
BID4R
System Requirements Specification
Version <1.0>
30/10/2024

Document Control

Distribution List

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Change Summary

The following table details changes made between versions of this document:

Version	Date	Modifier	Description
1.0	30/11/2024	Team	Initial Document

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1. Introduction

1.1. Purpose and Scope

The purpose of this System Requirements Specification (SRS) is to detail the system requirements for the BID4R Project, a biologically-inspired resilient rover system designed to replace AA battery-powered rovers with LiPo battery-powered rovers. The BID4R Project focuses on upgrading power systems for autonomous robots in the Biologically-Inspired Resilient Systems Test Arena (BIRSTA), with the goal of extending operational time and introducing wireless charging functionality. Identified through needs analysis, the customer's primary issue is the limited battery life of current rovers, which necessitates frequent manual recharging and maintenance. This new system addresses that challenge by incorporating LiPo batteries and a wireless Qi charging mechanism, enabling longer operational time and autonomous charging upon manual placement in the station. Applied to a swarm of 50 rovers, the system enhances power management, wireless charging, and control capabilities. Its top-level benefits include improved autonomy, reduced maintenance, and more efficient energy management, achieved through safe battery use managed by a Battery Management System (BMS) and optimized operational efficiency with wireless charging.

1.2. Intended Audience and Reading Suggestions

This document is intended for several types of readers involved in or evaluating the BID4R project:

- **Developers** responsible for designing and implementing the system.
- **Project Manager** who oversees project milestones and ensures that all requirements are met.
- **Customer** who will review the system requirements to assess alignment with project goals.
- **Professors and Teaching Assistants** who will evaluate and grade the document for technical accuracy and completeness.

The document is organized into sections covering both the technical and functional requirements of the system. It is recommended to begin with the **Introduction** to gain a general overview of the project, followed by the **General Description** section for a high-level understanding of the product features. Developers should focus on the **External Interface Requirements** and **Behavioral Requirements** sections for design and implementation guidance. Professors, teaching assistants, and the customer should review all sections to ensure the document fully addresses project requirements and goals.

1.3. Document Conventions

The following standards and typographical conventions are followed in this SRS to ensure consistency and clarity:

- **Hierarchical Structure:** All headings follow a hierarchical numbering system, with primary headings numbered as 1, 2, 3, etc., and subheadings as 1.1, 1.2, etc., to indicate document structure.
- **Fonts and Styles:** Body text is in 12-point Times New Roman, while headings are bolded for clear visual separation. Terms needing emphasis are italicized, while system names and technical terms are capitalized for clarity.
- **Requirement Numbering:** Each requirement is labeled with a unique identifier, such as "REQ-1," "REQ-2," and so on, for easy reference and traceability.
- **Priority Inheritance:** Priorities for higher-level requirements are inherited by lower-level requirements unless otherwise specified.

These conventions are intended to enhance readability and provide a structured approach to navigating the document.

1.4. Project References

This section lists key references and deliverables produced to date, which provide insight into system design choices, power calculations, and safety mechanisms related to LiPo battery management. All documents are accessible on the project's GitHub repository, with version control details included for reference.

- **Project Proposal, BID4R**
 - *Authors:* BID4R Team
 - *Date:* 2024
 - *Description:* An overview of project goals, requirements, and initial design considerations for the BID4R system.
 - *GitHub Location:*
https://github.com/turkia1/BID4R/blob/fc681bb0e57aabb8ba3e043f27d15630247c62c0/project_proposal/Project%20Proposal%20.pdf
- **Components Analysis and Suitability for BID4R Project**
 - *Author:* Mohammed Alasmari
 - *Date:* October 2024
 - *Description:* Analysis of key components required for the BID4R system, including suitability evaluations and performance considerations.
 - *GitHub Location:*
<https://github.com/turkia1/BID4R/blob/fc681bb0e57aabb8ba3e043f27d15630247c62c0/Sprint2/Components%20Analysis%20and%20Suitability%20for%20BID4R%20Project.pdf>
- **LiPo Battery Safety and Wireless Charging Mechanism: A Comprehensive Guide**
 - *Author:* Belal Abed
 - *Date:* October 2024
 - *Description:* Guidelines on LiPo battery safety standards and implementation of Qi wireless charging, focusing on safety protocols and regulatory compliance.
 - *GitHub Location:*
https://github.com/turkia1/BID4R/blob/fc681bb0e57aabb8ba3e043f27d15630247c62c0/Sprint2/LiPo_regulation.PDF

- **Final Power Calculations for BID4R**
 - *Authors:* Mohammed Alasmari and Belal Abed
 - *Date:* October 2024
 - *Description:* Comprehensive power calculations for the BID4R system under various operating conditions, including normal and stall power requirements.
 - *GitHub Location:*
<https://github.com/turkia1/BID4R/blob/fc681bb0e57aabb8ba3e043f27d15630247c62c0/Sprint2/FinalCalculation.Component.pdf>
- **Wiring Documentation for BID4R**
 - *Author:* Turki Alturki
 - *Date:* October 2024
 - *Description:* Detailed wiring documentation outlining component connections, safety protocols, and wiring schematics for BID4R.
 - *GitHub Location:*
<https://github.com/turkia1/BID4R/tree/fc681bb0e57aabb8ba3e043f27d15630247c62c0/Sprint3/Wiring>
- **Charging Station Documentation**
 - *Author:* Turki Alturki
 - *Date:* October 2024
 - *Description:* Technical documentation on the design and operation of the wireless Qi charging station, including alignment and power specifications.
 - *GitHub Location:*
https://github.com/turkia1/BID4R/tree/fc681bb0e57aabb8ba3e043f27d15630247c62c0/Sprint2/Charging_Station

1.5. Definitions, Acronyms, and Abbreviations

This section provides a glossary of terms and acronyms used in this document.

1.5.1. Definitions

Term	Definition
LiPo Battery	A type of rechargeable battery widely used for high-energy density applications.
BMS	Battery Management System, responsible for protecting batteries from overcharge, over-discharge, and short circuits.
Qi Charging	A wireless power transfer standard used for charging the rover's battery.
Arduino Nano	The microcontroller used to manage power and motor control in the system.

1.5.2. Acronyms

Term	Definition
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BMS	Battery Management System
SRS	System Requirements Specification
Qi	Wireless charging technology
BID4R	Biologically-Inspired Design for Resilience

1.5.3. Abbreviations

Term	Definition
e.g.	For example
V	Voltage
A	Amperes
W	Watts

2. General Description

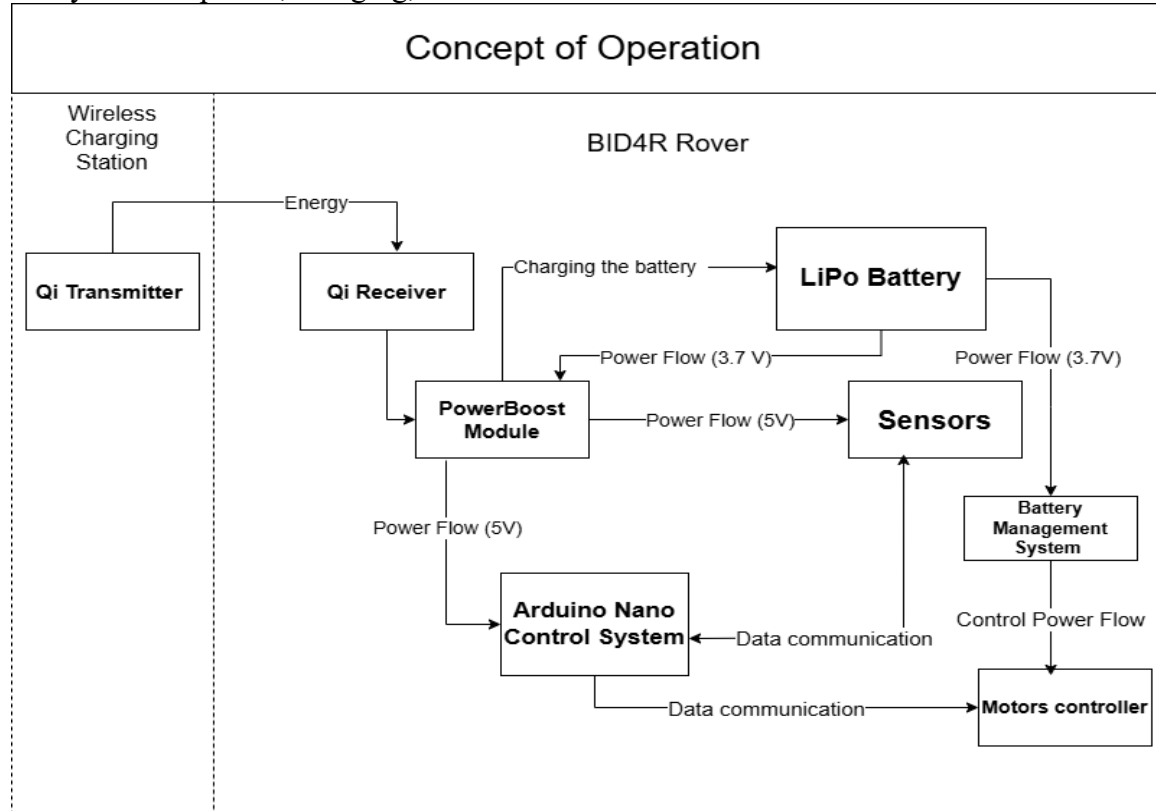
2.1. Product Perspective

The BID4R Project is a subsystem designed to improve the autonomy and operational efficiency of rovers used in the Biologically-Inspired Resilient Systems Test Arena (BIRSTA). Currently, BIRSTA's rovers rely on AA batteries, which require frequent manual replacements and limit runtime. This project aims to replace the AA batteries with a LiPo battery and integrate a Qi wireless charging system to allow convenient, operator-assisted charging.

This power upgrade enhances BIRSTA's ability to conduct continuous testing by reducing downtime due to manual battery changes. The BID4R system consists of four main components:

1. **LiPo Battery:** Replaces the original AA battery pack, providing higher capacity and improved power efficiency.
2. **Qi Wireless Charging Station:** Enables contactless charging of the rover by an operator who manually aligns the rover on the charging pad.
3. **Battery Management System (BMS):** Monitors battery voltage, prevents overcharging and over-discharging, and ensures safe operation.
4. **Arduino Nano-based Control System:** Manages communication between the Qi charging module, LED indicators, and the BMS, providing power status updates to the operator.

Figure X: BID4R Concept of operation illustrates the key components and connections within the system for power, charging, and control.



2.2. Product Features

The BID4R system introduces specific power management features designed to improve battery efficiency, provide safe charging, and enable operational monitoring by the user. Key features include:

- **Power Management:**
 - **Operator-Assisted Wireless Charging:** The system uses Qi wireless technology to enable contactless charging. When the battery is low, an operator places the rover on the charging station, which detects the connection and initiates charging.
 - **Battery Management System (BMS):** The BMS monitors the LiPo battery, preventing overcharging and over-discharging, which ensures safe battery operation and prolongs battery life.
 - **Power Monitoring:** Real-time monitoring of battery voltage and temperature, displayed via an LED indicator, helps operators assess the rover's power status.
- **System Control:**
 - **LED Indicators for Battery Status:** An LED indicator provides real-time feedback on the battery's charge status, showing low, charging, and fully charged states, allowing operators to manage charging effectively.
 - **Arduino-Controlled Charging Initiation:** The system includes an Arduino Nano microcontroller to handle battery status data, control the LED indicator, and communicate with the charging station.

2.3. User Classes and Characteristics

This system is used by the following user groups:

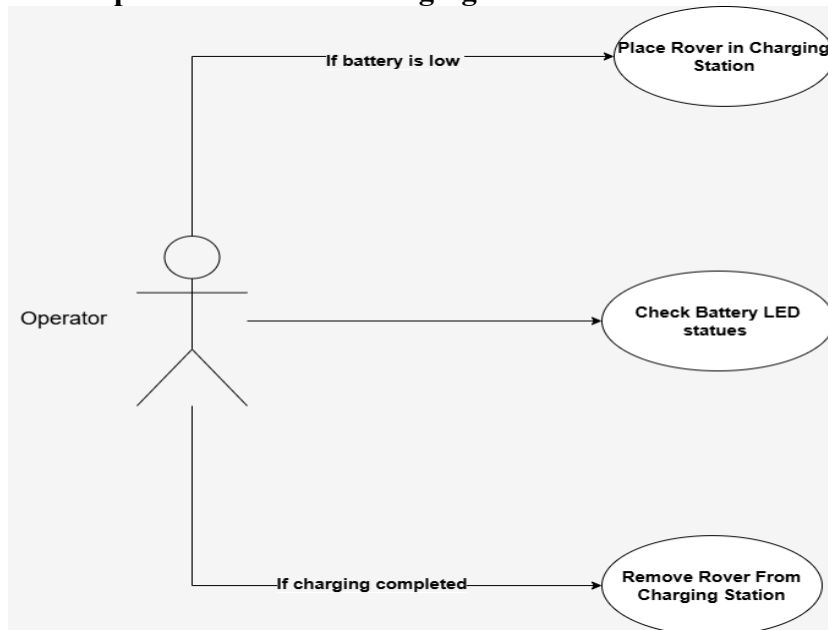
- **Primary User: BIRSTA Staff (System Operators)**
 - **Function:** The primary users are BIRSTA engineers or technical staff who operate and monitor the BID4R rover within the test arena.
 - **Use:** BIRSTA staff will place the rover on the charging station when the LED indicates low battery, monitor the LED status during charging, and remove the rover once fully charged.
 - **Privileges:** Full access to physical interactions with the system but no access to configurations or code adjustments.
 - **Technical Expertise:** Moderate; users need to understand LED indicators and basic power system handling but are not required to configure or troubleshoot the system beyond aligning the rover on the charging station.
- **Secondary Users: Students (Project Developers)**
 - **Function:** Students are responsible for developing, testing, and integrating the wireless charging station and LiPo battery upgrade, ensuring that the system operates safely and meets performance standards.
 - **Use:** Configure and test the Qi wireless charging system and BMS functionality.
 - **Privileges:** Full access to system setup and configuration but restricted to power management components.
 - **Technical Expertise:** Moderate-to-high; students are expected to understand LiPo battery management, wireless charging setup, and basic troubleshooting for integration.

2.3.1. Actors

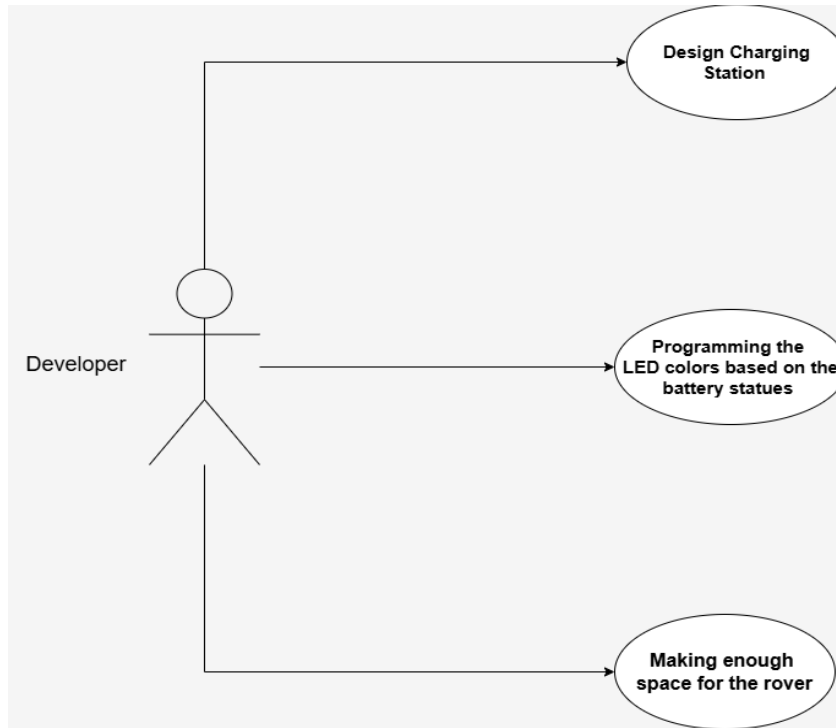
- **BIRSTA Staff (Operators):** Responsible for the day-to-day operation of the BID4R system, primarily focused on managing power levels through charging.
 - **Responsibilities:**
 - Observe LED indicators to monitor battery levels.
 - Place the rover on the charging station when necessary and remove it once fully charged.
- **Students (Project Developers):** Responsible for implementing and maintaining the charging system and battery management components.
 - **Responsibilities:**
 - Configure and test the Qi charging system and LiPo battery setup.
 - Monitor system safety compliance and handle troubleshooting as needed.

2.3.2. Use Cases

- **UC1: Operator-Assisted Charging**



- **Actors:** BIRSTA Staff (Operators)
 - **Description:** When the battery is low, the operator places the rover on the charging station, where the system automatically initiates charging.
 - **Precondition:** The battery level is low.
 - **Postcondition:** Charging begins, and the system logs the session.
 - **Alternative Scenario:** If alignment is incorrect, the LED remains in a low-battery state, signaling the need for realignment.
- **UC2: Create Charging Station System**



- **Actors:** Students (Project Developers)
- **Description:** The Developer designs a reliable charging station, programs LED indicators for battery status (Red, Yellow, Green, and Solid Blue), and ensures sufficient space for easy docking, removal, and maintenance of the rover.
- **Precondition:** All required components (charging station, LED indicators, and rover chassis) are available, and the design specifications are approved.
- **Postcondition:** The charging station is fully functional, LED indicators display the correct battery status, and the rover can dock, charge, and be removed easily for operation and maintenance.

2.3.3. Scenarios

This section presents scenarios for each use case described above.

Scenario 1: Initiating Charging

- **Description:** When the rover's LiPo battery is low, students monitor the LED indicator and manually place the rover on the Qi wireless charging station to initiate charging.
- **Actors:** Operators
- **Precondition:** The rover's battery level is low, as indicated by the LED.
- **Trigger:** The operator observes the LED indicator showing a low battery level.
- **Steps:**
 1. The operator checks the LED indicator to confirm the low battery.
 2. The operator ensures the charging station is clear and ready for alignment.
 3. The operator carefully places the rover on the Qi charging station, aligning it for effective power transfer.
 4. The LED indicator changes to indicate charging, confirming proper alignment.
 5. The operator observes the LED briefly to confirm charging stability.
- **Result:** The rover is charging, as indicated by the LED status light.

- **Alternative Path:**
 - **Step 3.1:** If the rover is misaligned and charging does not start, the LED remains in its low-battery state. The student repositions the rover until charging initiates.

Scenario 2: Removing the Rover After Full Charge

- **Description:** Once the rover's LiPo battery is fully charged, the student observes the LED indicator and removes the rover from the charging station for deployment within BIRSTA.
- **Actors:** Operators
- **Precondition:** The rover's battery is fully charged, indicated by the LED.
- **Trigger:** The operator observes the LED indicator showing a full charge.
- **Steps:**
 1. The operator verifies the LED to confirm the full charge status.
 2. The operator approaches the charging station to remove the rover.
 3. The operator carefully lifts the rover off the charging station.
 4. The operator inspects the LED indicator briefly to ensure it remains in the full charge state.
 5. The rover is now ready for BIRSTA deployment.
- **Result:** The rover is fully charged, removed from the charging station, and available for further use.
- **Alternative Path:**
 - **Step 3.1:** If the LED flashes unexpectedly after removal, the Operator checks the charging station for alignment or functionality issues before proceeding.

2.4. General Constraints

- **Code Accessibility:** The development team will not have access to the full codebase of the rover, as it is part of an unpublished project and cannot be shared with the team due to confidentiality restrictions. The team will therefore focus on developing code specifically for the battery management system (BMS) algorithm, ensuring independent functionality within the rover's existing power system.
- **Component Selection:** To maintain budgetary efficiency, the team will prioritize cost-effective components that meet performance requirements, aiming to reduce overall project costs without sacrificing quality or essential functionality.

2.5. Operating Environment

- The BID4R system will operate in a controlled laboratory environment within the Biologically-Inspired Resilient Systems Test Arena (BIRSTA) lab. Key environmental requirements include:
- **Temperature Range:** The system is designed to operate at ambient temperatures between **18°C and 27°C** (64°F to 80°F). This range helps prevent temperature-induced issues such as increased viscosity in adhesives and potential component stress, maintaining stability for all electronic parts.

- **Humidity:** The lab environment maintains a humidity range between **30% and 70%**, with a preferred range of 45-60%. These levels reduce the risk of electrostatic discharge (ESD) and prevent moisture damage to sensitive electronic components.
- **Hardware Platform:** The rovers are managed by an Arduino Nano microcontroller, and the Qi wireless charging station utilizes a PowerBoost 1000C module for reliable energy delivery.
- **Software Requirements:** The control software operates on the Arduino Nano, handling communications with integrated sensors, motors, and the Battery Management System (BMS) to support system functions.

2.6. User Documentation

The following user documentation will be provided with the BID4R system:

- **Charging Station Design Documentation:** Detailed design and setup instructions for the Qi wireless charging station, including component specifications and configuration guidelines to ensure proper alignment and functionality.
- **Wiring Diagram:** A visual guide detailing the connections between all system components, including the battery, sensors, motor drivers, and control modules, offering a reference for accurate assembly and troubleshooting.
- **Components and Power Consumption Calculation Documentation:** Documentation outlining the system's power requirements and consumption calculations to help users monitor and optimize energy use within safe operating limits.
- **LiPo Battery Safety Regulation:** Comprehensive guidelines on the safe handling, usage, and maintenance of LiPo batteries, including storage recommendations, charging protocols, and precautions to avoid overcharging or overheating.

All documentation will be provided in PDF format, formatted for clarity and ease of use, and will include annotated diagrams and visual aids where relevant to support user comprehension.

2.7. Assumptions and Dependencies

The following assumptions and dependencies affect the requirements outlined in this SRS:

- **Arduino Code Accessibility:** It is assumed that the source code for controlling the Arduino Nano 33 IoT will be accessible under supervision to the development team to facilitate integration and testing of the battery management system (BMS).
- **Component Provision:** The organization will supply all essential components, including the Battery Management System (BMS), Qi chargers, and LiPo batteries. These components are expected to be compatible with the BID4R system and aligned with the project's cost-efficiency goals.
- **Testing Infrastructure:** The system will be tested and integrated within the existing BIRSTA robotics infrastructure, assuming compatibility with current robotics protocols, interfaces, and communication systems.
- **Environment Control:** The system is designed for a controlled lab environment with stable temperature and humidity levels maintained within recommended ranges, supporting the safe and efficient operation of system components.

3. External Interface Requirements

3.1. User Interfaces

- [Req 1] The system shall require no interaction with a user interface beyond LED interpretation.

3.2. Hardware Interfaces

- [Req 2] The motor driver shall be connected to the Arduino for PWM control of motor speed and direction.
- [Req 3] The system shall use an Arduino Nano microcontroller for processing and control.
- [Req 4] The proximity sensor and Pixy2 shall be calibrated after installation to ensure accurate readings and communication with the Arduino.
- [Req 5] The system shall include temperature sensors to monitor the battery during charging.
- [Req 6] The PowerBoost 1000C shall provide power for the Pixy2 camera, VCNL4010 proximity sensor, APA106 LEDs, Arduino Nano 33 IoT, and other 5V components, totaling no more than 1A combined.
- [Req 7] The PowerBoost 1000C shall receive 3.7V input from the LiPo battery and provide a stable 5V output for connected components.
- [Req 8] The motor shall be directly connected to the battery through a BMS for protection.

3.3. Software Interfaces

- [Req 9] All components shall be compatible with Arduino programming standards.
- [Req 10] The software shall monitor battery health, alerting on issues such as temperature or swelling.
- [Req 11] Software logic shall control charging based on feedback from the battery sensors.

4. Behavioral Requirements

4.1. Modes

[Req 12] The system shall provide LED indicators for charging status, showing states such as charging, full, and standby.

The system will have two modes

- Charging Mode
 - [Req 13] In charging condition, the LED shall display flashing green when the battery is full.
 - [Req 14] In charging condition, the LED shall display flashing yellow when the battery is half-full.
 - [Req 15] In charging condition, the LED shall display flashing red when the battery is low.
 - [Req 16] In charging condition, the LED shall display solid blue when charging is complete.
- Operation Mode
 - [Req 17] In operation, the LED shall display green when the battery is full.
 - [Req 18] In operation, the LED shall display yellow when the battery is half-full.
 - [Req 19] In operation, the LED shall display red when the battery is low.

4.2. Related Real-world Objects

- [Req 20] The system shall alert the operator via LED if the temperature exceeds safe levels through the LED indicator.
- [Req 21] The Arduino shall automatically cut power if the battery temperature reaches unsafe levels.
- [Req 22] The charging station shall allow manual activation by the operator of the cooling fan.
- [Req 23] The charging station shall allow manual deactivation by the operator of the cooling fan.

4.3. Stimulus

- [Req 24] LED indicators shall change states according to battery level.

- [Req 25] Wireless charging shall commence automatically once the robot is aligned with the transmitter.
- [Req 26] The Arduino shall automatically cut power if the battery temperature reaches unsafe levels.
- [Req 27] The system shall resume charging automatically when temperature falls below 35°C if previously halted due to overheating.
- [Req 28] The system shall disable motors, the Pixy2 camera, and the proximity sensor during charging.

4.4. Functional

- [Req 29] The system shall stop charging when the battery voltage reaches or exceeds 4.2V.
- [Req 30] The system shall permit charging only when the battery voltage is below 4.2V.
- [Req 31] The LED indicator shall flash red when a thermal cutoff occurs due to high temperature.
- [Req 32] The system shall automatically stop all non-essential functions when the battery voltage is critically low (3.3V or below).

5. Non-behavioral Requirements

5.1. Performance Requirements

- [Req 33] The system shall support wireless charging via a Qi-compatible charging station.
- [Req 34] The rover shall use a LiPo battery for primary power.
- [Req 35] The BMS shall prevent battery overcharge.
- [Req 36] The BMS shall prevent battery over-discharge.
- [Req 37] The system shall provide power to the rover continuously for a minimum of one hour of operation.
- [Req 38] The Qi transmitter shall maintain a stable position on the charging station base to ensure consistent power transfer.
- [Req 39] The charging station shall ensure efficient power transfer throughout the charging process without interruptions.
- [Req 40] The system shall consume no more than 13.05W at peak usage.
- [Req 41] The Qi receiver and transmitter shall be aligned within ± 3 mm to optimize charging efficiency and prevent power loss.
- [Req 42] The charging station shall incorporate a rising edge and block system to ensure precise docking alignment.
- [Req 43] The LiPo battery shall have a capacity of at least 3000 mAh.
- [Req 44] The motors shall draw 2.22W during normal operation (3.7V at 300mA per motor).
- [Req 45] The motors shall draw 11.1W under stall conditions (3.7V at 1.5A per motor).
- [Req 46] Under normal operating conditions, the LiPo battery shall provide a runtime of approximately 2.66 hours.
- [Req 47] Under stall conditions, the LiPo battery shall provide a runtime of approximately 51 minutes.
- [Req 48] The total power consumption during normal operation, including motors and PowerBoost-powered components, shall not exceed 4.17W.
- [Req 49] The total power consumption during motor stall conditions shall not exceed 13.05W.
- [Req 50] The Qi wireless charging transmitter shall provide 5W output to the Qi receiver with an efficiency of 80%.
- [Req 51] The Qi charging system shall fully recharge the LiPo battery within approximately 2.78 hours.
- [Req 52] The BMS shall not consume significant power during normal
- [Req 53] The BMS shall not consume significant power during normal operation, functioning as a passive protection component.
- [Req 54] The system shall monitor battery temperature using a DS18B20 temperature sensor.
- [Req 55] The BMS protection module shall be installed between the LiPo battery and the load to manage safe charging and discharging.
- [Req 56] The system shall be able to provide sufficient power for different components on the robot.

5.2. Safety Requirements

- [Req 57] All wiring shall be neatly organized and securely fastened to prevent interference with the robot's movement and docking.
- [Req 58] The BMS shall protect the battery from over-discharge.
- [Req 59] The thermal cutoff shall disconnect charging if the temperature exceeds 113°F (45°C).
- [Req 60] All electrical connections shall be insulated to prevent accidental short circuits or interference.
- [Req 61] The system shall include a BMS for parts connected directly to the battery.

5.3. Qualitative Requirements

5.3.1. Security

- [Req 62] Access to the code for the battery management system (BMS) shall be restricted to authorized team members only, ensuring secure control over system operations and modifications.

5.3.2. Maintainability

- [Req 63] The BMS code shall be modular to allow for future updates and improvements without affecting unrelated system components, supporting efficient system maintenance and upgrades

5.4. Design and Implementation Constraints

- [Req 64] The robot chassis shall securely mount the Qi receiver, providing enough space and accessibility for wiring and maintenance.
- [Req 65] The robot chassis shall securely mount all components, providing enough space and accessibility for wiring and maintenance.
- [Req 66] The Arduino Nano 33 IoT shall be positioned to allow easy access to all sensor and power connections
- [Req 67] The PowerBoost 1000C shall be positioned to allow airflow for cooling, ensuring stable operation under continuous load.
- [Req 68] The proximity sensor shall be placed at the front of the robot for optimal obstacle detection.
- [Req 69] The APA106 LEDs shall be positioned to remain visible to the operator, providing clear feedback on system status.
- [Req 70] The Qi receiver shall be positioned on the bottom surface of the robot for direct alignment with the transmitter on the charging station.
- [Req 71] Wires shall not interfere with the robot during docking.

- [Req 72] The LiPo battery shall be securely housed to prevent movement, impact, or damage during operation.
- [Req 73] All components shall be fastened securely to avoid damage or disconnection from vibrations or sudden movements.
- [Req 74] The charging station shall be designed for easy assembly and disassembly to facilitate maintenance.
- [Req 75] The design shall accommodate the BID4R robot configuration, which includes two wheels and a middle stabilizer.
- [Req 76] The Qi transmitter shall be positioned at the front of the charging station to align with the BID4R robot's docking requirements.
- [Req 77] The station shall include a cooling fan.
- [Req 78] The charging station shall include an adjustable fan positioned above the robot to regulate temperature during charging.

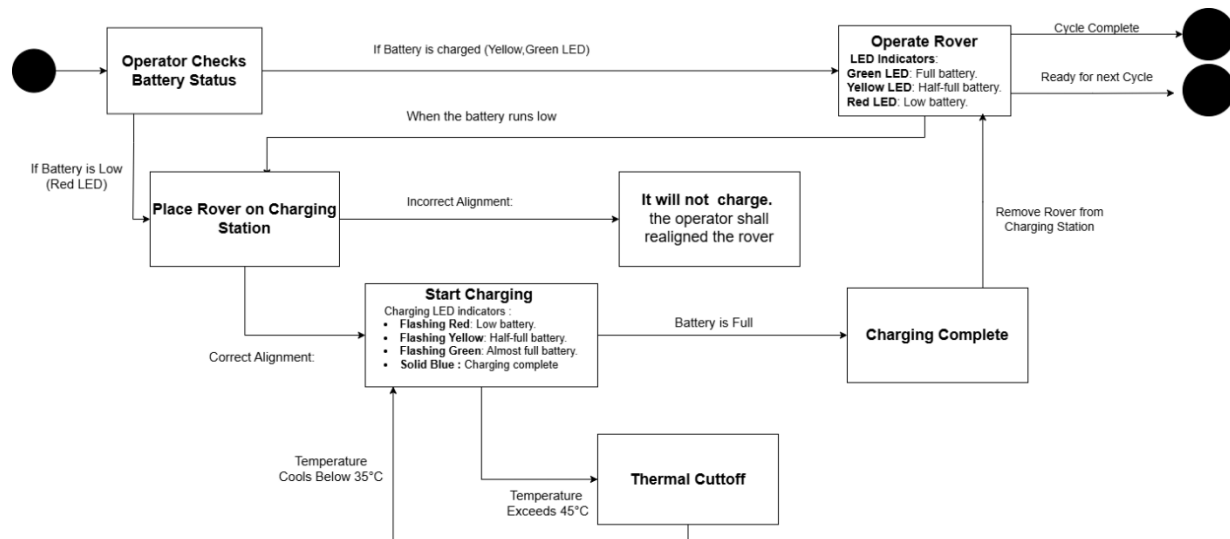
6. Other Requirements

6.1. User Documentation

- [Req 79] Instructions for proper wire routing to avoid docking interference shall be included in the user manual.
- [Req 80] The documentation shall provide instructions on interpreting LED colors for different battery charge levels.
- [Req 81] The documentation shall specify the LED flashing pattern to indicate thermal cutoff during overheating.

7. Analysis Models

7.1. State Model



8. To Be Determined List

- [TBD-1] Confirmation of the controlled lab environment's specific temperature and humidity range requirements to support optimal system operation.
- [TBD-2] Finalization of authorized personnel roles for accessing and modifying the battery management system (BMS) code.
- [TBD-3] Validation of testing infrastructure compatibility with current BID4R robotics protocols and communication standards.