

HUGIN

Lunar Rover Project

Sara Julia Bajardo – System Team Lead & Main Author
Erik Hauger – Project Manager & Power System & Communication
Rodrigo Conti Gallenti – Motion Control
Tommy Loke Eilertsen – Wheel & Leg Design
Andreas Jæger Lyngmo – Body Design
Peiyi Wu – Pathfinding & Imaging
POLARIX UiT – Student Space Organization

Development Period: 9 Weeks

Author Affiliations

All authors of this report are students at UiT The Arctic University of Norway.

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1 Project Overview

1.1 Background

The HUGIN project was undertaken by POLARIX UiT, a student space organization at the Arctic University of Norway. The project focused on the development of a lunar rover designed to compete in the iSpace class 1 in the LOOK Competition set by Kongsberg.

1.2 Technical Specifications

- **Mass:** 15 kg
- **Dimensions:** 60 cm × 20 cm × 20 cm
- **Primary Objective:** Mapping a simulated lunar environment
- **Development Timeline:** 9 weeks

1.3 Team Structure

The project was organized with clear leadership and subsystem teams:

- **Project Manager:** Overall coordination, timeline management, and stakeholder communication
- **System Team:** Integration oversight, requirements validation, and system-level testing
- **Subsystem Teams:** Seven specialized teams working in parallel

1.4 Project Team

The HUGIN project was carried out by a multidisciplinary team from POLARIX UiT, organized into a project management role, a system integration team, and seven specialized subsystem teams. Table 1 summarizes the team structure, including team leaders and members for each subsystem.

Table 1: HUGIN Project Team Structure by Subsystem

Subsystem	Team Leader	Team Members
Project Manager	Erik Hauger	—
System Team	Sara Julia Bajardo	Seweryn Filip Roznowski
Power System	Erik Hauger	Askar Storbakk, Erik Christoffer Kristiansen
Motion Control	Rodrigo Conti Gallenti	Lars Strand, Simon Tøllefsen
Wheel & Leg Design	Tommy Loke Eilertsen	Tim Leander Lillevold
Body Design	Andreas Jæger Lyngmo	—
Pathfinding	Camille Céline Manon Clement	Anna Lignarska, Peiyi Wu
Imaging	Peiyi Wu	Erik Hauger, Eirik Jenssen Reinåmo
Communication	Erik Hauger	—

1.5 Priority System

Each subsystem was assigned a priority number (1–4) based on criticality to mission success. Development efforts were allocated accordingly over the 9-week period.

2 Development Timeline – 9 Weeks

Table 2: 9-Week Development Schedule

Week	Key Activities
1	Project kickoff, design development, subsystem planning
2	Preliminary design reviews, component selection
3	Detailed design, CAD modeling, Design iteration
4	Prototyping begins (Priority 1 & 2 subsystems)
5	Hardware procurement, implementation of the final design
6	Integration of priority 1 subsystems
7	System integration, priority 3 & 4 development
8	Full system integration, testing, and debugging
9	Final testing, validation, and project delivery

3 System Overview

3.1 Methodology and Architecture Approach

The system architecture was analyzed and modeled using **Capella**, a Model-Based Systems Engineering (MBSE) tool. Since a high-level system concept was already established at the project's inception, the systems engineering process was initiated at the **Logical Architecture layer**, which allowed for a methodical breakdown of the rover's functional subsystems and their logical interactions.

From this foundation, the model was transitioned to the **Physical Architecture layer**, with a specific focus on detailing the implementation of key components—such as the computing hardware, motor drivers, and sensor suite—while maintaining traceability back to the logical functions.

3.2 High-Level System Context

The system models a lunar exploration rover designed for autonomous and remote operation.

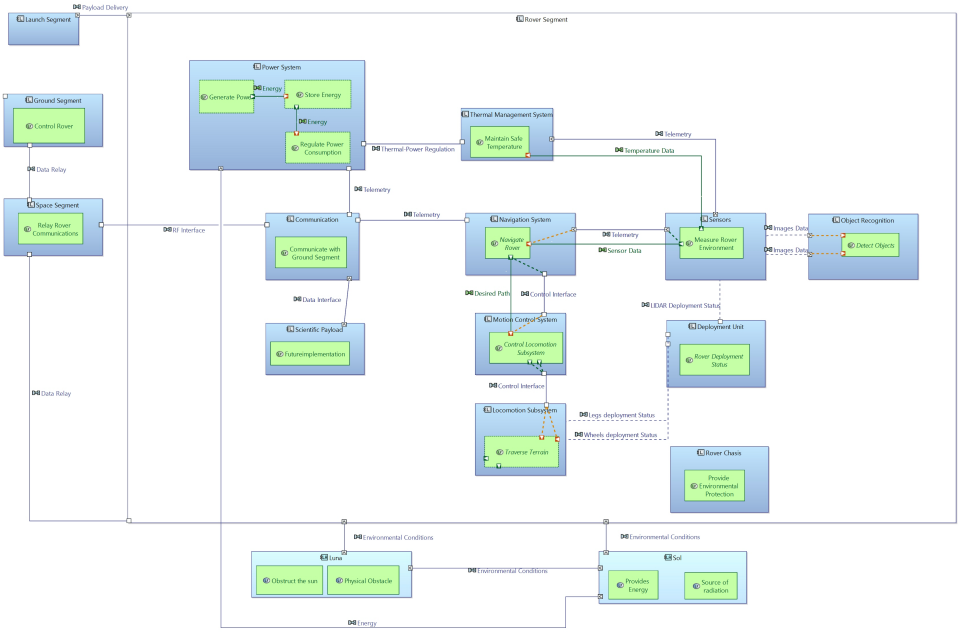


Figure 1: High-level Architecture system diagram showing external interfaces.

As illustrated in the rover segment diagram in Figure 1, the platform interacts with several external entities:

- **Ground Segment:** Via Space Segment relay for command and telemetry
- **Launch Segment:** For deployment and initial activation
- **Environment:** Luna (terrain, lighting, temperature) and Sol (solar energy)

The rover is built around a hybrid mobility concept, which uses both wheels and legs to traverse complex terrain. It relies on:

- A **Mobility Subsystem** (motors, drivers, and microcontroller)
- A **Locomotion Subsystem** for physical movement
- A **Power System** (solar generation, storage, and BMS)

3.3 Key Functional Subsystems (Logical Layer)

The logical architecture defines the following primary functionalities:

Table 3: Logical Architecture Functional Subsystems

Functional Subsystem	Responsibility
Navigation System	Determine rover position (via sensors), receive desired positions (telemetry), calculate Desired Path using pathfinding logic
Motion Control System	Translate desired path from Navigation into specific control inputs for wheel and leg actuators
Locomotion Subsystem	Execute physical traversal of terrain, receiving direct control commands
Sensors & Object Recognition	Collect environmental data (IMU, temperature, LIDAR, cameras); process images to detect obstacles; provide sensor data back to Navigation
Power System	Manage energy generation (solar), storage (batteries), distribution, and battery temperature control
Communication & Telemetry	Handle data relay between rover segments, ground control, and internal subsystems
Deployment Unit	Manage physical deployment of legs and LIDAR mechanisms

3.4 Logical Architecture Diagrams

The following figures detail the logical architecture of each functional subsystem. Each diagram is presented on its own page to ensure readability.

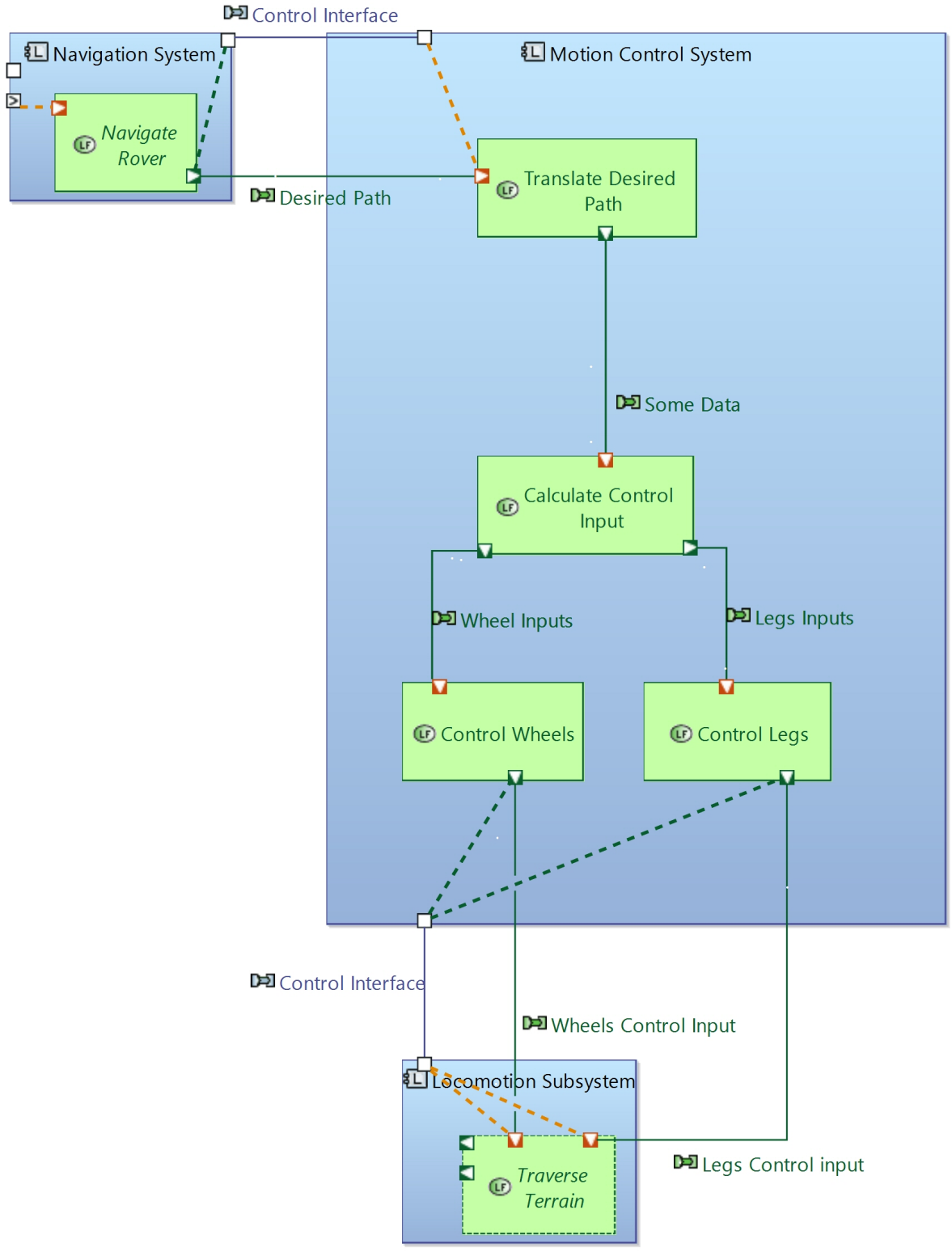


Figure 2: Motion Control System logical architecture.

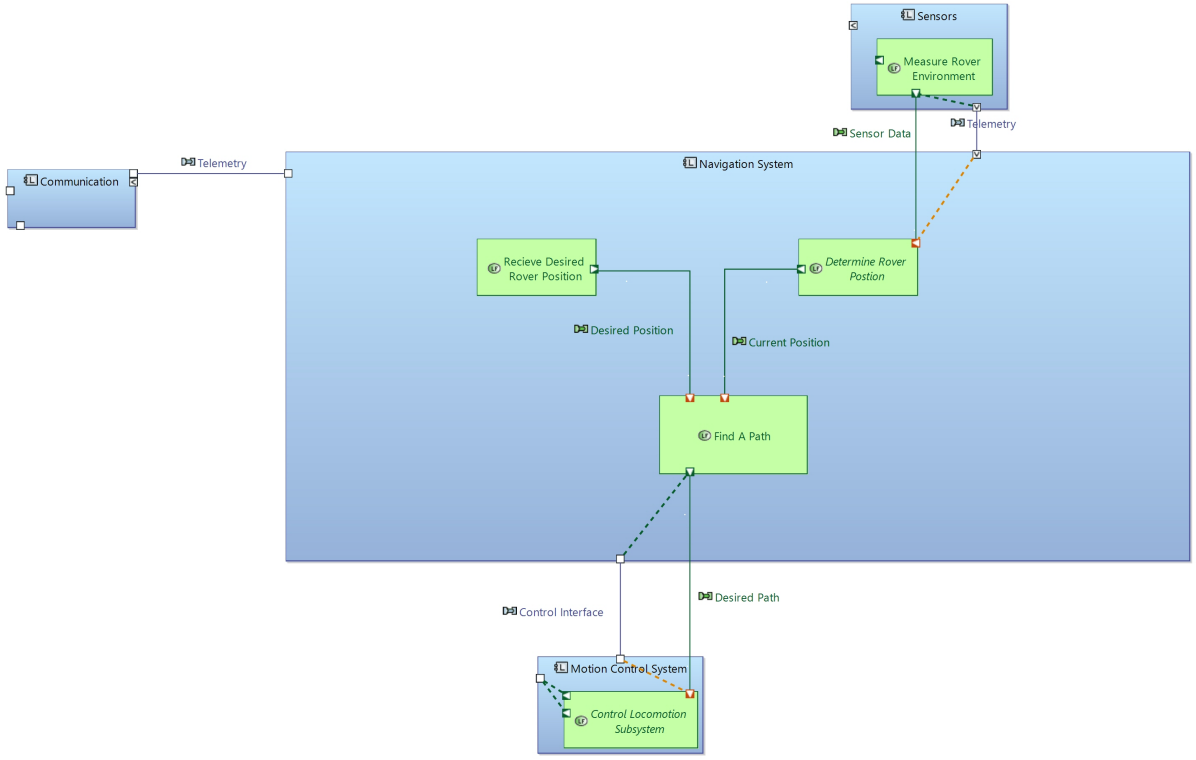


Figure 3: Navigation System logical architecture.

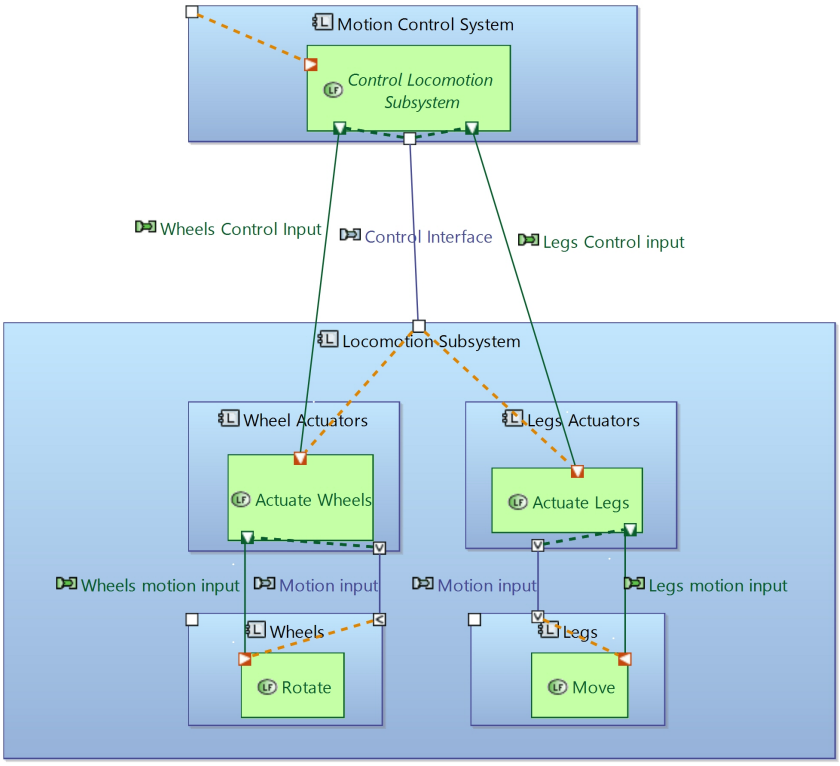


Figure 4: Locomotion Subsystem logical architecture.

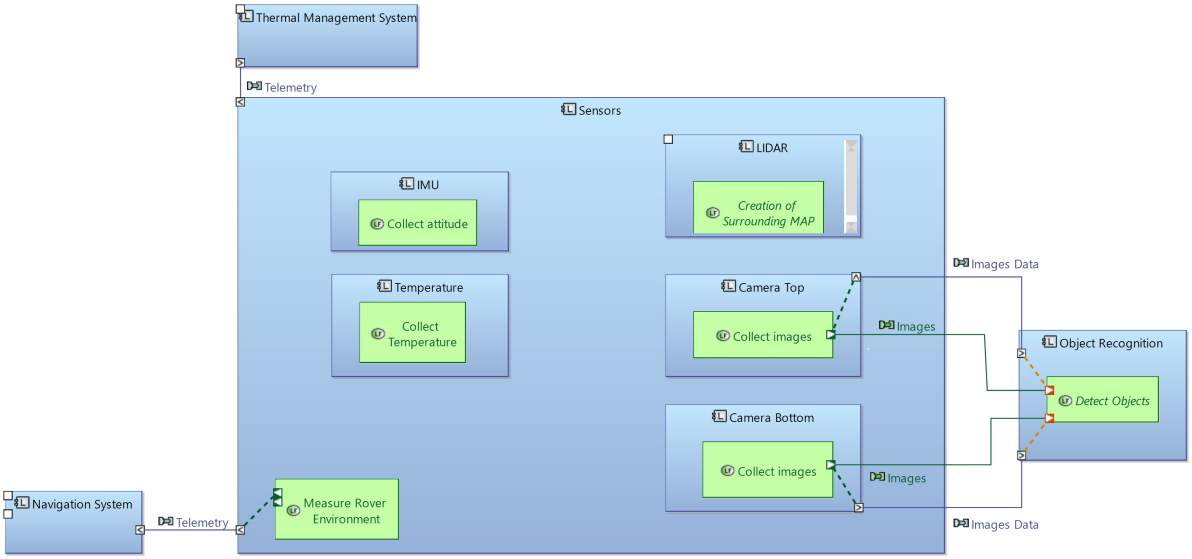


Figure 5: Sensors logical architecture.

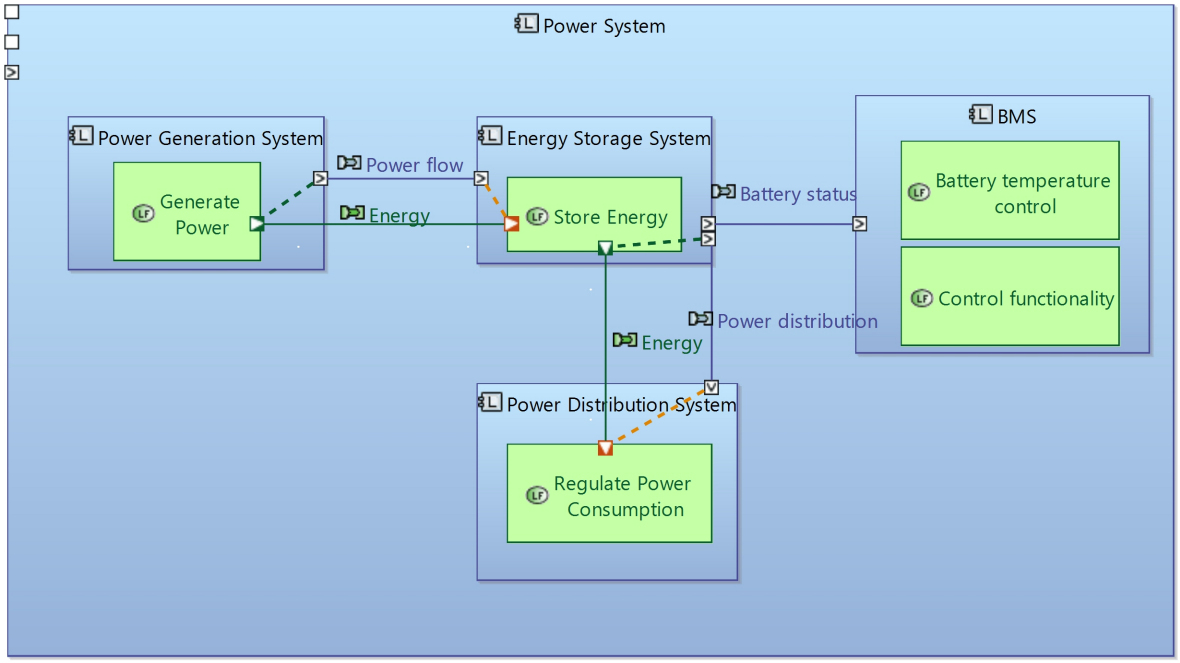


Figure 6: Power System logical architecture.

3.5 Physical Implementation (Physical Layer)

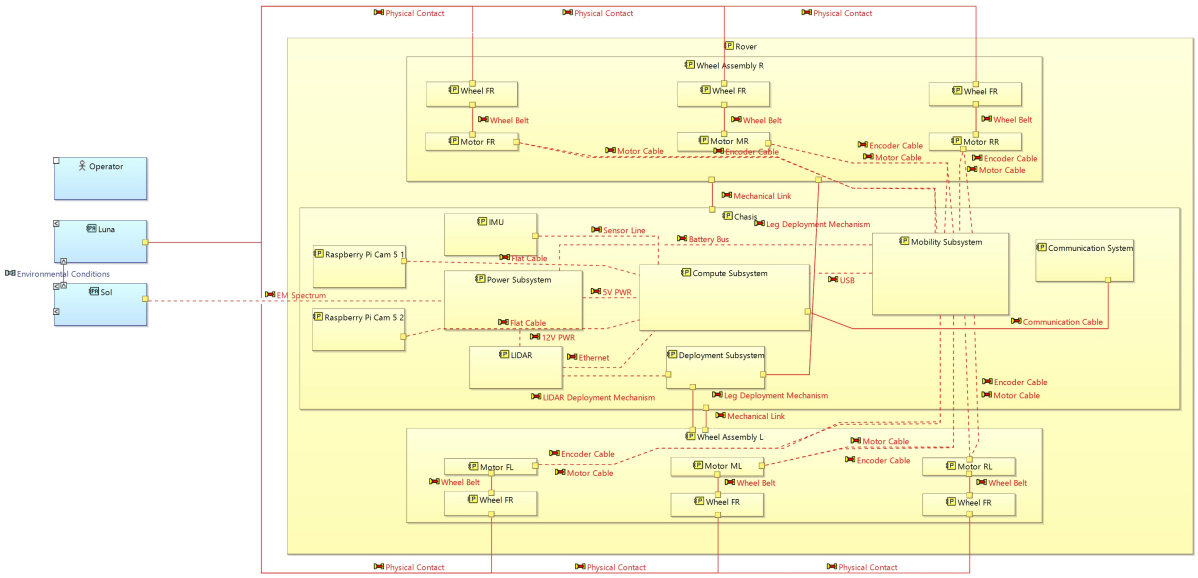


Figure 7: Physical system diagram.

The physical architecture details the specific hardware realization of the logical functions:

Compute and Control

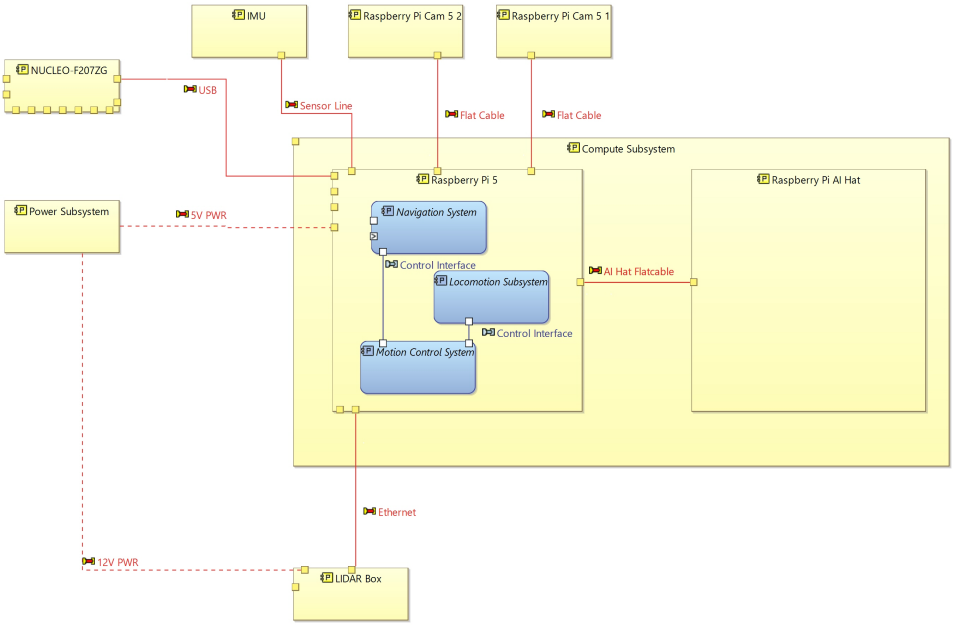


Figure 8: Physical architecture diagram showing the Raspberry Pi 5, NUCLEO-F207ZG microcontroller, and motor drivers.

- **High-Level Processing:** Raspberry Pi 5 hosts high-level logic including navigation and object recognition
- **Low-Level Control:** NUCLEO-F207ZG microcontroller interfaces with motor drivers for real-time motion control

Mobility Hardware

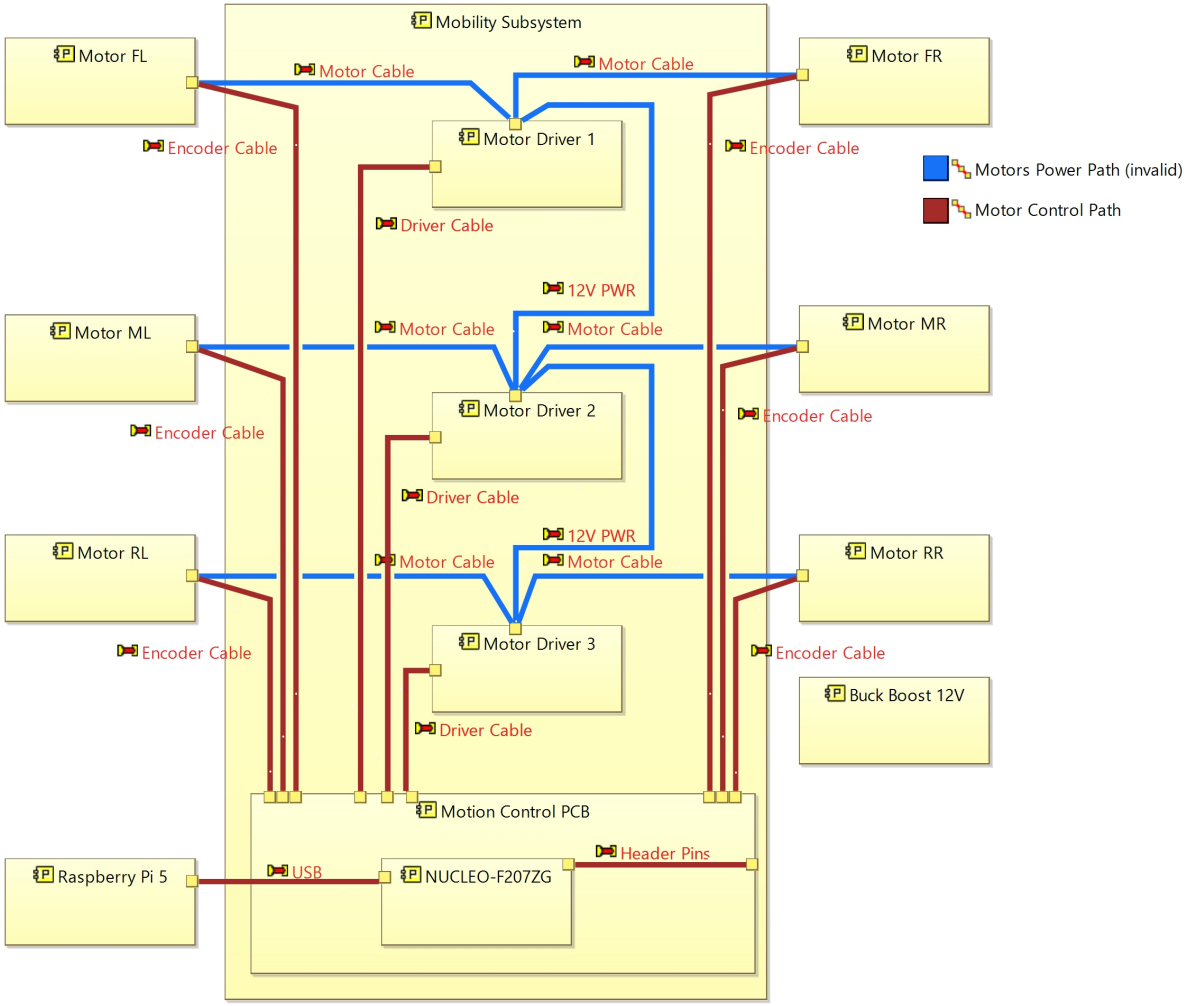


Figure 9: Physical architecture diagram showing the Motor Drivers, Motors, and Interfaces.

- **Motor Drivers:** 3x Cytron Technologies MDD10A drivers
- **Motors:** Six motors (Front Left/Right, Middle Left/Right, Rear Left/Right)
- **Interfaces:**
  - 6-wire control interface
  - 6-wire power interface
  - Voltage margins: 3.0V–5.5V (control), 12V–30V (power)

Sensor Suite

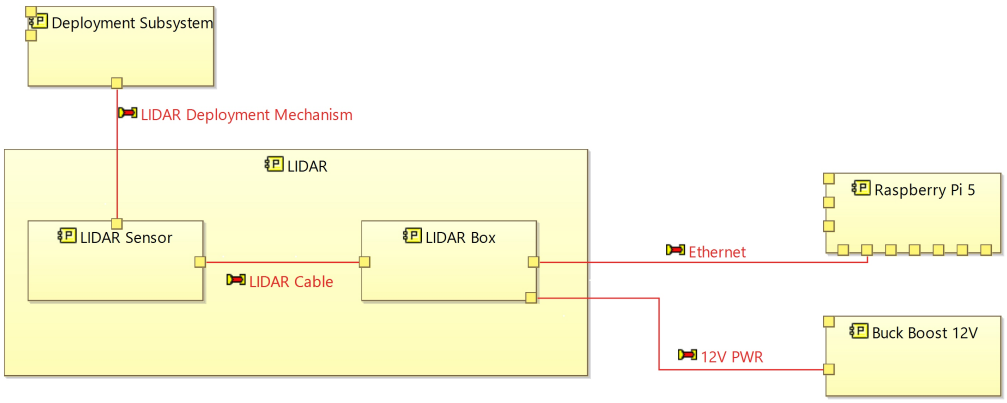


Figure 10: Physical architecture diagram showing the LIDAR and its connections.

- 2x Raspberry Pi cameras (top and bottom)
- LIDAR sensor (via Ethernet)
- IMU (via sensor line)

Mechanical Integration

The physical architecture highlights the integration of:

- Wheels and motor belts
- Motor cables
- Mechanical links and deployment mechanisms
- Chassis mounting for all components

Power Subsystem

The Power Subsystem acts as the central energy hub of the rover architecture, organized into four primary stages: energy acquisition, power conditioning, power management and distribution, and energy storage.

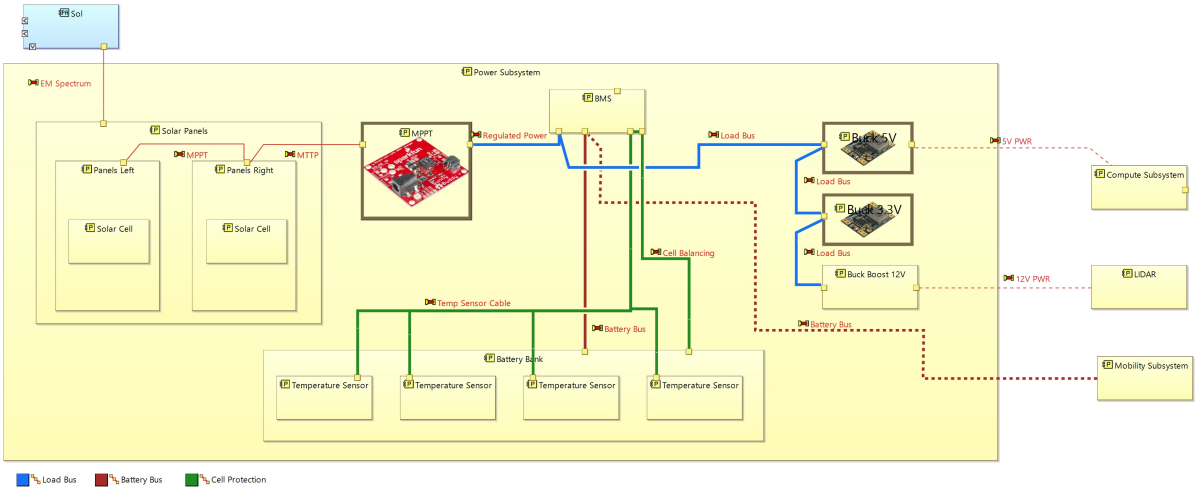


Figure 11: Physical architecture diagram showing the Power generation, storage and distribution.

- **Energy Acquisition:** Solar array with two wings (Left and Right) routing raw power via MPPT interface
- **Power Conditioning:** MPPT board optimizes energy harvesting and outputs regulated power
- **Power Management & Distribution:** BMS handles routing and protection via two primary buses:
  - **Load Bus (Blue):** Routes power to DC-DC converters (5V, 3.2V, 12V)
  - **Battery Bus (Red):** Interfaces with energy storage for charging/discharging
- **Energy Storage & Protection:** Battery bank with 4 temperature sensors and Cell Protection bus (Green) for balancing and thermal cutoff

Table 4: Power subsystem bus color coding

Color	Function
Blue	Load Bus: Power distribution to subsystems
Red	Battery Bus: Storage interface
Green	Cell Protection: Temperature monitoring and balancing

3.6 System Flows and Interactions

The architecture is driven by three primary flows:

Table 5: System Interaction Flows

Flow Type	Description
Data Flow	Telemetry to Ground; IMU Sensor Data to Navigation; Camera Images to Object Recognition; Desired Path to Motion Control
Energy Flow	Solar energy generation → Battery storage → Power distribution to subsystems
Control Flow	High-level compute (Raspberry Pi) generates control signals → Low-level MCU (NUCLEO) translates them → Motor Drivers send power to actuators

3.7 Architecture Summary

The HUGIN rover architecture follows a clear separation of concerns:

- **Logical Layer:** Defines *what* the system must do (functions, behaviors, interactions)
- **Physical Layer:** Defines *how* the system does it (hardware components, interfaces, implementation)
- **Traceability:** Every physical component maps back to one or more logical functions

This MBSE approach ensured that the 9-week development timeline remained focused on delivering a coherent, well-integrated system.

4 Subsystem Breakdown

The table below summarizes all subsystems with their team sizes, priority rankings, and development focus.

Table 6: Subsystem Overview with Priorities

Subsystem	Team	Priority Level	Description
Power System	3	**Priority 1 (Highest)**	Battery management, power distribution, motor selection
Motion Control	3	**Priority 2**	Motor drivers, speed control, steering algorithms
Wheel & Leg Design	2	**Priority 2**	Mechanical locomotion, suspension, terrain adaptation
Body Design	1	**Priority 3**	Chassis structure, thermal management, component housing
Pathfinding	2	**Priority 3**	Navigation algorithms, obstacle avoidance, route planning
Imaging	3	**Priority 4**	Object detection, camera systems, image processing
Communication	2	**Priority 4**	Telemetry, command uplink/downlink, data transmission

5 Subsystem Details

5.1 Power System (Priority 1)

Team Size: 3 members

Power Supply

The power supply was constructed as indicated in Figure 12. The Battery Management System (BMS) was supplied by the MPPT with connected solar panels, a 12.6V battery pack and a 12.6V load bus. The load bus consisted of one 3.3V buck converter, providing power to the rover's floodlights, two 5V buck converters supplying power to the two Raspberry Pi 5 units, a 12V buck/boost converter supplying power to the LIDAR system and a motor controller supplied from the 12.6V load bus.

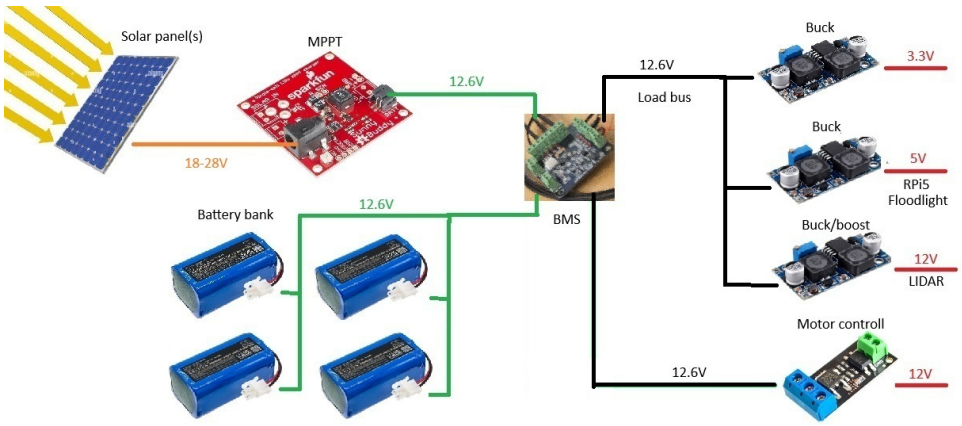


Figure 12: Power distribution sketch

During initial testing of the buck converters, the converters were able to supply approximately 500mA constantly before starting to experience thermal overheating and power throttling. As the Raspberry Pi 5 can draw up to 5A at maximum, this was deemed insufficient, and when the converters were connected to a dummy load of 4A for testing, the converter went into thermal throttling within approximately 10 seconds. It was decided to add two heat sinks to the converters to combat the overheating issue, one slightly smaller directly attached to the MOSFET and one slightly larger on the backside of the PCB parallel with where the MOSFET was located. Testing with the new setup proved that the converter was now able to supply 4A for several minutes without experiencing thermal throttling, although at 5A

load the system still experienced thermal throttling after roughly 1 minute. This was deemed acceptable as the RP5 load was measured to peak at around 3.5A during operations and was therefore expected to remain below the thermal throttling threshold during nominal operations. The converter hardware is shown in Figure 13.

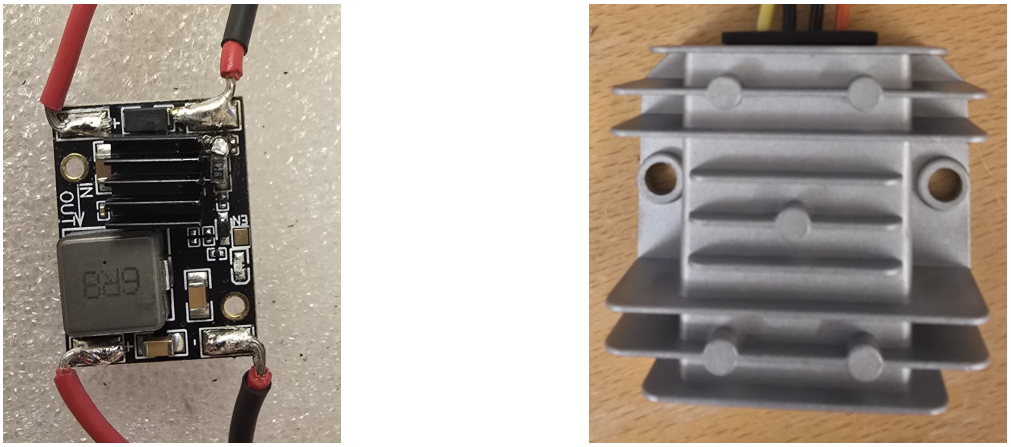


Figure 13: 3.3V buck converter for the Raspberry Pi 5 units & LED floodlights and 12V buck-boost converter for the LIDAR

Power Generation

The solar panels selected for the rover were the Adafruit P124 ($113.00 \times 66.00 \times 2.90\,\text{mm}$) solar panels. The panels were chosen for their high efficiency ($> 22\%$), minimal framing and suitable voltage levels. Each side of the rover was planned with 4 series-connected panels, parallel connected to one common Maximum Power Point Tracker (MPPT). Each panel produces approximately 1.2 watts at maximum output. The rover equipped with all 8 panels therefore has a maximum peak power production of 9.6 watts.

The SunBuddy MPPT was selected due to its reasonable pricing and suitable voltage range. While the supplier recommends a maximum voltage of 20 volt, component documentation indicates that the recommended upper limit is up to 32V, with 40V absolute maximum. This made the SunBuddy an excellent choice as four series solar panels produced an open-circuit voltage of maximum 28.4 volt, and voltage at max power point of approximately 24 volts, well within tolerance. The SunBuddy is delivered with 450mA charge setting and an output voltage of 4.2 volts for a single cell; the board was modified to allow up to 850mA charge current with output configured to 12.6 volts to match the battery bus.

During testing, 4 series-connected panels provided approximately 23.2 volt and 120mA output from the solar panels to the MPPT, with 12.6 volts on the MPPT output during partially clouded conditions, verifying power generation. The hardware setup is shown in Figure 14.

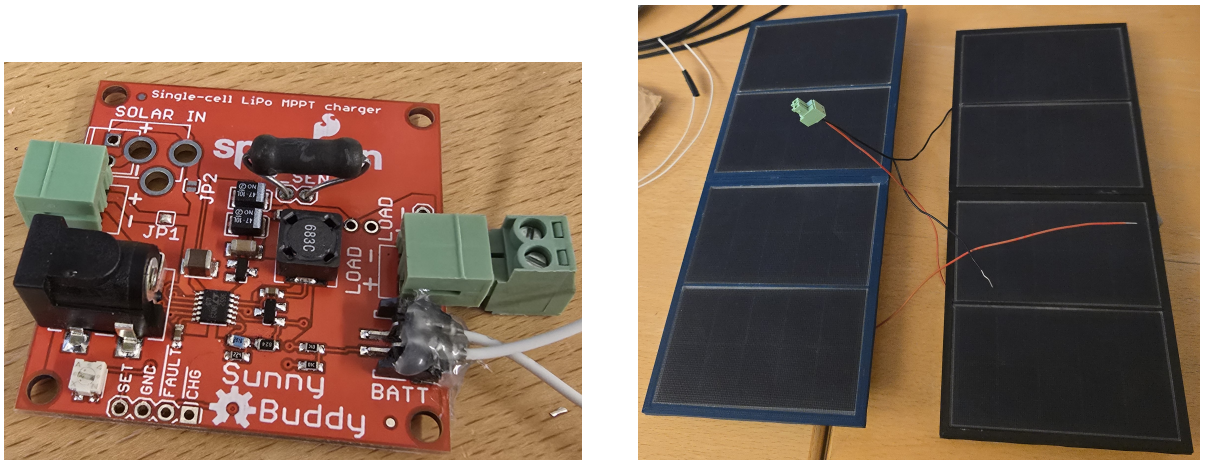


Figure 14: SunBuddy Maximum Power Point Tracker (MPPT) and P124 Solar panels during testing

Battery Management System (BMS)

Currently the BQ41Z50RSNR is used as the main BMS for the Hugin project, with BQ296907DSGR serving as a secondary-level protector. The BQ41Z50RSNR supports 2 to 4 cells in series and multiple battery chemistries. It has integrated primary and secondary protection features and provides protection against overvoltage, undervoltage, overcurrent during charge and discharge, short circuit, overtemperature, and charge timeout. It uses two FET drivers to independently control the charge and discharge paths, allowing charging to be blocked while still permitting the battery to discharge. In addition to the FET drivers, a chemical fuse is included to provide emergency cutoff of the power path in the event that one of the FET drivers malfunctions. Communication with the BMS is performed using the SMBus protocol, which is used to read status information and configure protection thresholds, cell chemistry, capacity, temperature limits, and charge/discharge settings.

The PCB uses a two-layer design with a minimum clearance of 0.5mm between power traces. Power ground and logic ground are connected through a net tie. High-current paths were designed for a continuous current of 10 A. The finished BMS PCB is shown in Figure 15.

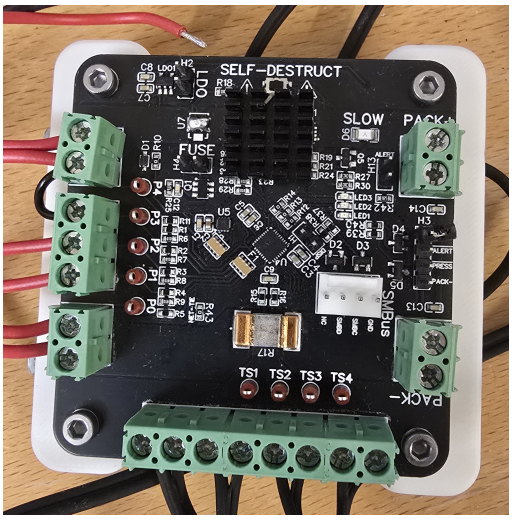


Figure 15: The finished PCB (BMS) and the 18650 batteries used in the battery pack

The battery pack used consists of 12 Li-ion cells configured as three cells in series and four in parallel (3S4P). Four thermistors monitor the battery pack temperature. A 15A slow-blow fuse is installed at the pack output as a final level of protection. The 18650 cells are shown in Figure 16.

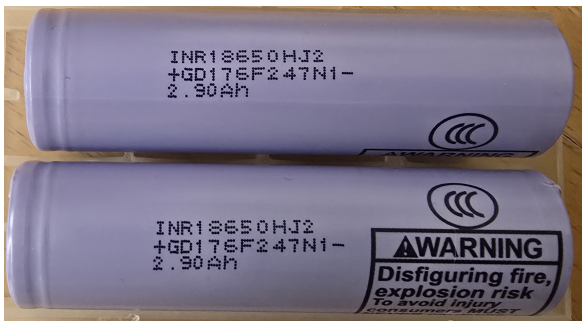
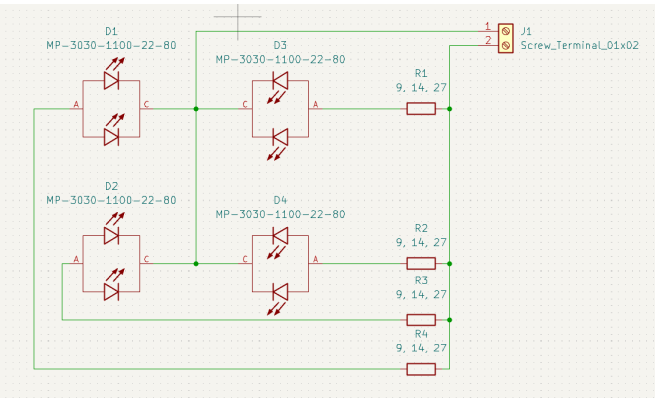


Figure 16: 18650 batteries used in the battery pack

LED Lights

The JK3030 1W 3.15V 164lm LED chip was chosen for nighttime illumination. The PCB was designed with large copper areas to provide heat dissipation. The LED lights were connected to the 3.3V buck converter with the enable pin (EN) tied to the microcontroller. The KiCad schematic and finished floodlights are shown in Figure 17.



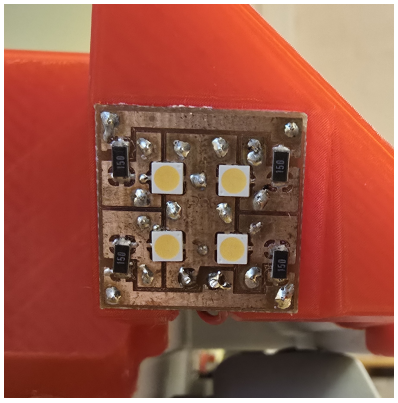


Figure 17: Simple diagram in KiCad and the finished LED floodlights

5.2 Motion Control (Priority 2)

Team Size: 3 members

The Motion Control subsystem converts high-level velocity commands into stable motion through kinematic modeling, slip-aware odometry, and real-time distributed motor control.

Rover Geometry and Kinematic Model

HUGIN is a six-wheel skid-steer rover. All wheels are fixed in orientation and driven independently. Let r denote wheel radius and b the half-track width. Body twist (V_x, ω) maps to wheel angular velocities via:

$$\omega_L = \frac{V_x - b\omega}{r}, \qquad \omega_R = \frac{V_x + b\omega}{r}. \tag{1}$$

These angular velocities are applied uniformly to the three wheels on each respective side.

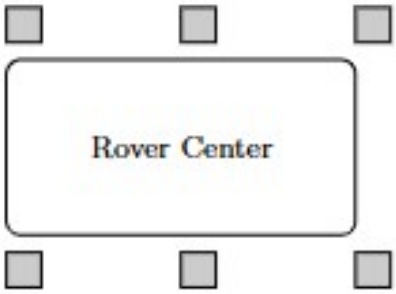


Figure 18: Top-down schematic of the six-wheel skid-steer geometry.

Pose Integration and Odometry

Given left and right linear wheel velocities $v_L = \omega_L r$ and $v_R = \omega_R r$:

$$v = \frac{v_L + v_R}{2}, \qquad \omega_{\text{enc}} = \frac{v_R - v_L}{2b}. \tag{2}$$

The rover pose evolves according to:

$$\theta_{k+1} = \theta_k + \omega\,\Delta t, \tag{3}$$

$$x_{k+1} = x_k + v\cos\theta_k\,\Delta t, \tag{4}$$

$$y_{k+1} = y_k + v\sin\theta_k\,\Delta t. \tag{5}$$

Slip is quantified as $s = |\omega_{\text{enc}} - \omega_{\text{imu}}|$, and the fused yaw rate is:

$$\omega = \begin{cases} 0.7\,\omega_{\text{enc}} + 0.3\,\omega_{\text{imu}}, & s < s_{\text{th}}, \\ \omega_{\text{imu}}, & s \geq s_{\text{th}}, \end{cases} \tag{6}$$

where s_{th} is the slip threshold.

Dynamics and Traction Constraints

The total tractive force required to climb an incline is:

$$F_{\text{total}} = mg \sin \alpha + c_r mg \cos \alpha, \tag{7}$$

where α is the slope angle and c_r the rolling resistance coefficient. The corresponding per-wheel torque demand is:

$$T_{\text{wheel}} = \frac{F_{\text{total}}\, r}{N_{\text{wheels}}}. \tag{8}$$

The traction limit requires:

$$T_{\text{required}} \leq \mu N r, \tag{9}$$

where μ is friction coefficient and N normal force per wheel.

Motor Control Architecture

Each wheel's PID controller regulates angular velocity:

$$u(t) = K_p e(t) + K_i \int e(t)\, dt + K_d \frac{de}{dt}, \tag{10}$$

where $e(t)$ is the difference between commanded and measured speed.

5.3 Wheel & Leg Design (Priority 2)

Team Size: 2 members

Design Basis and Suspension Architecture

The rover uses a fully driven six-wheel layout adapted from rocker–bogie planetary suspensions. The LOOK Class 1 rules limited the rover to a mass of 15 kg and a packed volume of $500 \times 200 \times 200$ mm [1][cite: 1, 3]. The wheel diameter was 90 mm[cite: 1, 3].

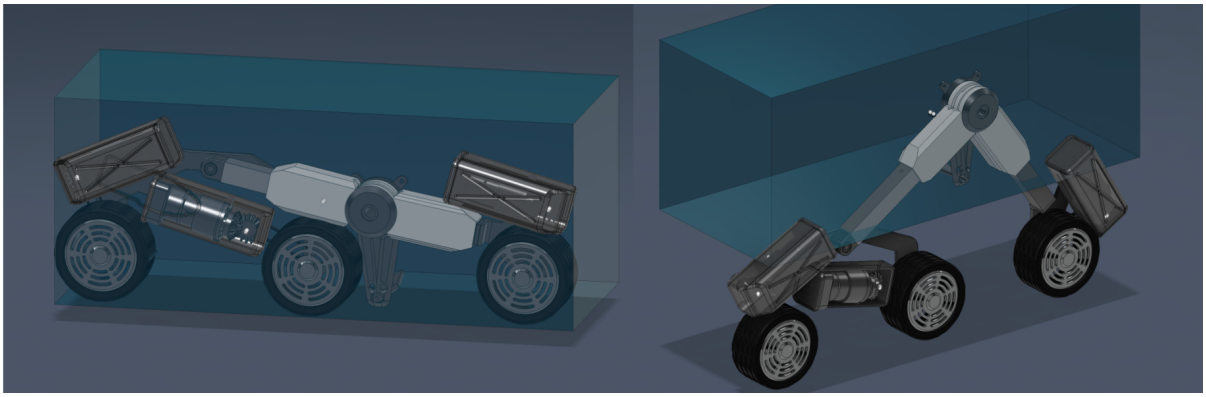


Figure 19: Critical-design-review renders of the suspension in stowed and deployed states.

The principal link lengths for the rocker–bogie geometry are:

$$l_1 = \sqrt{d_{fm}^2 + h_r^2}, \qquad l_2 = \sqrt{d_{bm}^2 + (h_r - h_b)^2}, \tag{11}$$

$$l_3 = \sqrt{d_{bm}^2 + h_b^2}, \qquad l_4 = \sqrt{d_{br}^2 + h_b^2}. \tag{12}$$

Packaging and Leg Deployment

Each leg telescopes along a 20×20 mm aluminium square tube and pivots 90° into deployed position via internal nylon monofilament driven by a central motor and worm gear.

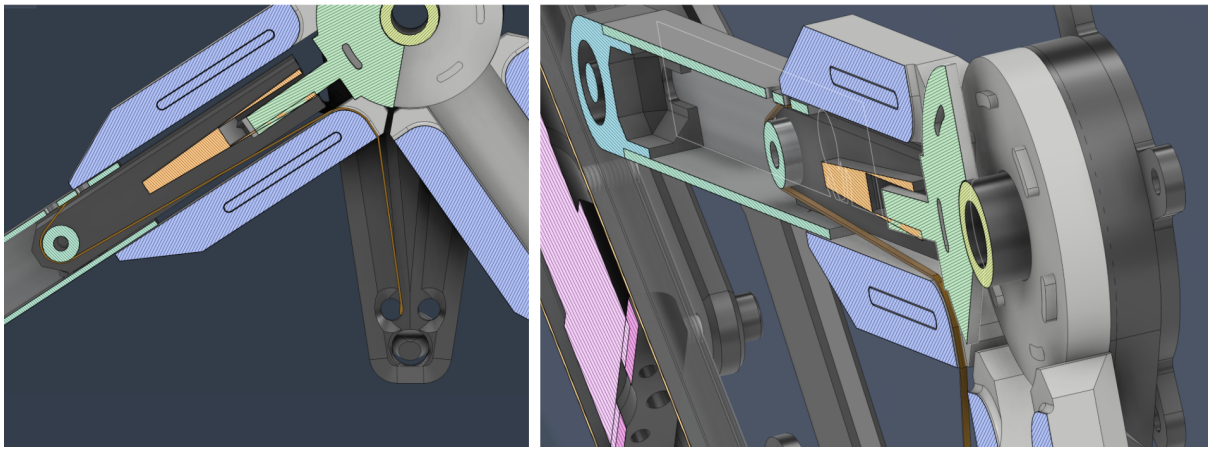


Figure 20: Sectioned CDR views showing internal telescoping members and deployment mechanism.

Wheel Drive and Construction

Longitudinal motors transmit torque to each wheel through bevel gears and timing belts.

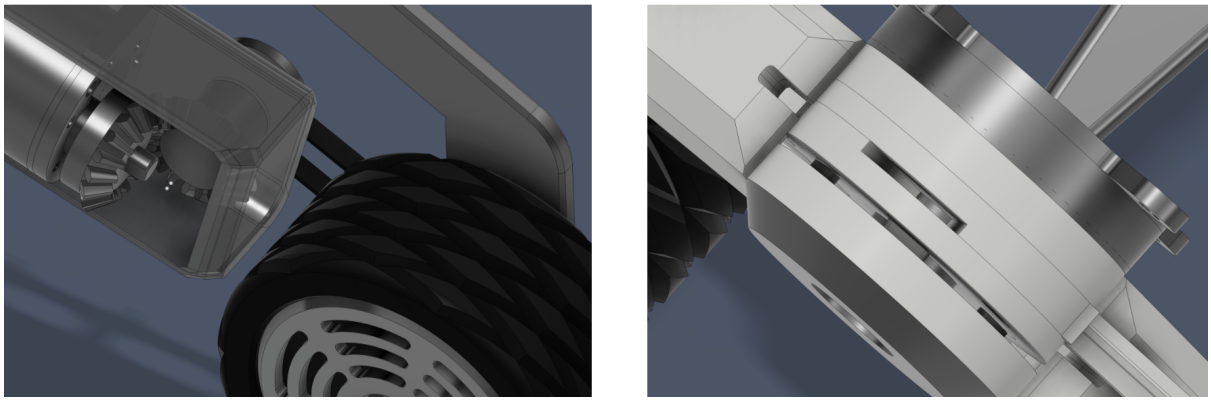


Figure 21: CDR details of the bevel-gear and timing-belt wheel drive (left) and cam restraint (right).

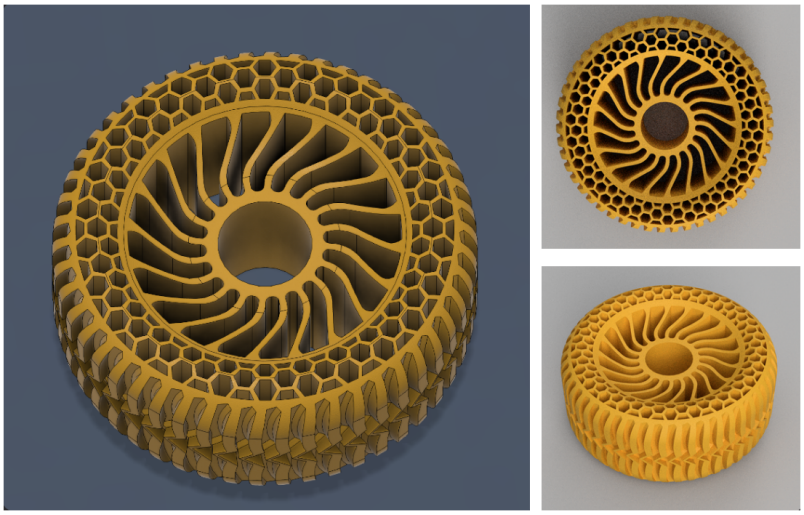


Figure 22: Final 90 mm TPU tyre design with compliant lattice and directional tread.

Table 7: Reference properties of materials used in the wheel and leg assembly

Material	**Primary Use**	**Density (g/cm^3)**	E_{XY} **(MPa)**	$\sigma_{t,XY}$ **(MPa)**	**Relevant Indicator**
Aluminium alloy	Square tubes, brackets	≈ 2.70	$\approx 69{,}000$	Grade-dep.	Alloy/temper not recorded
PAHT-CF	Gears, pulleys, bushings	1.06	3860 ± 230	92 ± 7	HDT 194 °C
PETG Basic	Housings and interfaces	1.25	1460 ± 190	32 ± 4	HDT 69 °C
PLA Tough	Covers, non-structural parts	1.26	2330 ± 240	44 ± 2	HDT 55 °C
TPU 95A HF*	Compliant tyres	1.22	9.8 ± 0.7	27.3 ± 0.8	Elongation $> 650\%$

5.4 Body Design (Priority 3)

Team Size: 1 member

The rover chassis features a T-shape with sloped wings for the solar panels, leaving space for internal electronics and wheel mount cutouts.

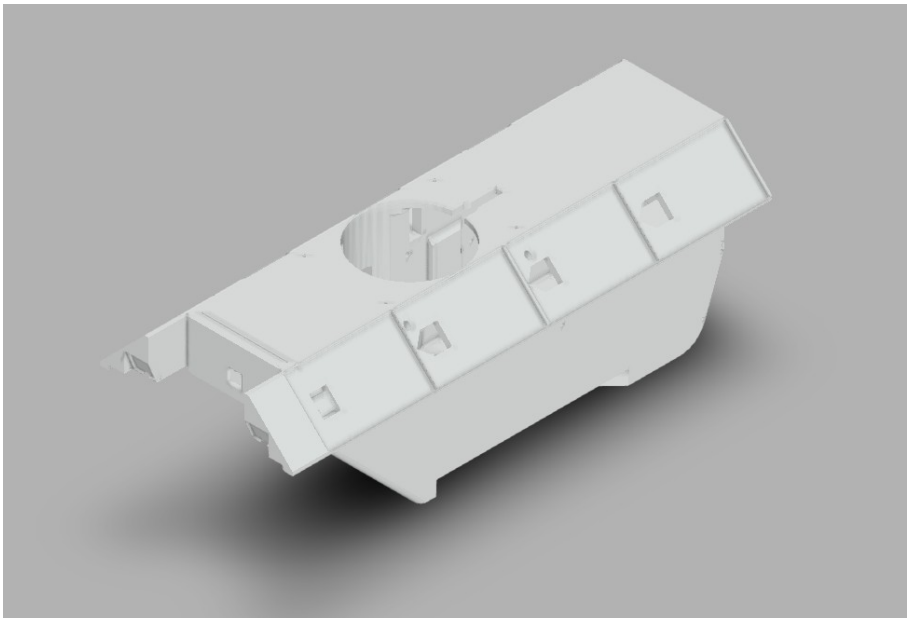


Figure 23: Chassis Exterior Design.

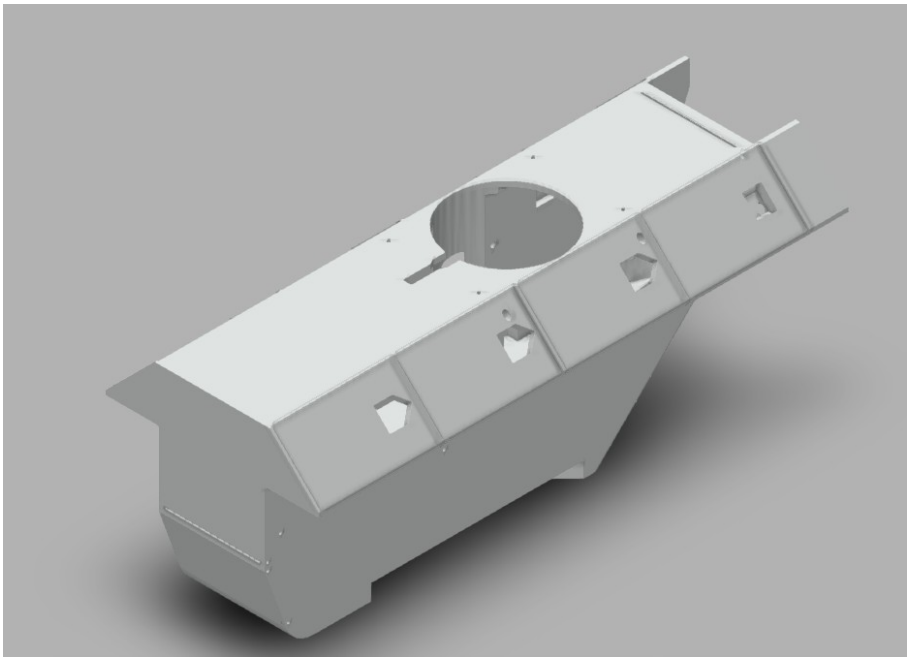


Figure 24: Chassis Exterior Design: detailed external holes from top view.

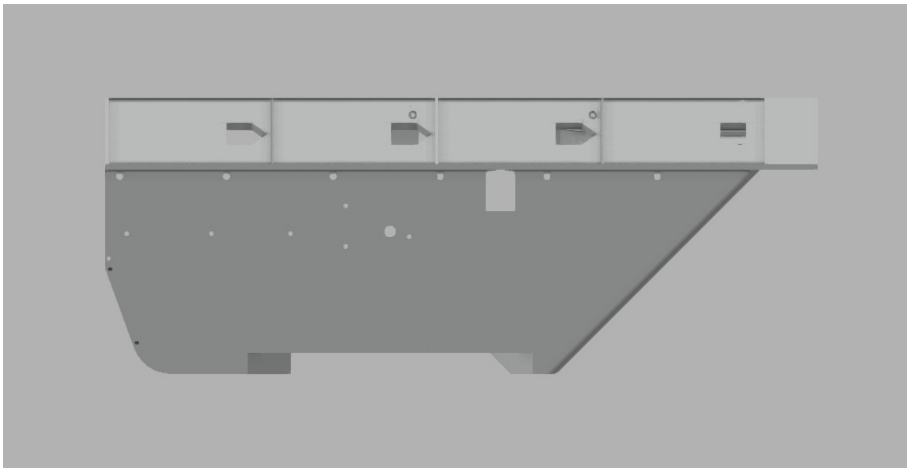


Figure 25: Chassis Exterior Design: detailed external holes from side view.

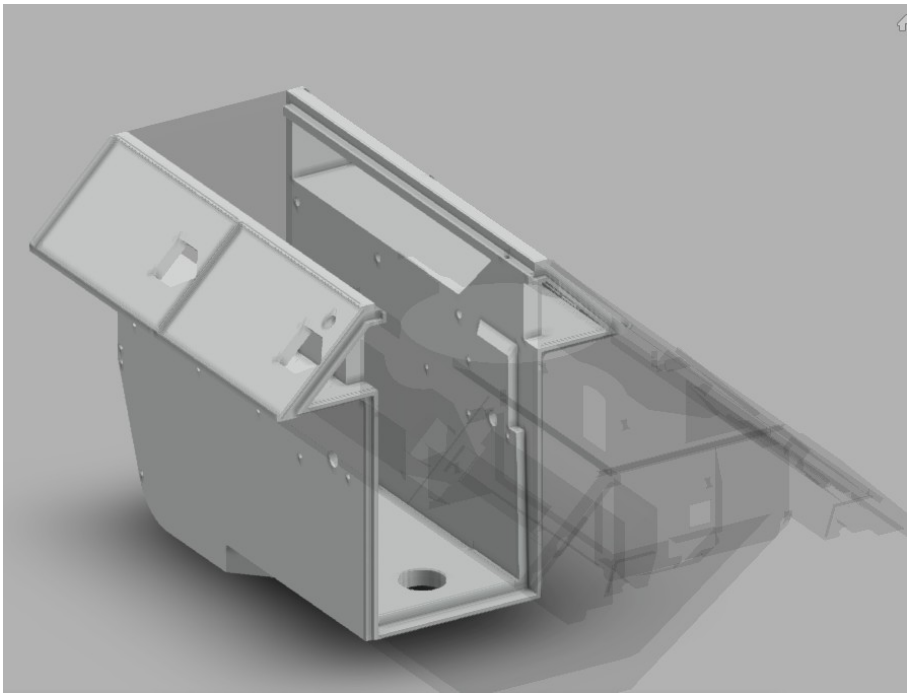


Figure 26: Chassis Interior Design showing internal bay.

5.5 Pathfinding (Priority 3)

Team Size: 2 members

A Velodyne VLP-16 LiDAR was connected to the Raspberry Pi 5 through an Ethernet cable with an IMU communicating orientation data.

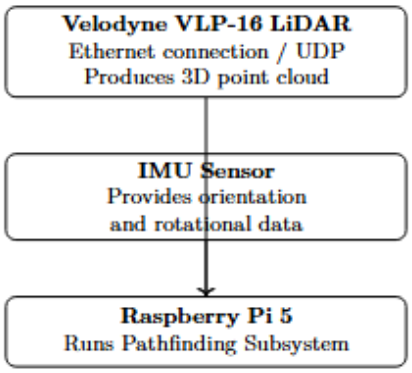


Figure 27: Hardware architecture of the pathfinding subsystem.

The pathfinding system processes sensor inputs via SLAM Toolbox to produce occupancy maps for Nav2 path planning.

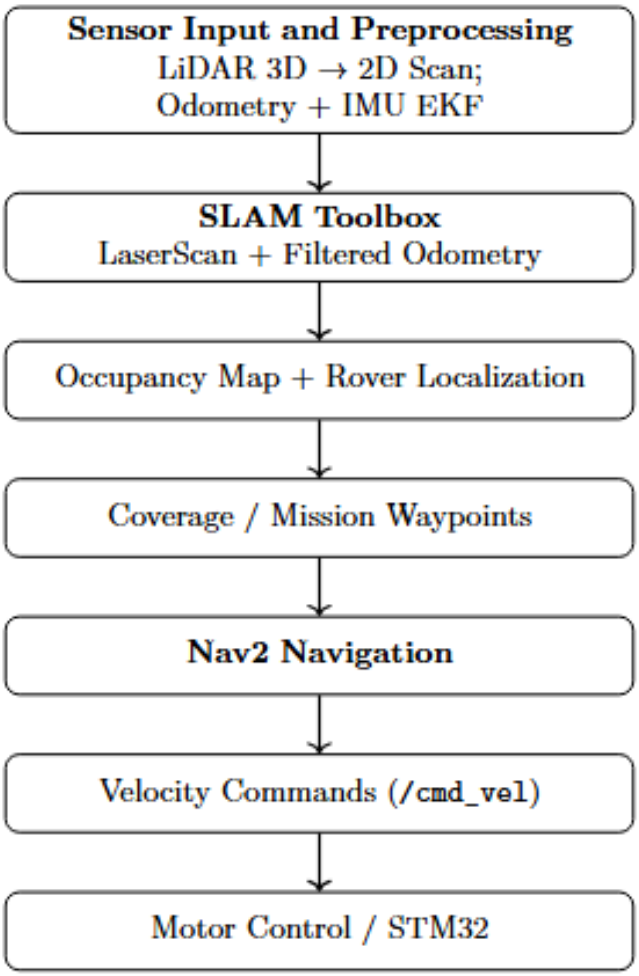


Figure 28: Software pipeline of the pathfinding system.

5.6 Imaging: Object Detection (Priority 4)

Team Size: 3 members

The imaging system detects partially buried target objects in simulated lunar regolith using YOLO11n object detection alongside an EfficientNet-B0 classifier.

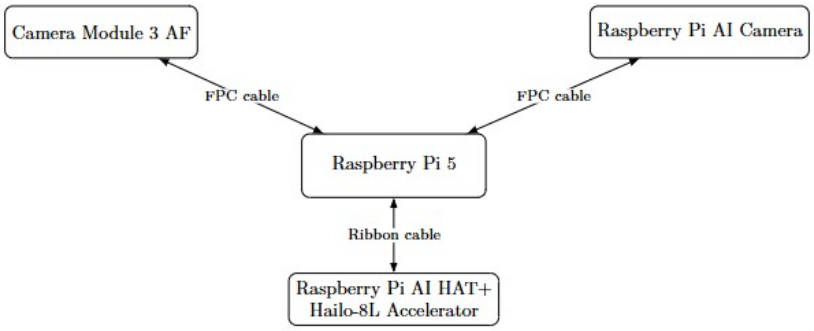


Figure 29: Hardware setup of the imaging system.

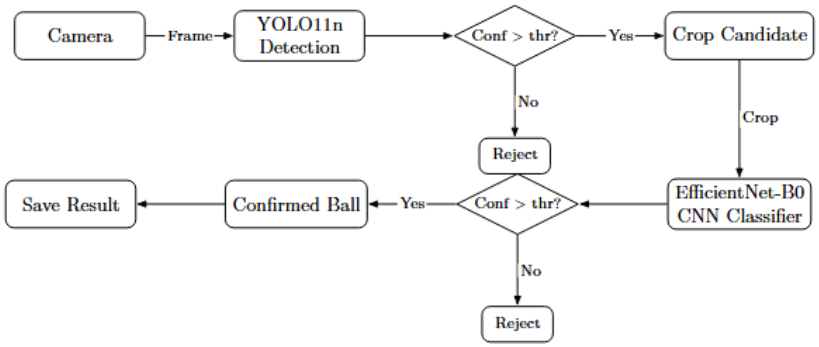


Figure 30: Software pipeline for ball detection and classification.



Figure 31: Environment for taking training photos and unit tests.

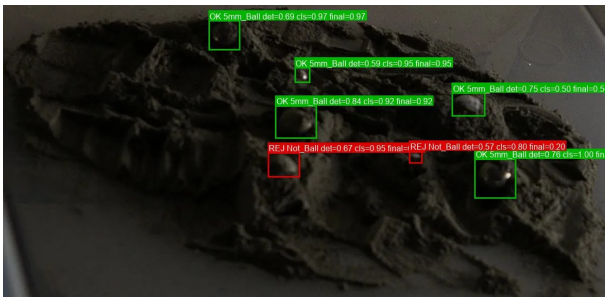


Figure 32: Example of CNN classification result.

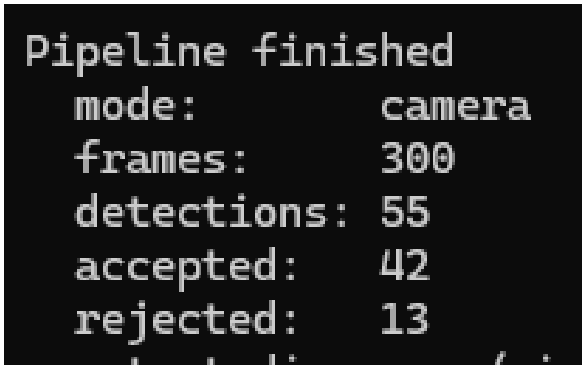


Figure 33: Final Unit Test Result with Floodlight.

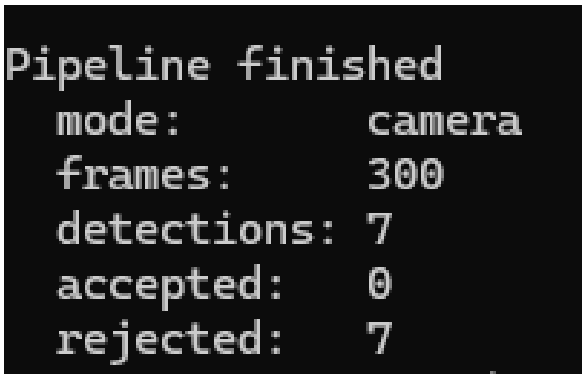


Figure 34: Final Unit Test Result without Floodlight.

5.7 Communication (Priority 4)

Team Size: 1 member

A UDP server was set up on the operator laptop communicating over Wi-Fi with the imaging Raspberry Pi 5. Whenever target objects were identified and logged, a script periodically transferred confirmed frames and metadata over SSH at 30-second intervals.

6 Integration and Testing

6.1 Integration Approach

1. **Week 6–7:** Priority 1 and 2 subsystems integrated first
2. **Week 7–8:** Priority 3 subsystems added
3. **Week 8:** Priority 4 subsystems integrated
4. **Week 9:** Full system testing and validation

6.2 Testing Phases

- **Unit Testing:** Each subsystem was independently validated.
- **Integration Testing:** The interfaces of the subsystems were verified within the limits of preliminary data.
- **System Testing:** Full rover functionality was tested in the days immediately preceding the competition.

7 Challenges and Lessons Learned

- **Time Management:** A 9-week timeline required strict prioritization to achieve core rover operation.
- **Power Management:** Buck converters were adjusted from 5.0V to 5.1V to prevent under-voltage dropouts on the Raspberry Pi 5 during transient current surges.
- **CAD & Mechanical Integration:** Future iterations require unified top-level CAD modeling early to prevent interface mismatches between wheel mechanisms and chassis bays.



Figure 35: Complete rover in deployed configuration.

8 Conclusion

This report has summarized the development of the HUGIN rover for the LOOK competition. While time constraints resulted in drivetrain motor failures during the competition, the project validated the MBSE logical-to-physical methodology and established a foundation for POLARIX UiT's planned 2027 entry.

9 Acknowledgments

We extend our gratitude to our sponsors, particularly NITO, and UiT Narvik for providing facilities, workspace, and instrumentation.

References

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A Appendix A: Acronyms

- **BMS:** Battery Management System
- **CAD:** Computer-Aided Design
- **CNN:** Convolutional Neural Network
- **FEA:** Finite Element Analysis
- **PID:** Proportional-Integral-Derivative
- **IMU:** Inertial Measurement Unit
- **PDU:** Power Distribution Unit
- **MPPT:** Maximum Power Point Tracking
- **RF:** Radio Frequency
- **FPC:** Flexible Printed Circuit
- **LIDAR:** Light Detection and Ranging
- **RRT:** Rapidly-exploring Random Tree
- **SLAM:** Simultaneous Localization and Mapping
- **YOLO:** You Only Look Once

B Appendix B: Subsystem Priority Justification

Table 8: Priority Level Justifications

Priority	Justification
1	*Critical path:* Failure means total mission failure
2	*High impact:* Essential for movement and mobility
3	*Moderate impact:* Important but with workarounds
4	*Lowest impact:* Can be minimized or simplified if time-constrained