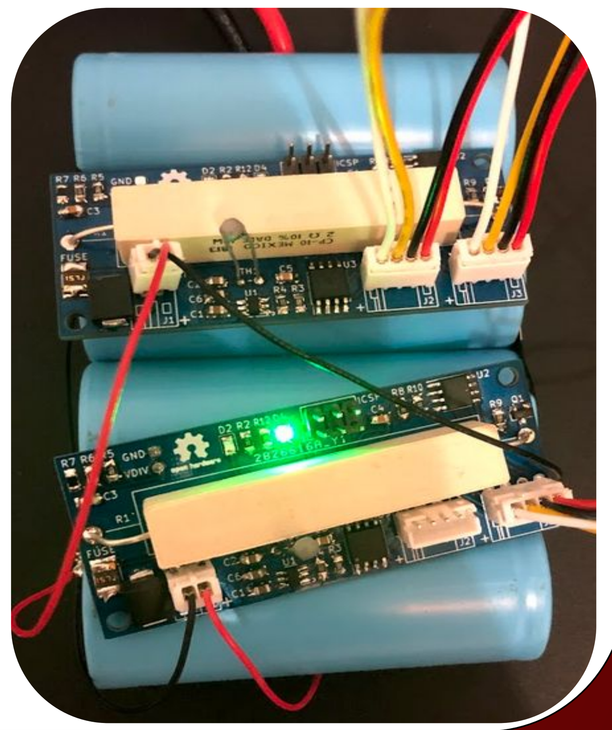

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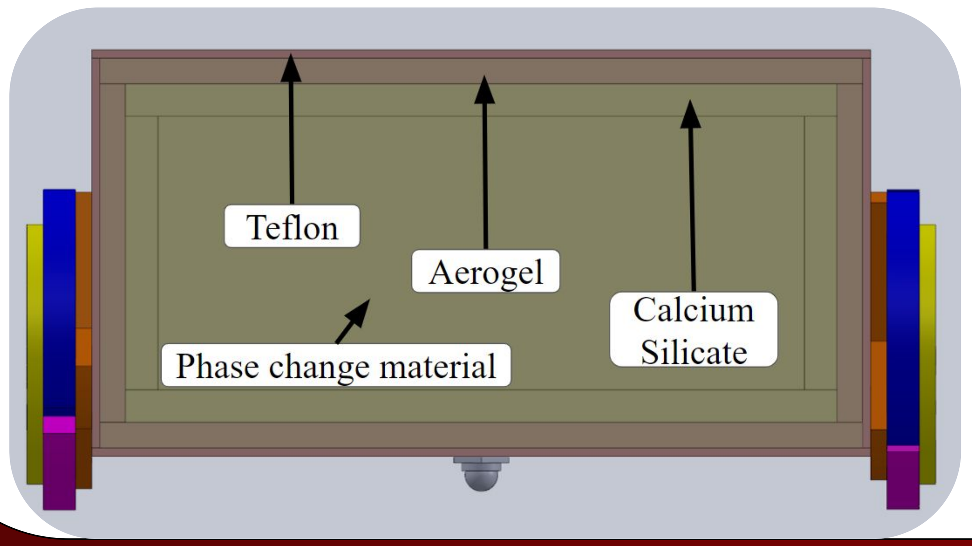

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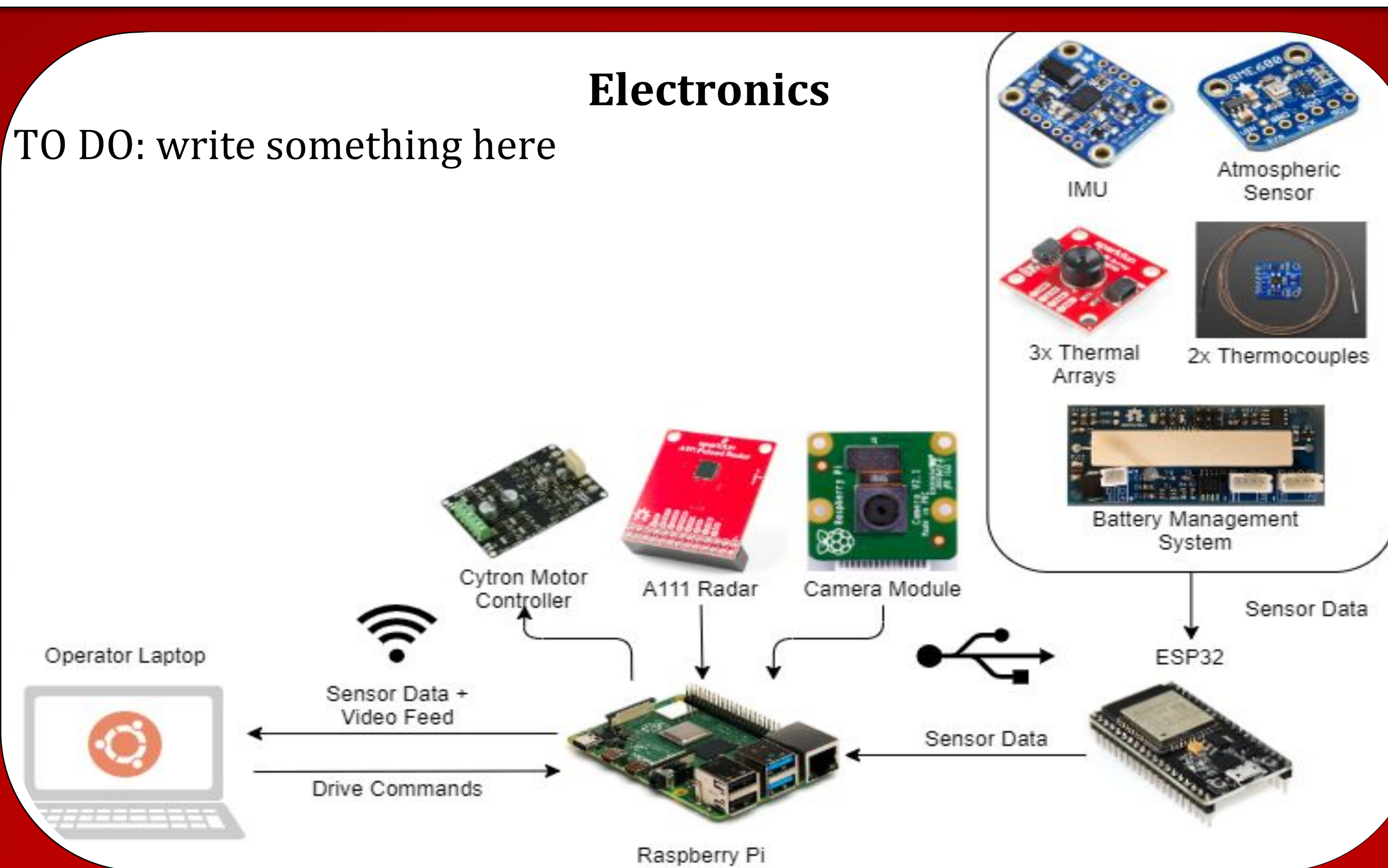

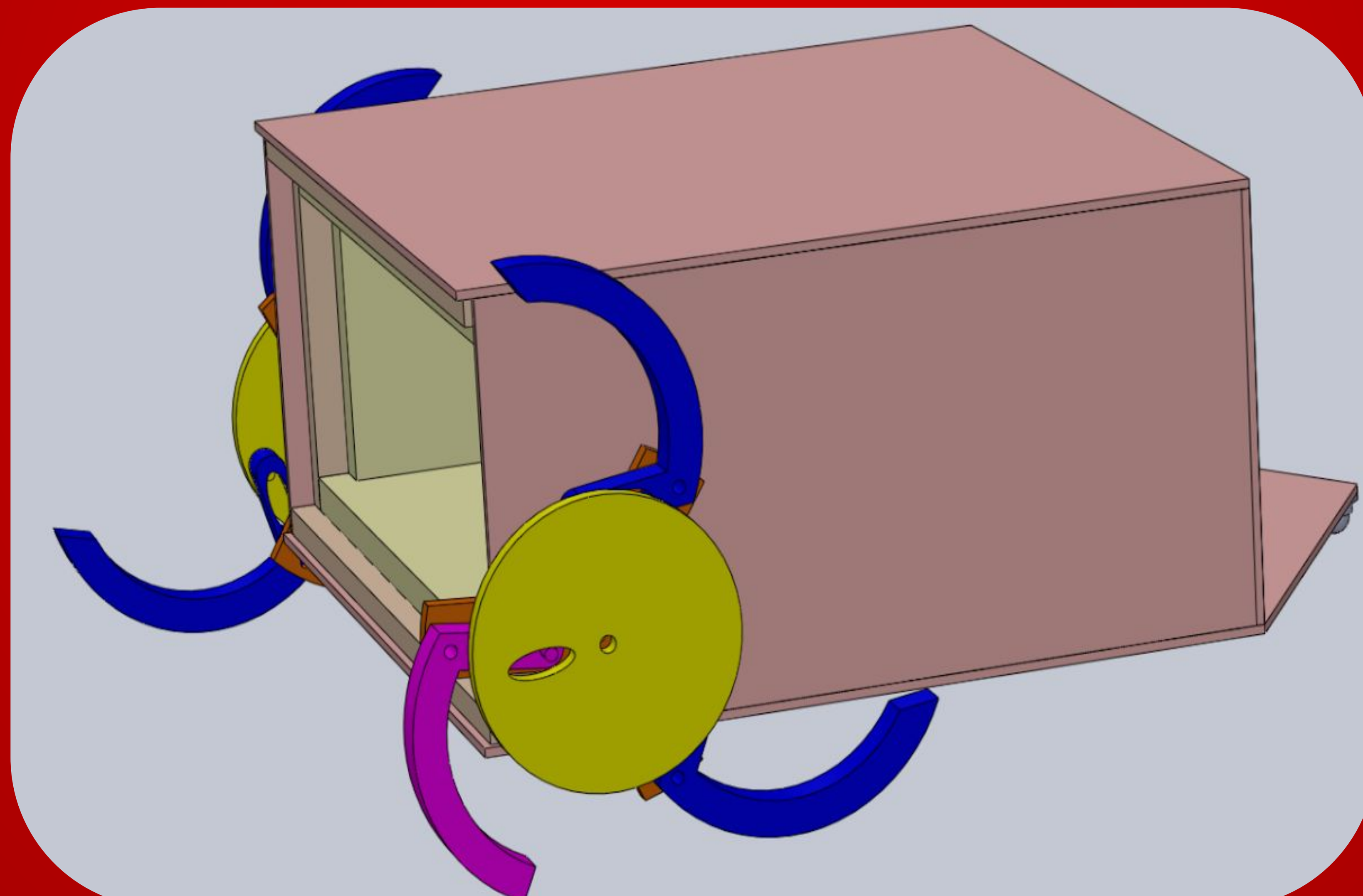

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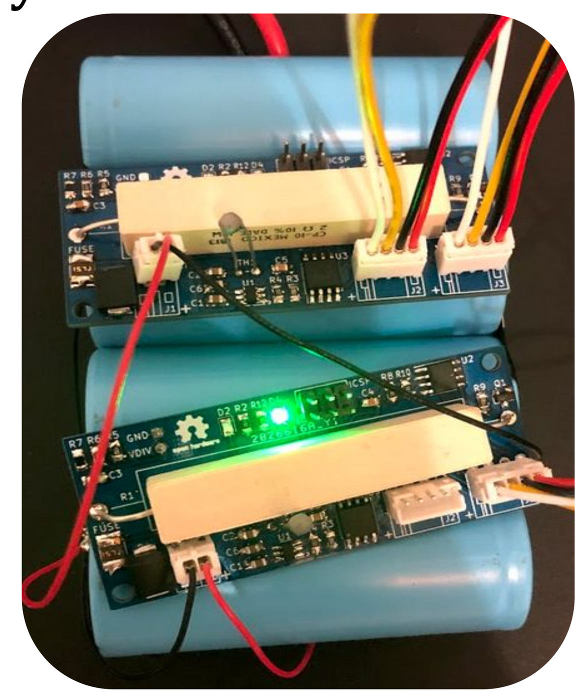
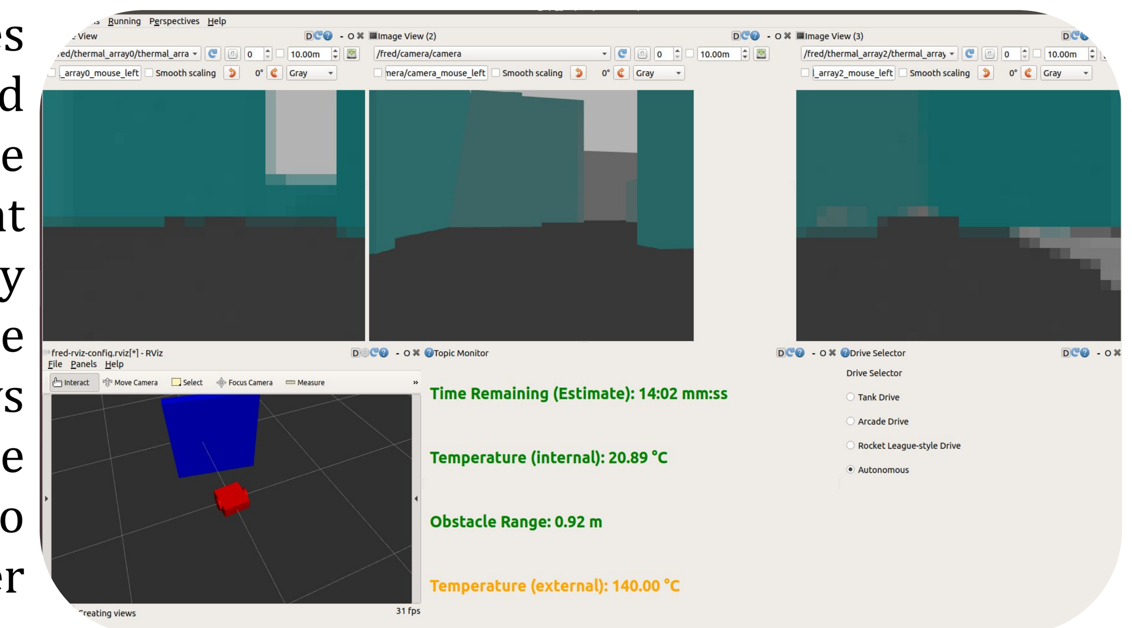


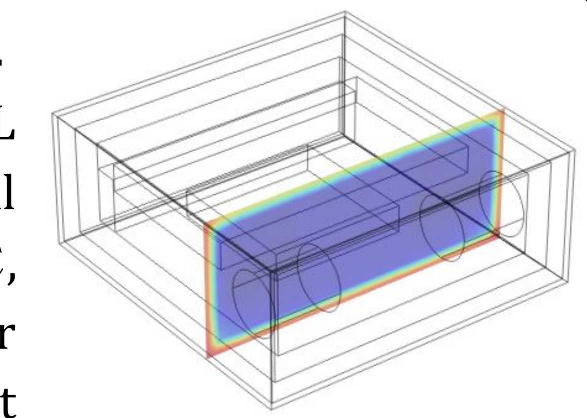
Graphical User Interface

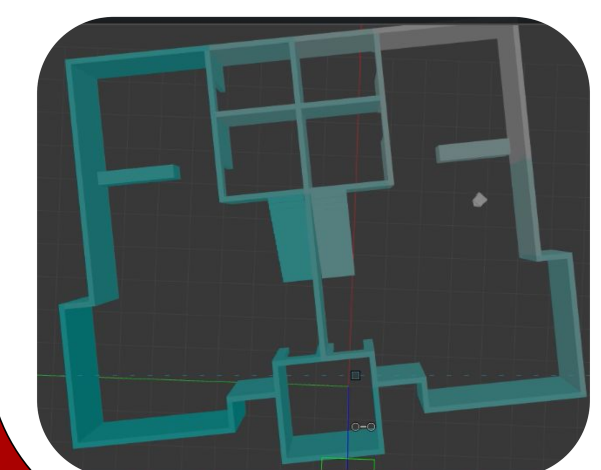
A unified GUI gives firefighters live visual and thermal video feeds from the robot and displays important sensor data color-coded by how dangerous it is to the robot. The GUI also displays an estimate of how long the robot can continue to operate and allows the user to change control schemes or enter autonomous mode.



Simulation & Testing.

For chassis testing, we modelled the robot in COMSOL and ran time-dependent studies at various external temperatures. At an external temperature of 160 ℃, the material layering successfully kept the interior under 60 ℃ for 15 minutes, passing the requirement metric in simulation.





As a system test, the robot navigated through a virtual “fireground”, created in Gazebo, for 15 minutes. The fire was modelled by the color on the walls, where the simulated temperature sensor would extract a color code to determine the temperature. The robotic model used included the following simulated components: camera, IR thermal arrays, radar, and battery.

Lessons Learned

TODO: Talk about the complexity in designing a robot suitible for said environment. Technical lessons learned. Maybe touch about the change to simulation focused work in D term due to COVID-19