BID4R
System Design Document
Version <1.0>
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Document Control

Distribution List

The following list of people will receive a copy of this document every time a new version of this document becomes available:

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Change Summary

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

Version	Date	Modifier	Description
1.0	10/30/2024	Belal	Initial creation- Introduction
1.0	11/2/2024	Mohammed	System Architecture
1.0	11/3/2024	Turki	System Architecture- Diagrams
1.0	11/4/2024	Mohammed	Human - Machine interface
1.0	11/6/2024	Turki	Detailed Design- Hardware
1.0	11/8/2024	Mohammed	Detailed Design- Software
1.0	11/9/2024	Belal	Detailed Design- Internal Communication
1.0	11/11/2024	Belal	External Interface – Hardware
1.0	11/16/2024	Turki	External Interface – Software
1.0	11/19/2024	Turki	Revise the Detailed Design Hardware
1.0	11/20/2024	Turki	Revise the Internal communication
1.0	11/21/2024	Mohammed, Belal, Turki	Final revision

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1. Introduction

1.1. Purpose and Scope

The purpose of this System Design Specification (SDS) is to detail the technical requirements and design for the BID4R project. The project involves upgrading an existing robot by replacing AA batteries with a LiPo battery and integrating a Qi-compatible wireless charging system. The system aims to extend operational runtime while ensuring safety through battery management and thermal monitoring.

1.2. Project Executive Summary

The BID4R project focuses on improving robot functionality by implementing a more efficient power system. This includes transitioning to a LiPo battery, integrating a Qi wireless charging solution, and enhancing safety with thermal and battery monitoring. These upgrades will reduce downtime, improve usability, and enable future enhancements like autonomous docking.

1.2.1. System Overview

The BID4R system is a power management solution for a mobile robot, designed to extend its operational time and reduce the need for manual recharging through wireless charging. This system comprises two main components: a Qi-compatible wireless charging station and an upgraded power system within the robot, which includes a LiPo battery and a Battery Management System (BMS).

The robot, initially powered by AA batteries, has been modified to incorporate a LiPo battery, which provides a longer operational time per charge. The wireless charging station enables the robot to recharge its battery without the need for physical connection ports. The charging process is initiated automatically when the robot is manually placed on the charging station by an operator. An LED indicator on the robot provides real-time feedback to show the current battery status, signaling when it is fully charged or in need of recharging.

To ensure safety during charging, the system includes a thermal management feature that prevents overheating. The overall system design is straightforward and focused on efficient power integration rather than advanced autonomous functions. In the future, additional navigation features could be added to allow the robot to automatically dock onto the charging station, further enhancing its autonomy.

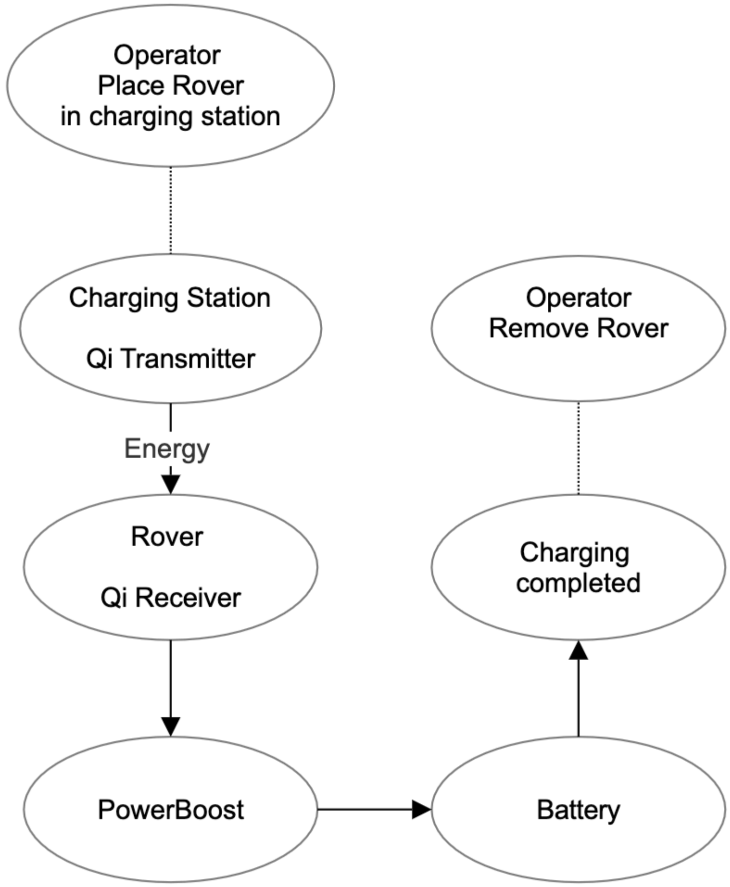

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Figure 1. High-Level Charging Process Flow

1.2.2. Design Constraints

The BID4R system design is subject to several constraints that influence its hardware, software, and operational setup. These constraints include:

1. **Limited System Autonomy**:
   The system relies on manual docking for charging as autonomous navigation is outside the current scope. This requires the operator to manually align and place the rover on the charging station. Future updates could address this limitation by integrating sensors and navigation algorithms for autonomous docking.
2. **Power Source Limitations**:
   The system uses a 3.7V, 3000mAh LiPo battery, which provides extended usage but introduces charging and discharging constraints. A robust Battery Management System (BMS) is required to monitor and protect the battery from overcharging or over-discharging, ensuring safe and efficient operation.
3. **Qi Wireless Charging Constraints**:
   The Qi charging setup includes a transmitter capable of delivering up to 1000mA;

however, the receiver is limited to 500mA. This results in extended charging times, which may not be ideal for high-demand applications. Future upgrades to the Qi receiver could address this bottleneck.

4. **Environmental Restrictions**:
   The BID4R system is optimized for use in controlled indoor environments with stable temperature and humidity. It is not designed for rugged conditions such as high dust levels, extreme temperatures, or exposure to moisture. Modifications would be required for outdoor or industrial applications.
5. **Software and Hardware Requirements**: The system is controlled by an Arduino Nano IoT, with code running on limited memory and processing power. The system's software is optimized for this low-power environment, meaning complex tasks or additional processes could exceed the capabilities of the microcontroller. The system does not require an external operating system, network connection, or high RAM capacity due to the limited computational demands of the task.

Assumptions:

- The operator will be present to manually place the rover on the charging station.
- The operator will monitor the battery levels through the LED status indicators to determine when the rover requires charging or when the battery is fully charged.
- The components used are compatible with Qi wireless charging standards, ensuring efficient energy transfer between the charger and the receiver in the rover.
- The environment is free from high levels of dust, humidity, or temperature fluctuations, as the system is not designed for rugged conditions.

1.2.3. Future Contingencies

The BID4R project has been designed with specific functionality and constraints; however, several future contingencies could alter the development direction. These contingencies include potential system upgrades, architectural changes, and external dependencies that may arise as the system evolves or new requirements are introduced.

1. **Integration of Autonomous Docking**: Currently, the system requires an operator to manually place the rover on the charging station. Future developments may add autonomous navigation and docking capabilities to enhance system autonomy. This would involve integrating additional sensors (e.g., LiDAR, ultrasonic) and navigation algorithms. The system architecture may require updates to accommodate these changes, including more advanced processing capabilities.

2. **Upgraded Qi Wireless Receiver:** The current Qi wireless charging system utilizes a transmitter capable of delivering up to 1000mA; however, the receiver is limited to a maximum current of 500mA. This limitation prolongs the charging

time of the system. Future upgrades could involve replacing the Qi receiver with a higher-capacity model capable of matching the transmitter's output. This enhancement would reduce charging time, improve efficiency, and align the receiver's performance with the transmitter's capabilities.

3. **Higher Capacity Battery and Charging System**: If extended operational time is required beyond the current LiPo battery capacity, a higher capacity battery or a more efficient wireless charging system may be needed. This could involve re-evaluating the Qi wireless standard or increasing the charging power, which may impact thermal management and require additional safety controls.
4. **Environmental Adaptation:** The current system is intended for indoor environments. If the system is required to function in outdoor or rugged conditions, modifications may be needed to weatherproof the components, enhance the thermal management system, and ensure reliable operation in varying environmental conditions. This adaptation could necessitate using more robust materials, enclosures, and environmental sensors.
5. **Compatibility with External Systems**: Future versions of BID4R may need to interface with external systems such as fleet management software or centralized monitoring systems for coordinated operation in larger deployments. This would require network connectivity and standardized communication protocols, which could impact the system's hardware and software requirements.

Workarounds and Alternative Plans:

- For autonomous docking, alternative navigation methods (e.g., manual alignment aids or low-cost beacons) could be considered if advanced sensors are not feasible.
- If a higher-capacity Qi receiver is not available, the current system can continue to operate with the existing 500mA receiver. While this setup results in longer charging times, it ensures that the system remains fully functional and reliable.
- If a higher capacity battery is required but Qi charging power cannot be increased, a dual-battery system could be used to swap batteries periodically for charging.
- To ensure compatibility with external systems, modular software architecture and standardized data formats could be implemented, allowing future integration with minimal changes.

These contingencies are considered as potential future directions that may arise based on user requirements, system performance, and evolving operational needs.

1.3. Document Organization

This System Design Document (SDD) is organized to provide a comprehensive view of the BID4R project's design, including its purpose, architecture, and specific design components. Each section addresses a different aspect of the system to ensure a clear and structured understanding of the project. The document is organized as follows:

- **Section 1: Introduction** – Provides the purpose, scope, executive summary, overview of the system, design constraints, future contingencies, and references. It establishes the project context and introduces key objectives and assumptions.
- **Section 2: System Architecture** – Details the high-level hardware and software architecture, describing the main components of the BID4R system and how they interact. This section includes diagrams to illustrate the system's structure.
- **Section 3: Human-Machine Interface** – Defines the inputs and outputs relative to the user or operator, detailing how the operator interacts with the system, particularly through the manual docking and LED status indicators.
- **Section 4: Detailed Design** – Provides a comprehensive breakdown of the hardware and software design, including specifications for each component and detailed design for internal communications.
- **Section 5: External Interfaces** – Describes the hardware and software interfaces between the BID4R system and any external systems, including the protocols and standards used for these interactions.

Each section is designed to guide the development, integration, and testing of the BID4R project, providing a clear framework for both current and future system requirements. Diagrams and references are included throughout to support the understanding of the design and implementation processes.

1.4. Project References

This section lists the key references and resources consulted during the development of the BID4R project. These references provide background information, technical specifications, and industry standards relevant to the design and implementation of the wireless charging and battery integration solution.

1. **Arduino Nano IoT Documentation** – Technical documentation for the Arduino Nano IoT, including pin configurations, power limitations, and programming guidelines essential for the control system of the BID4R project.

   Link: https://github.com/turkia1/BID4R/blob/main/Wiring_documentation/Component_Documentation/ABX00027-datasheet.pdf

2. **Adafruit PowerBoost 1000C Documentation** – Specifications and usage information for the PowerBoost 1000C module, including voltage conversion and

output capabilities that enable efficient energy transfer from the Qi receiver to the LiPo battery.

Link:
https://github.com/turkia1/BID4R/blob/main/Wiring_documentation/Component_Documentation/adafruit-powerboost-1000c-load-share-usb-charge-boost.pdf

3. **3D Design and CAD Files for Charging Station** – CAD files and design guidelines used to model the physical structure of the wireless charging station, with specific features for alignment and thermal management.

   Link:

   https://github.com/turkia1/BID4R/tree/main/Charging_Station_Documentation

4. **Wiring and Circuit Design References** – Fritzing diagrams and wiring guidelines, used to assemble and validate the connectivity of electronic components, ensuring correct voltage levels, ground connections, and data flow between modules.

   Link:

   https://github.com/turkia1/BID4R/tree/main/Wiring_documentation

5. **Project Requirements Document** – A prior document detailing the functional and non-functional requirements of the BID4R project, which provided a foundation for the system design and identified specific operator needs.

   Link:

   https://github.com/turkia1/BID4R/blob/main/class_documentation/SRSv1.docx

6. **Components Analysis for BID4R Project** – Analysis report on component suitability and performance metrics, including the choice of sensors, LEDs, and connectors necessary for the seamless operation of the BID4R system.

   Link:

   https://github.com/turkia1/BID4R/blob/main/Sprint2/Components%20Analysis%20and%20Suitability%20for%20BID4R%20Project.pdf

7. **LiPo Battery Safety Regulations** -A Comprehensive guidelines on LiPo battery safety standards and implementation of
   Qi wireless charging, focusing on safety protocols and regulatory compliance.

   Link:

   https://github.com/turkia1/BID4R/blob/main/Sprint2/LiPo_regulation.PDF

These references serve as foundational resources for understanding the technologies, safety protocols, and design considerations applied in this project. They provide essential information for the development team and stakeholders to understand the scope, constraints, and technical direction of the BID4R project.

1.5. Definitions, Acronyms, and Abbreviations

This section provides a glossary of terms, acronyms, and abbreviations used in this document to assist readers in understanding technical terminology specific to the BID4R project.

1.5.1. Definitions

This section lists terms used in this document and their associated definitions.

Table 1: Definitions

Term	Definition
Battery Management System (BMS)	A system that monitors and manages the charging and discharging of a battery, ensuring safety and efficiency.
Qi Wireless Charging	A standard for wireless energy transfer using inductive charging over distances of up to 4 cm.
Thermal Management	The process of controlling the temperature of components to ensure safe operating conditions.
Manual Docking	The process of physically placing the robot onto the charging station by an operator for charging.
LiPo Battery	A rechargeable lithium polymer battery known for its high energy density and compact size.

1.5.2. Acronyms

This section lists the acronyms used in this document and their associated definitions.

Table 2: Acronyms

Term	Definition
SDD	System Design Document
BID4R	Battery Integration and Docking for Rover
BMS	Battery Management System
LED	Light Emitting Diode
IoT	Internet of Things

1.5.3. Abbreviations

This section lists the abbreviations used in this document and their associated definitions.

Table 3: Abbreviations

Term	Definition
e.g.	For example
i.e.	That is
V	Volt
mA	Milliampere

2. System Architecture

This section provides an overview of the BID4R system architecture, focusing on the hardware and software components that enable wireless charging and effective battery management. The BID4R system comprises two primary components: a wireless charging station and a rover equipped with a LiPo battery, Battery Management System (BMS), and status indicators. This section will describe the organization of the system, its components, and their roles in achieving the project objectives.

2.1. System Hardware Architecture

The BID4R system's hardware architecture consists of two main components: **Charging Station Components** and **Rover Components**. Together, these components enable seamless wireless charging through inductive coupling based on the Qi wireless power transfer standard and facilitate efficient power management. Below is a detailed breakdown of each component and its role within the system.

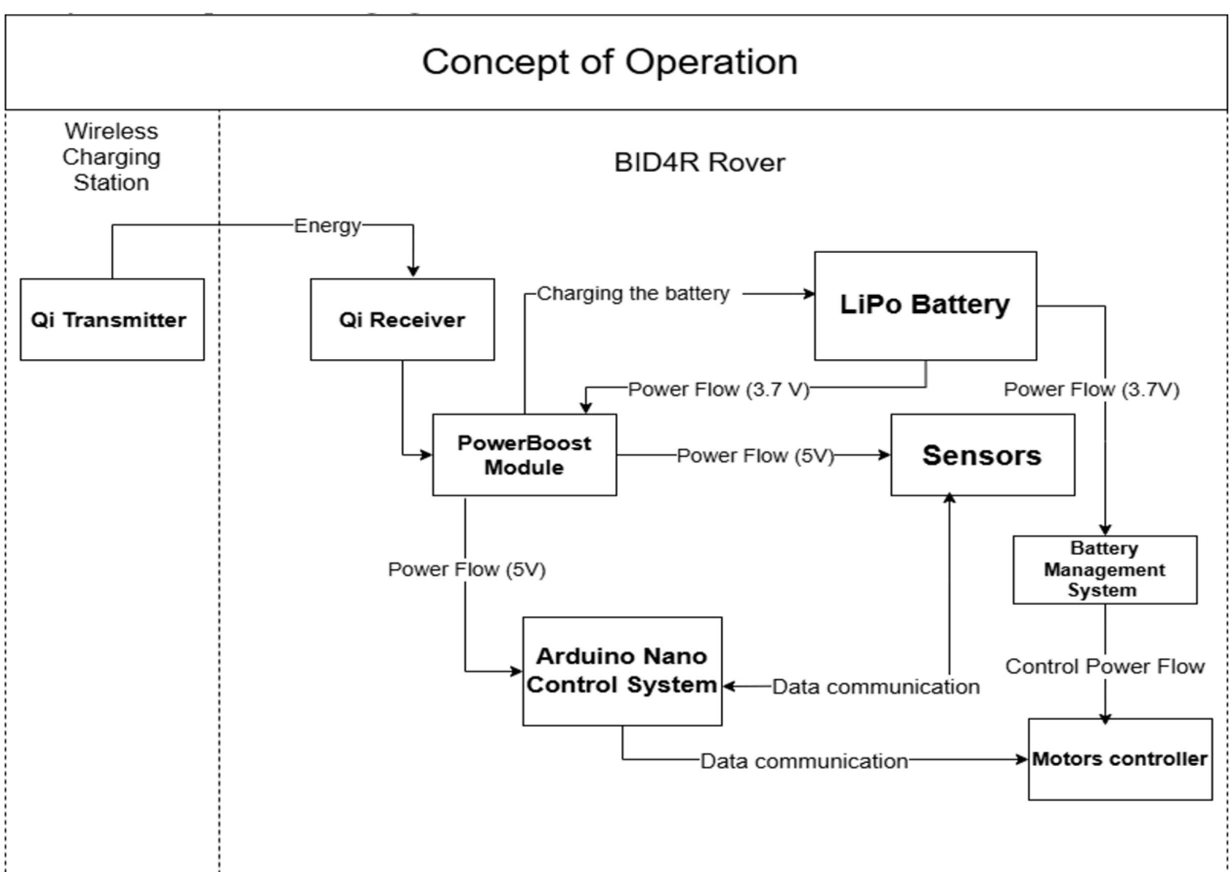

Figure 2. Hardware Architecture

2.1.1. Rover Components

1. **Qi Receiver Module**
   - Function: Receives power wirelessly from the Qi transmitter and forwards it to the PowerBoost module for voltage regulation and distribution.
   - Placement: Positioned on the rover to align precisely with the Qi transmitter on the charging station.
2. **PowerBoost 1000C Module**
   - Function: The PowerBoost 1000C serves two primary functions:
     - Battery Charging: Converts the Qi receiver's input to a stable 5V output to charge the LiPo battery.
     - Voltage Boosting and Distribution: Boosts the voltage from the LiPo battery to provide a stable 5V output, distributing power to other components within the system.
   - Safety Features: Includes built-in protection to ensure controlled charging and regulated power output to other components.
3. **LiPo Battery (3.7V, 3000mAh)**
   - Function: Serves as the primary power source for the rover, providing extended operational time beyond standard AA batteries.
   - Connections: Connects to the PowerBoost module for charging and to the BMS for direct motor power with over-discharge protection.
4. **Battery Management System (BMS) Components**
   - **BMS Module**
     - Purpose: Protects the battery by managing power output to the motors and preventing over-discharge.
     - Connections: Interfaces directly with the battery and motors to maintain safe discharge levels during operation.
5. **Arduino Nano IoT**
   - Function: Central control unit for processing power signals, monitoring sensors, and controlling LED indicators for battery status.

- Integration: Interacts with the custom BMS, processes sensor data, and coordinates battery status feedback.

6. **LED Indicators**
    - Purpose: Provides visual feedback on battery charging status, informing the operator of battery levels.
    - Indicators: Display different colors and patterns to indicate states such as charging, full, half-full, and low battery levels.
7. **Temperature Sensor (DS18B20)**
    - Purpose: Monitors system temperature, specifically during charging cycles, to prevent overheating.
    - Integration: Communicates temperature data to the Arduino Nano IoT for monitoring and thermal management.
8. **Motor Controller and DC Motors**
    - Purpose: Enables the rover's movement, powered by the battery.
    - Power Source: Connected to the battery through the pre-existing BMS module to prevent battery over-discharge during usage.

2.1.2. Charging Station Components

1. **Qi Wireless Charging Transmitter**
    - Function: Transmits power through inductive coupling to the Qi receiver on the rover, facilitating inductive charging.
    - Placement: Aligned to ensure effective power transfer with the Qi receiver on the rover when docked.
2. **Cooling Fan**
    - Purpose: Provides airflow over the charging components on the charging station to manage temperature during operation.
    - Operation: The fan is powered separately and is manually controlled by the operator, not connected to the rover's control system or charging circuitry.

2.2. System Software Architecture

The software architecture for the BID4R system is organized into modular components, each responsible for handling specific functions, including power monitoring, charging control, temperature monitoring, and user feedback through LED indicators. The system is programmed using **C++** and developed within the **Arduino IDE**. The modular approach provides scalability and maintainability, allowing each function to operate independently while interacting with shared data elements.

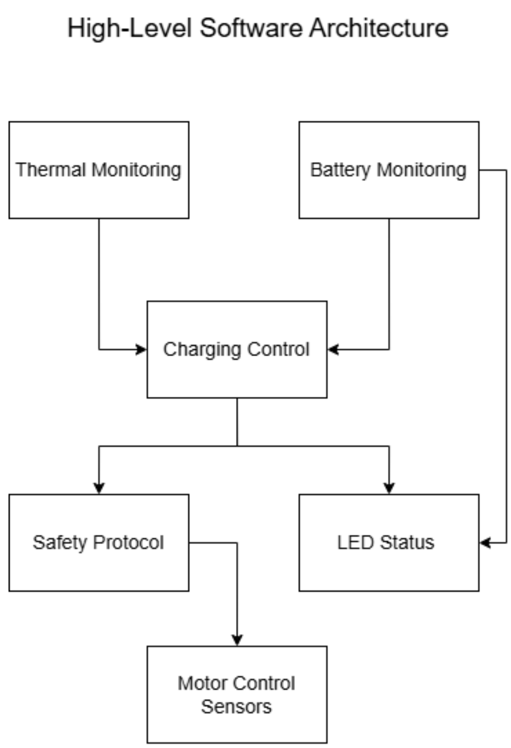

Figure 3. Software Architecture

2.2.1. High-Level Software Architecture

The BID4R software is structured around the following key modules:

1. **Battery Monitoring Module**
    - Description: This module is responsible for continuously monitoring the LiPo battery's voltage level and sending relevant data to other modules, especially for determining battery charge status.
    - Interactions: Provides battery level data to the Charging Control and LED Status Indicator modules for managing charging operations and displaying real-time feedback.
    - Purpose: Enables real-time power management, ensuring that the system responds appropriately to low, medium, and full battery states.

2. **Thermal Monitoring Module**
    - Description: This module monitors the system temperature, specifically during the charging process, to prevent overheating. The DS18B20 temperature sensor provides temperature data, which is processed by this module.
    - Interactions: Works in conjunction with the Safety Protocol and Charging Control modules.
    - Purpose: Protects the battery and circuitry by halting charging if the temperature exceeds safe limits.
3. **Charging Control Module**
    - Description: Controls the charging process based on inputs from the Battery Monitoring and Thermal Monitoring modules. It can start or stop charging based on battery levels and temperature.
    - Interactions: Receives battery status updates from the Battery Monitoring module and temperature data from the Thermal Monitoring module.
    - Purpose: Ensures safe and efficient charging of the battery by managing the Qi charging process according to predefined safety protocols.
4. **LED Status Indicator Module**
    - Description: This module controls the LED indicators, providing the operator with real-time visual feedback on battery charge levels. Different colors and flashing patterns represent various states such as charging, full charge, or low battery.
    - Interactions: Communicates with the Battery Monitoring and Charging Control modules to display appropriate status.
    - Purpose: Serves as the primary user interface for battery monitoring, alerting the operator about the battery's current charge level.
5. **Motor Control Interface**
    - Description: Although not directly involved in the charging process, this module provides an interface to control the rover's movement. For future developments, it may be integrated with autonomous navigation functions.
    - Interactions: Primarily interfaces with the pre-existing BMS for motor power management.
    - Purpose: Allows for potential expansion of the system to include navigation capabilities.

6. **Safety Protocol Module**
   - Description: This module handles safety checks, including monitoring for over-temperature or low battery conditions. It coordinates with other modules to implement protective actions when necessary.
   - Interactions: Works closely with the Thermal Monitoring, Battery Monitoring, and Charging Control modules to execute shutdowns or alerts during unsafe conditions.

   Purpose: Maintains system stability and safety by enforcing operational limits and initiating appropriate responses to critical conditions

2.2.2. Development Tools and Environment

- Programming Language: The software is developed in C++, a language well-suited for embedded systems and compatible with the Arduino platform.
- Development Platform: The Arduino IDE is used to code, compile, and upload the software onto the Arduino Nano IoT microcontroller. It provides access to essential libraries for handling sensors, battery monitoring, and LED control.
- Libraries: Standard Arduino libraries are employed for sensor data acquisition, power monitoring, and LED control. These libraries simplify hardware interfacing and enable efficient development.

2.3. Internal Communications Architecture

The internal communications architecture of the BID4R system facilitates data exchange between the various hardware components and software modules, allowing seamless communication of battery status, charging conditions, and operational feedback among the modules. This architecture supports effective power management and user feedback while integrating newly added components with existing parts of the rover.

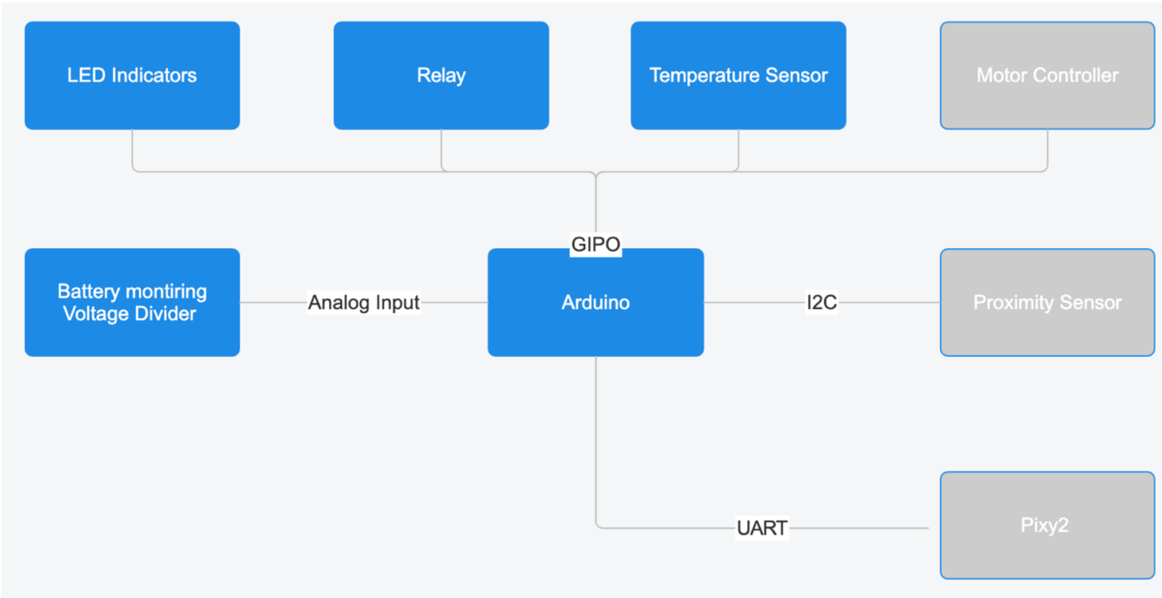

Figure 4. Internal Communications Diagram.

This diagram shows the data pathways and communication protocols (I2C, UART, GPIO) within the BID4R system. Components in blue are directly involved in the project, while faded components (gray) are pre-existing robot elements impacted but not directly modified in this project.

3. Human-Machine Interface

The Human-Machine Interface (HMI) for the BID4R system focuses on the interaction between the operator and the system, specifically through user inputs and outputs. The primary input involves manually placing the rover on the charging station, and the primary outputs are visual indicators that communicate the system's status, including battery charge level and charging progress.

3.1. Inputs

Since the BID4R project's scope does not include an interactive digital interface, the inputs from the operator are limited to **manual actions**. These inputs are directly mapped to the system functions described in **Section 1.2.1 System Overview**.

Input Actions

1. **Manual Docking**
   - Description: The operator places the rover onto the charging station, ensuring the Qi transmitter and receiver are aligned for charging to begin.
   - Mapping to System Flow: When the rover is correctly positioned, the charging station's Qi transmitter begins transferring power to the Qi receiver on the rover. This action initiates the charging sequence, which is then managed automatically by the system.
2. **Manual Fan Control**
   - Description: The user manually activates a cooling fan during charging if overheating is detected.
   - Mapping to System Flow: Although independent from the control system, the fan assists in maintaining safe temperatures. This input is manually controlled without direct communication with the system's logic.

Access Restrictions and Security Considerations

- The manual docking process requires **precise alignment** between the rover and the charging station for efficient charging. There are no digital access restrictions for these inputs, as they are purely physical interactions.
- No security protocols are required for input access, as the inputs are simple manual actions without authentication or verification processes.

3.2. Outputs

The system's outputs to the operator are conveyed through **LED indicators** on the rover. These indicators provide critical feedback on battery levels and charging status, ensuring the operator can monitor the system's operation in real-time.

LED Indicators as System Outputs

The LED indicators serve as the primary user interface for communicating the system's status. The LED displays various colors and patterns to represent different battery levels and charging states, enabling the operator to understand the system's current state at a glance.

The following tables summarize the LED indicators and their meanings:

Table 4: Battery Status Indicator

LED Color/Pattern	Indicator Name	Description	Condition
Red (Solid)	LowBatteryLED	Indicates a low battery level.	Battery level is below safe operational range.
Yellow (Solid)	HalfBatteryLED	Indicates a medium battery level.	Battery is partially charged (approximately 50%).
Green (Solid)	FullBatteryLED	Indicates a nearly full battery level.	Battery is close to full capacity.

Table 5: Charging Status Feedback

LED Color/Pattern	Indicator Name	Description	Condition
Blue (Solid)	ChargingCompleteLED	Indicates the battery is fully charged.	Battery has reached maximum capacity.
Orange (Flashing)	OverheatAlertLED	Indicates an overheat alert.	Temperature exceeds safe operational levels.
Red (Flashing)	ChargingLowBatteryLED	Indicates that charging is in progress with a low battery level.	Battery is below 30% while charging.
Yellow (Flashing)	ChargingMediumBatteryLED	Indicates that charging is in progress with a medium battery level.	Battery is between 30% and 50% while charging.

Green (Flashing)	ChargingHighBatteryLED	Indicates that charging is in progress with a high battery level.	Battery is above 50% while charging.

Purpose and Primary User

The LED indicators serve as the primary user interface for battery monitoring and charging status. They provide instant visual feedback for the operator, enabling them to monitor the battery charge levels and detect any abnormal conditions (such as overheating) during charging.

- Primary User: The operator, who monitors these visual indicators to assess the battery's charge level and charging status.

Access Restrictions and Security Considerations

- **Access Control**: Since the LED indicators are visible to anyone within the vicinity, there are no access restrictions on the outputs. The visual signals are intentionally designed to be observable without specific access permissions.
- **Security Considerations**: No additional security considerations are needed, as the LED indicators do not store sensitive data or control system operations beyond visual status display.

4. Detailed Design

This section contains the detailed hardware and software design of the BID4R autonomous charging and power management system.

4.1. Hardware Detailed Design

This section provides a complete breakdown of the hardware components used in the BID4R system, including their placement, integration, and connections. The design is divided into three subsections: Rover Power and Control System Components, Charging Station Components, and Graphical Representation.

4.1.1. Rover Components:

4.1.1.1 Control System

1. Arduino Nano 33 IoT
    - Placement: Mounted on the upper layer of the robot for centralized access and ease of wiring.
    - Integration: Serves as the main controller, managing all component communication, control, and monitoring.
    - Pin Configuration:

Table 6: Arduino Pins

Pin	Component Connection
D0 (RX)	Pixy2 Camera (RX for serial communication)
D1 (TX)	Pixy2 Camera (TX for serial communication)
D2	Motor Driver AIN1 (Motor 1 Control)
D3	Motor Driver AIN2 (Motor 1 Control)
D4	DS18B20 Temperature Sensor (Data pin)
D5	Motor Driver BIN1 (Motor 2 Control)
D6	Motor Driver BIN2 (Motor 2 Control)
D7	PowerBoost ENABLE through transistor 2A2222A
D8	APA106 LED (DIN) for controlling the LED strip
D9	Control Power Relay
D10	LED for robot feedback
D11	PowerBoost battery monitoring

D12	Motors Sleep
D13	Battery Charging
3.3v	Robot LED + Power relay
A0	Voltage Divider for battery level monitoring
A4 (SDA)	Proximity Sensor (SDA pin for I2C communication)
A5 (SCL)	Proximity Sensor (SCL pin for I2C communication)

- Power and Ground:
  5V: Supplied by PowerBoost to power the Arduino and connected peripherals.
  GND: Common ground across the system.

2. DS18B20 Temperature Sensor
   - Placement: Near the battery to monitor temperature.
   - Integration: Monitors temperature to prevent overheating during charging.
   - Connections:
     - VDD: Connected to Arduino’s 3.3V pin.
     - GND: Shared ground.
     - Data Pin: Connected to D2 on Arduino.
3. Pixy2 Camera System
   - Placement: Mounted on the front of the rover for potential vision-based enhancements.
   - Integration: Communicates with Arduino via serial connection.
   - Connections:
     - TX/RX: Connected to Arduino’s D0 (RX) and D1 (TX).
     - 5V Power: Supplied by PowerBoost.
     - GND: Connected to shared ground.
4. Proximity Sensor (Adafruit #466)
   - Placement: Mounted on the front of the rover, near the Pixy
   - Integration: Assists the robot on detecting objects
   - Connections:
     - SDA: Connected to Arduino A4 (I2C data).
     - SCL: Connected to Arduino A5 (I2C clock).
     - VDD: 3.3V from Arduino.
     - GND: Shared ground.
5. Relay
   - Placement: Mounted on the second layer of the robot, adjacent to the motor controller for efficient space utilization and wiring
   - Integration: Controls charging by connecting or disconnecting the Qi receiver.

- Connections:
  - COM: Connects to Qi receiver positive terminal.
  - NO: Connects to PowerBoost.
  - Control Pin: Connected to D9 on Arduino.

6. APA106 RGB LED
   - Placement: Mounted on the upper layer of the robot for visibility.
   - Integration: Provides visual feedback for charging and battery status.
   - Connections:
     - DIN: Connected to Arduino's D8 pin.
     - 5V Power: Supplied by PowerBoost.
     - GND: Common ground.

4.1.1.2 Power System

1. LiPo Battery (3.7V, 3000mAh)
   - Placement: Positioned at the back of the robot in a custom-designed case to provide protection and stability.
   - Integration: Main power source for the system.
   - Connections:

     Positive Terminal:
     - Connected to the PowerBoost's BAT pin
     - Connected to motor controller through BMS.

     Negative Terminal: Common ground
2. Motor Controller and DC Motors
   - Placement: The motor controller (Adafruit DRV8833) is mounted on the second layer of the robot, while the DC motors are securely positioned on the lower layer to provide stability and support.
   - Integration: The motor controller manages the DC motors, enabling precise speed and directional control. It is powered by the LiPo battery through the BMS, which protects against over-discharge. The controller receives control signals from the Arduino, translating them into motor actions for navigation and movement.
   - Connections:

- AIN1/AIN2: Connected to Arduino D3 and D4 for Motor A control.
- BIN1/BIN2: Connected to Arduino D5 and D6 for Motor B control.
- VMOT: Connected to the LiPo battery through the BMS for regulated power.
- GND: Shared ground with all components

3. PowerBoost 1000C
   - Placement: Mounted on the upper layer of the robot near the Arduino to ensure proper ventilation, as the module generates heat during charging and requires airflow for cooling.
   - Integration: Regulates power, providing a stable 5V output for system components and managing battery charging.
   - Connections:
     - BAT: Connects to the positive terminal of the LiPo battery.
     - 5V Output: Powers the Arduino and other 5V components.
     - LBO Pin: Sends low battery status signal to Arduino's D7.

4. Battery Management System (BMS)
   - Placement: Positioned between the LiPo battery and the motor controller to ensure safe power delivery to the motors.
   - Integration: The BMS safeguards the LiPo battery by monitoring and regulating its charge and discharge cycles. It prevents overcharging, over-discharging, and short circuits, ensuring stable and safe power delivery to the motor controller. The BMS is essential because the PowerBoost 1000C cannot handle the high current draw required by the motors, making the BMS a critical component for reliable motor operation and overall system safety.
   - Connections:
     - Battery Input: Connected to the LiPo battery's positive and negative terminals.
     - Output Terminals: Connected to the motor controller's VMOT and GND pins.

4.1.1.3 Voltage Divider

1. Battery Voltage Monitoring:

- Purpose: The battery voltage divider is used to monitor the voltage of the LiPo battery (nominal 3.7V) and scale it down to a range readable by the Arduino.
- Resistor Values:
  - R1=3300 Ω
  - R2=10,000 Ω
- Calculation:
  Using the formula:

$$V_{out} = V_{in} \times \frac{R2}{R1 + R2}$$

Assume Vin = 4.2 V (maximum battery voltage):

$$V_{out} = 4.2 \times \frac{10,000}{3300 + 10,000}$$

$$V_{out} = 4.2 \times \frac{10,000}{13,300}$$

$$V_{out} \approx 3.16\,V$$

This ensures the battery voltage is scaled safely for the Arduino's analog input.

- Integration: Connected to the LiPo battery's positive terminal and an analog input pin on the Arduino.

2. **Receiver Voltage Monitoring**:
   - Purpose: Detects when power is being supplied by the Qi wireless receiver, signaling the Arduino that the robot has docked and triggering the charging process.

- Resistor Values:
  - R1=3300 Ω
  - R2=10,000 Ω

- Calculation:
  Assume Vin = 5 V (voltage output from Qi receiver):

$$V_{out} = V_{in} \times \frac{R2}{R1 + R2}$$

$$V_{out} = 5 \times \frac{10,000}{12,000 + 10,000}$$

$$V_{out} = 5 \times \frac{10,000}{22,000}$$

$$V_{out} \approx 2.27\,V$$

This output voltage is within the safe range for the Arduino's analog input to detect the Qi receiver's power signal.

- Integration: Connected to the Qi receiver's output and an analog input pin on the Arduino.

4.1.1.4 Graphical Representation

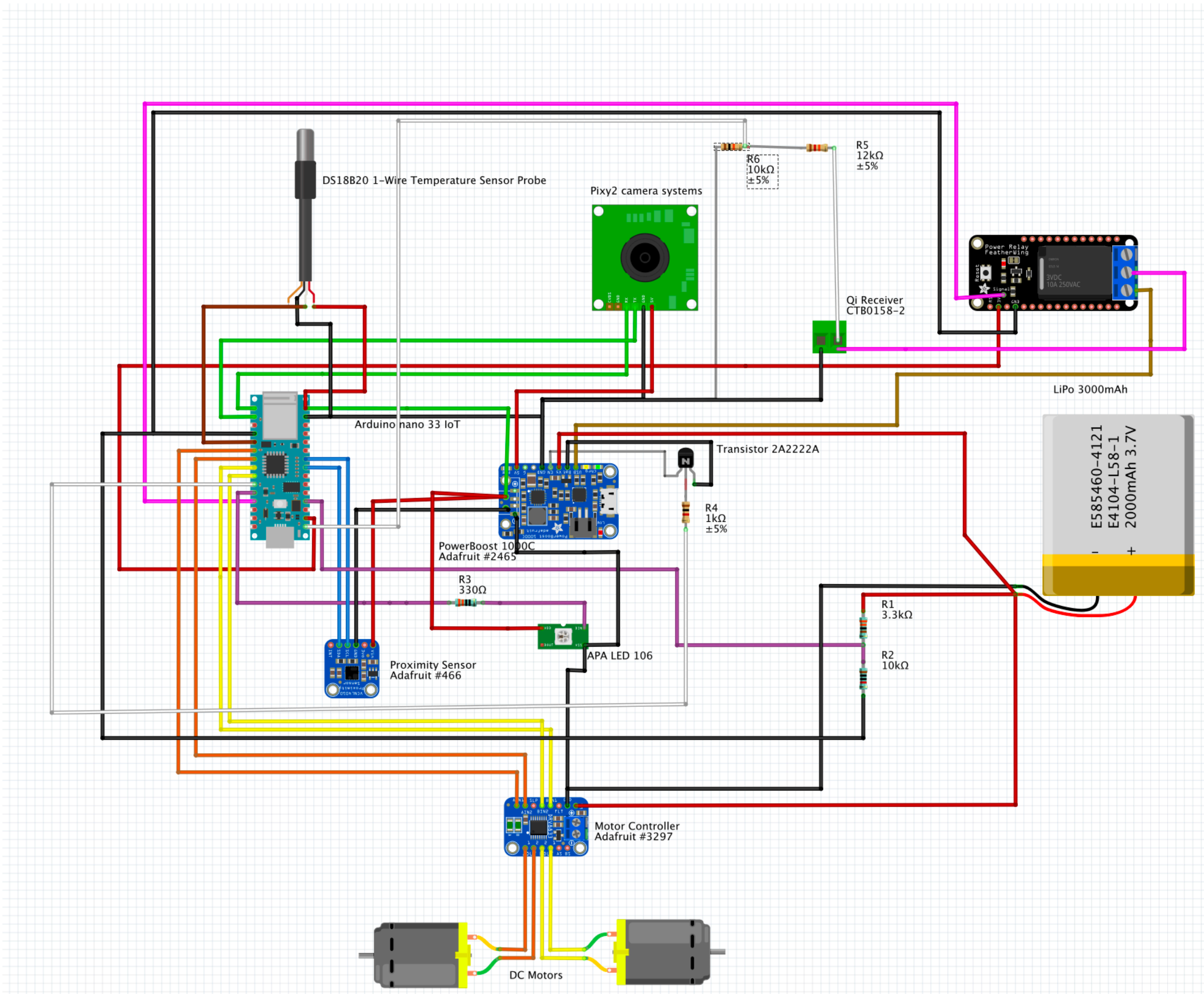

Figure 5: Robot Wiring Diagram.

The diagram above shows all critical connections, including the Arduino, power distribution, and sensor integrations. This graphical representation complements the detailed descriptions provided for each hardware component, ensuring a comprehensive understanding of the system's configuration.

4.1.2. Charging Station Components

1. **Base**
   - Placement: Serves as the foundational component of the charging station, positioned on the floor or a stable surface.
   - Integration: Houses the Qi wireless charging transmitter and ensures stable alignment for charging. The circular cutout in the base is

specifically designed to securely hold the transmitter in place, optimizing energy transfer during the charging process.

- Specifications: it features pre-drilled holes for mounting components, ensuring stability and alignment.

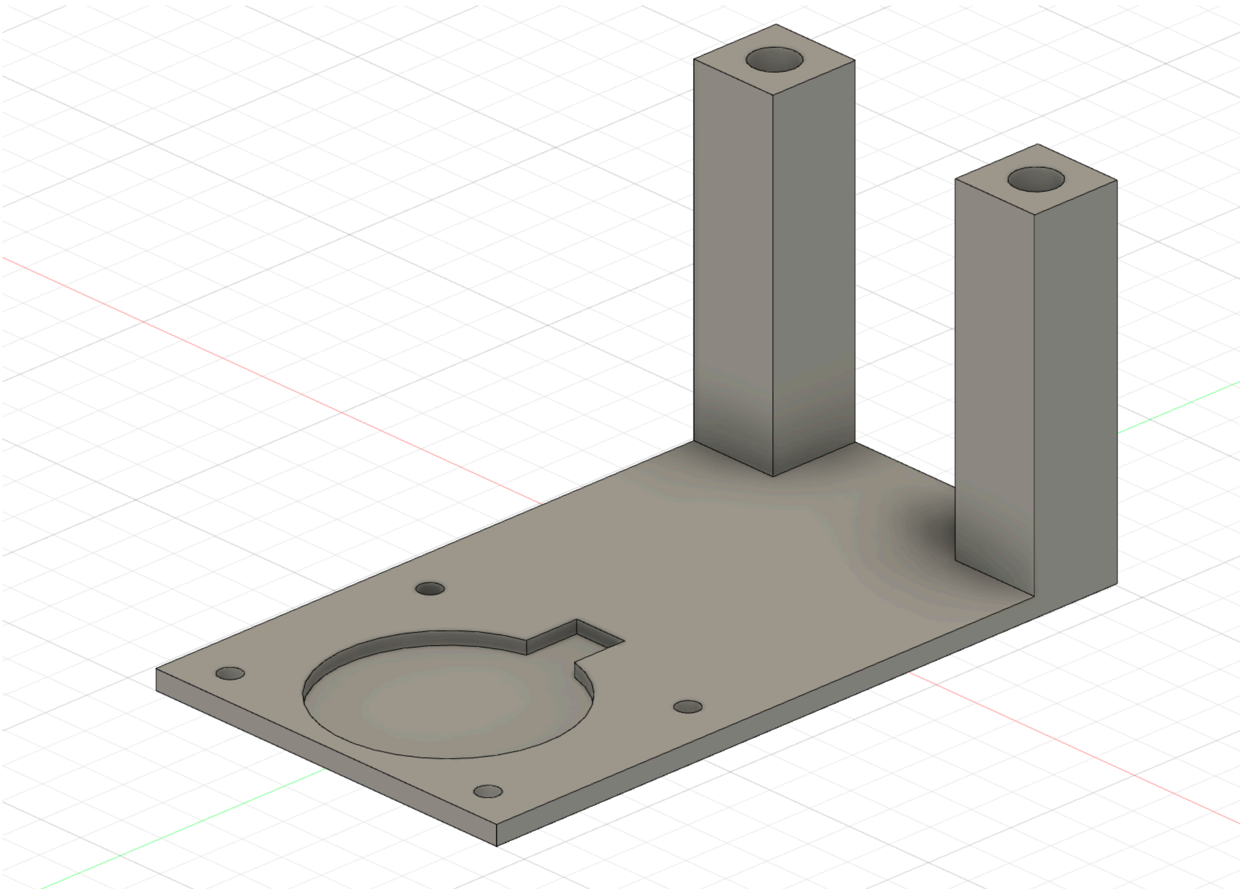

Figure 6. Charging Station -Base

2. **Rising Edge Docking Guide**
   - Placement: At the entry of the charging station’s docking pad.
   - Integration: Guides the rover into correct alignment.
   - Specifications: Sloped edges to facilitate alignment.

The base includes a rising edge and block system that guides the robot into the correct docking position, securing it in place during the charging process

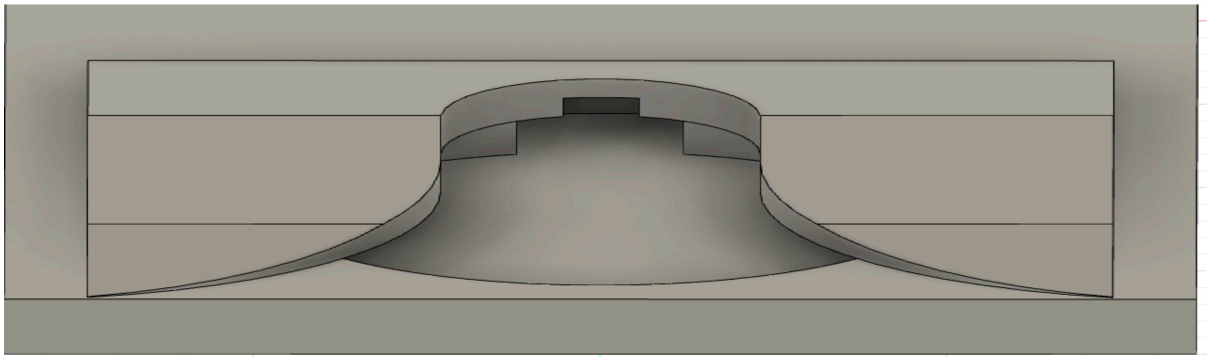

Figure 7. Base Rising Edge

3. **Circular Docking Feature**
   - Placement: Centered above the Qi transmitter on the charging pad.
   - Integration: Holds the rover securely during charging.
   - Specifications: Circular ridge for alignment.

Chassis: The robot’s chassis incorporates a circular docking feature that integrates smoothly with the rising edge and block on the base. This ensures precise alignment with the transmitter for effective wireless charging.

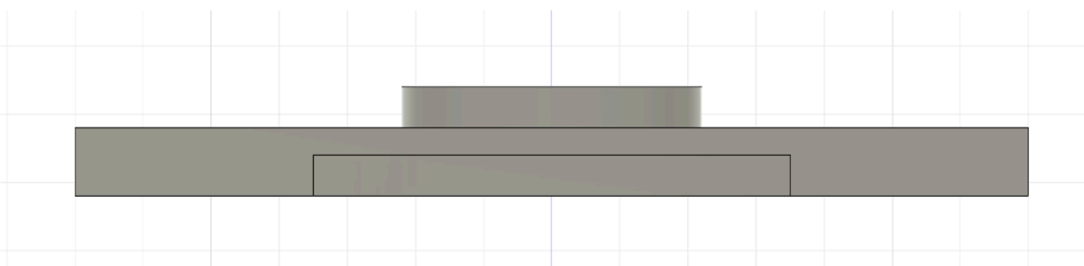

Figure 8: Circular Docking Feature

4. **Cooling Fan with Mount**
   - Placement: Near the Qi transmitter for heat dissipation.
   - Integration: Maintains safe temperatures during prolonged charging.
   - Control: Manually operated by the user.

- The fan mount is positioned above the robot to regulate the temperature during charging. Its adjustable design allows for precise positioning overheat-sensitive areas, providing optimal cooling for the PowerBoost 1000C charger.

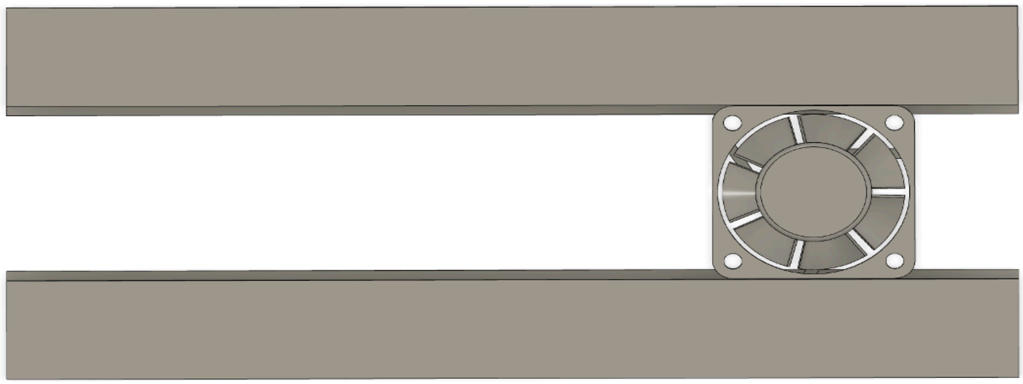

Figure 9. Fan Mount for cooling the Charger

5. **Complete Design**
   - Placement: The charging station is designed as a single integrated unit, positioned on a stable surface to provide consistent functionality.
   - Integration: Combines all individual components (base, rising edge, docking guide, and cooling fan) into a cohesive structure. The charging station seamlessly aligns with the BID4R robot during docking, ensuring proper positioning and efficient wireless charging.
   - Specifications: The design includes structural supports for stability, precise cutouts for the Qi transmitter and fan, and an ergonomic layout to guide the robot into the docking position effortlessly.

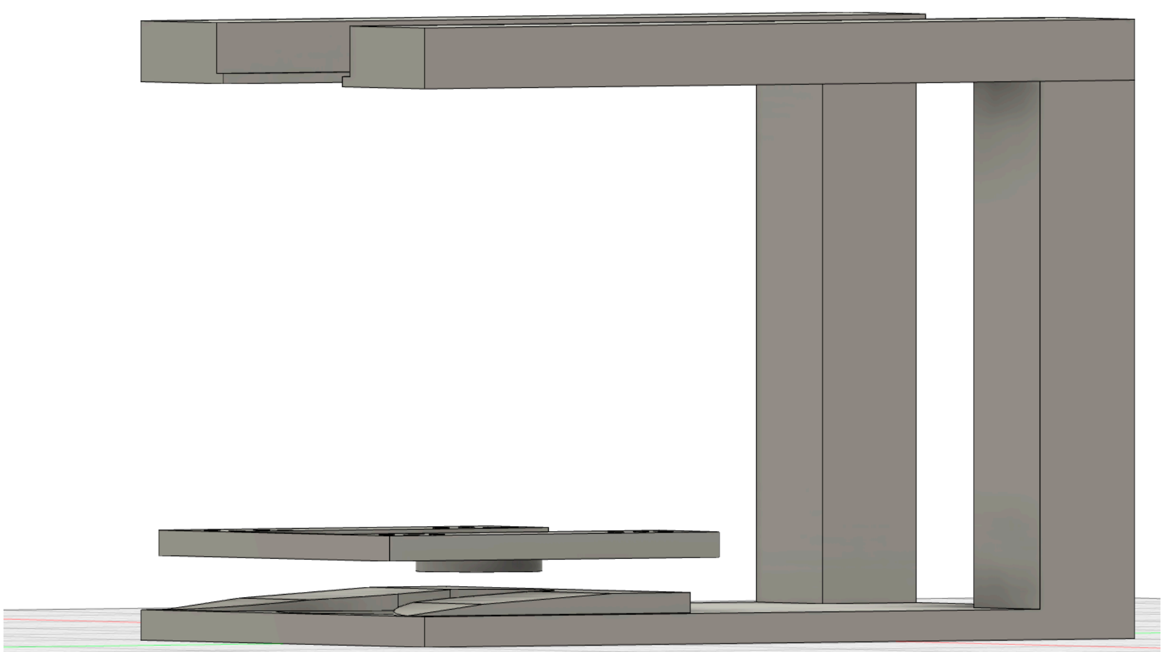

Figure 10: Complete Design of the Charging Station

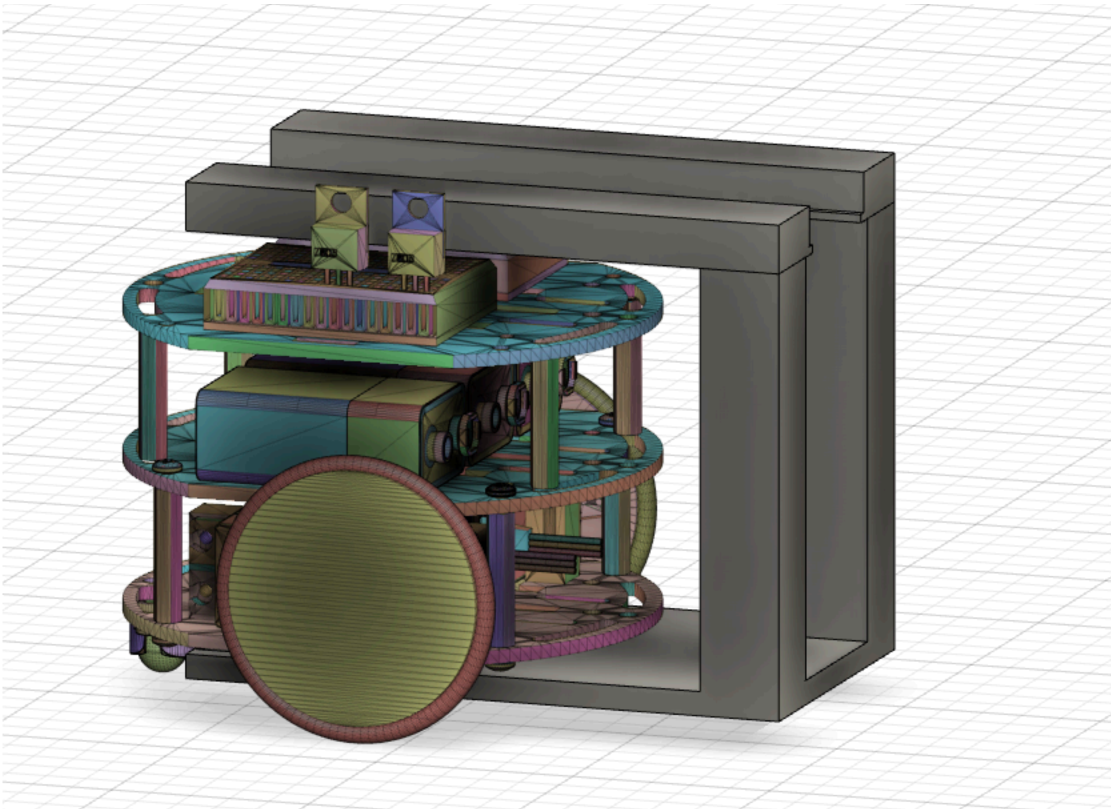

Figure 11: Robot Docking on the Charging Station

This image illustrates the integration of the BID4R robot with the charging station. The docking process demonstrates how the robot aligns with the rising edge and block system, ensuring proper positioning over the Qi transmitter for efficient wireless charging. This setup highlights the seamless interaction between the robot and the charging station.

4.2. Software Detailed Design

This section provides a comprehensive overview of each software module within the BID4R system. Each module includes functionality, conditions for execution, processing logic, interfaces, and any relevant security requirements. Additionally, graphical representations and flow diagrams are provided for each module to visually demonstrate the module's flow and logic.A narrative description of each module, its function(s), the conditions under which it is used (called or scheduled for execution), its overall processing, logic, interfaces to other modules, interfaces to external systems, security requirements, etc. Explain any complex algorithms used by the module in detail

4.2.1. Setup and Initialization Module

- Function: Initializes all sensors, pins, and communication protocols at system startup.
- Conditions: This module is called once at the start of the system.

- Logic: Sets up serial communication, sensors, LED indicators, motor pins, and charging controls.
- Graphical Representation:

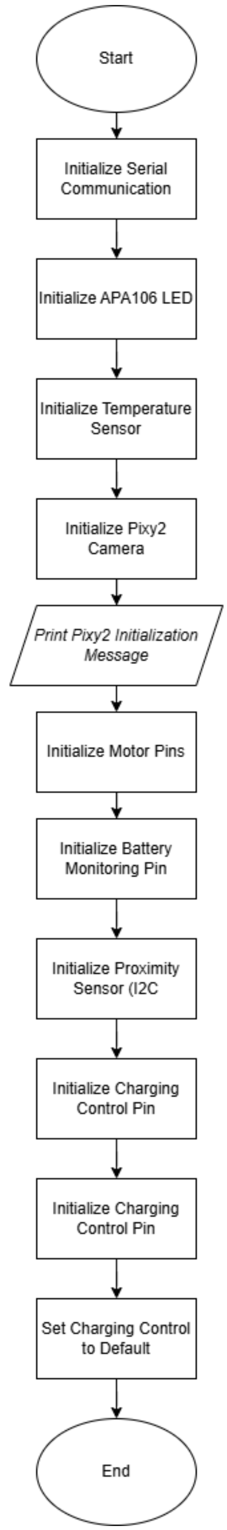

Figure 12: Setup and Initialization Flow Diagram.

4.2.2. Main Loop Module

- Function: Acts as the primary loop of the system, monitoring battery voltage, temperature, and charging status.
- Conditions: Runs continuously after system setup.
- Logic: Determines if the system is in charging mode or normal operation and updates LED indicators accordingly.
- Graphical Representation:

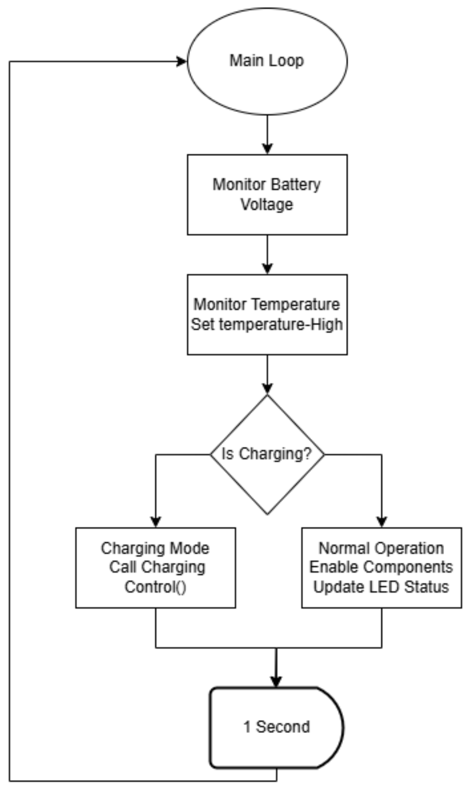

Figure 13: Main Loop Flow Diagram.

4.2.3. Temperature Monitoring Module

- Function: Continuously reads the temperature sensor data and provides feedback to the main control system.
- Conditions: Called at regular intervals to ensure safe operating temperatures.
- Logic: Requests temperature data from the DS18B20 sensor and checks against predefined thresholds.

- Graphical Representation:

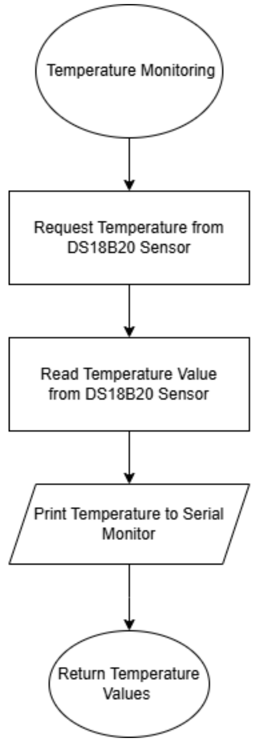

Figure 14: Temperature Monitoring Flow Diagram.

4.2.4. Battery Monitoring Module

- Function: Reads and calculates the battery voltage through a voltage divider, enabling battery status monitoring.
- Conditions: Monitored at regular intervals during operation.
- Logic: Converts analog voltage readings to digital values and calculates actual voltage using a predefined formula.
- Graphical Representation:

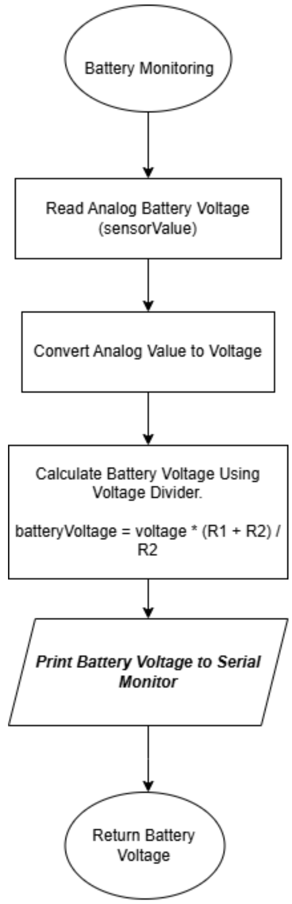

Figure 15: Battery Monitoring Flow Diagram.

4.2.5. Charging Control Module

- Function: Manages charging operations by enabling or disabling the relay to the Qi wireless charging receiver based on battery and temperature data.
- Conditions: Engages when charging is detected
- Logic: Monitors battery voltage and temperature to control charging and prevent overcharging.
- Graphical Representation:

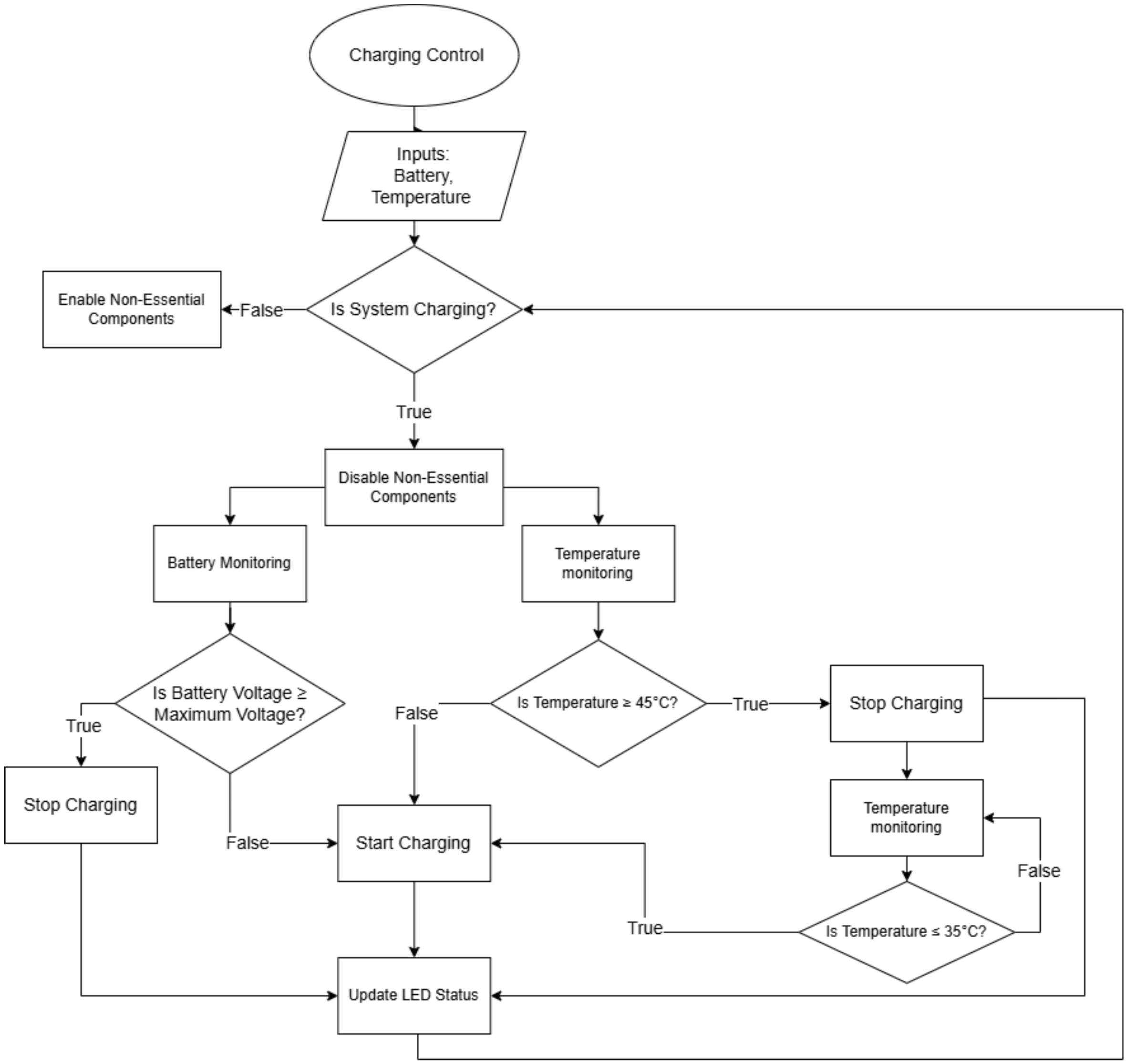

Figure 16: Charging Control Flow Diagram.

4.2.6. LED Status Module

- Function: Manages the LED indicators to display system status, including battery level, charging status, and temperature alerts.
- Conditions: Activated by changes in battery level, charging status, or temperature.
- Logic: Displays different colors and flashing patterns based on system status.
- Graphical Representation:

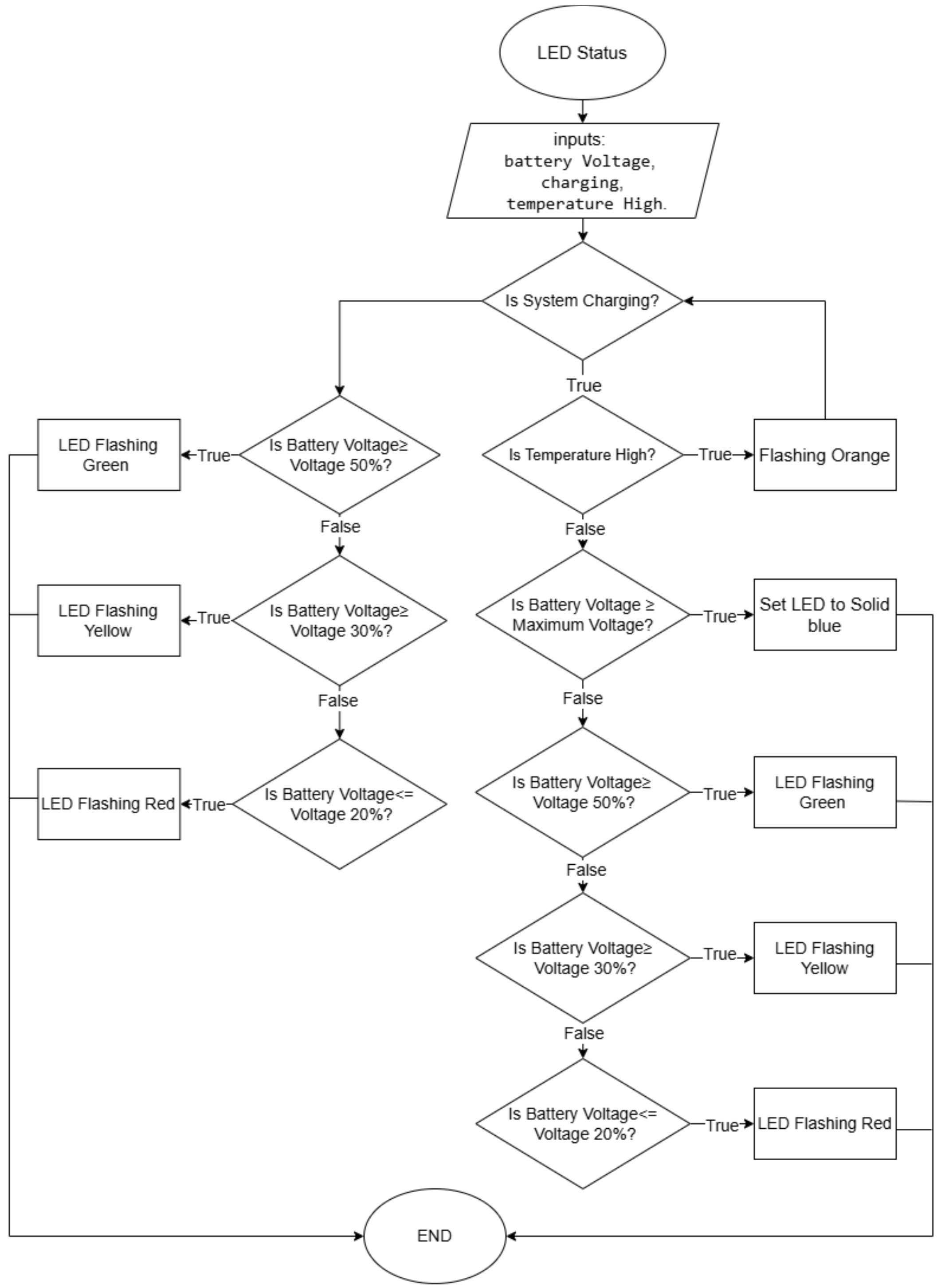

Figure 17: LED Status Flow Diagram.

4.3. Internal Communications Detailed Design

This section provides an in-depth look at the internal communication architecture of the BID4R system, expanding upon the high-level overview provided in Section 2.3. Here, we detail the design, protocols, data formats, and specific connectivity requirements that enable seamless interaction among the system's components. The communication design is critical for managing power, ensuring safe charging, and providing operational feedback to the user.

4.3.1. Communication Protocols

1. **I2C (Inter-Integrated Circuit)**
   - Description: The I2C protocol is used for communication between the Arduino Nano and certain sensors, such as the proximity sensor. I2C allows multiple devices to share the same bus, enabling efficient data transfer with minimal wiring.
   - Functionality:
     - The Arduino Nano acts as a master device, sending requests and receiving data from slave devices.
     - Example: The proximity sensor is connected via the I2C bus using pins A4 (SDA) and A5 (SCL), allowing the Arduino to receive alignment data during docking.
2. **UART (Universal Asynchronous Receiver-Transmitter)**
   - Description: UART is primarily used for communication with external modules, such as the Pixy2 camera system, which is part of the pre-existing setup for the rover.
   - Functionality:
     - The Arduino Nano communicates with the Pixy2 camera over serial lines using pins D0 (RX)and D1 (TX).
     - Example: While the Pixy2 camera provides vision-based data for potential enhancements, it is not directly involved in the BID4R project scope but remains part of the original rover design.
3. **GPIO (General Purpose Input/Output)**
   - Description: GPIO pins on the Arduino are utilized for control and signaling, allowing basic on/off functionality for components such as the relay, motor controller, and LED indicators.
   - Functionality:
     - Temperature Sensor: Sends temperature readings to the Arduino through D4 (GPIO) for thermal monitoring during charging.
     - LED Indicators: Controlled via D8 (GPIO), the RGB LED provides visual feedback on the battery status using various colors and patterns.
     - Example: The Arduino uses GPIO pins to activate the relay (D9), monitor temperature (D4), and update LED status (D8).
4. **Analog Input**
   - Description: Analog input pins are used to read variable voltage levels, such as the battery's voltage, through a voltage divider circuit.
   - Functionality:
     - Battery Voltage Monitoring: The Arduino reads the battery voltage via pin A0 (Analog Input). This scaled-down voltage signal is used to assess the battery level and control the charging process.

- Example: The analog input allows real-time monitoring of the battery's voltage and updates the LED indicator and relay status accordingly.

4.3.2. Communication Paths

The communication paths within the system connect new and existing components, enabling efficient data transfer and control signals. Below is an overview of the primary communication pathways:

- **Data Flow from Sensors to Arduino**:
  - The temperature sensor sends thermal data to the Arduino via D4 (GPIO), allowing the system to monitor conditions during charging.
  - The proximity sensor, connected via A4 (SDA) and A5 (SCL), provides alignment data to assist with docking.
  - The battery voltage divider, connected to A0 (Analog Input), provides real-time voltage data for safe charging.
- **Control Signals for Charging**:
  - The Arduino sends signals via D9 (GPIO) to the relay, activating or deactivating charging based on battery level and temperature conditions.
- **LED Status Updates**:
  - Using D8 (GPIO), the Arduino controls the RGB LED indicators to display the battery status with various colors and patterns.
- **Existing Components**:
  - The proximity sensor (I2C), Pixy2 camera (UART), and motor controller (GPIO) are pre-existing components in the rover. While interfaced with the Arduino, they remain outside the primary scope of the BID4R project but demonstrate the system's capability to manage multiple communication protocols.

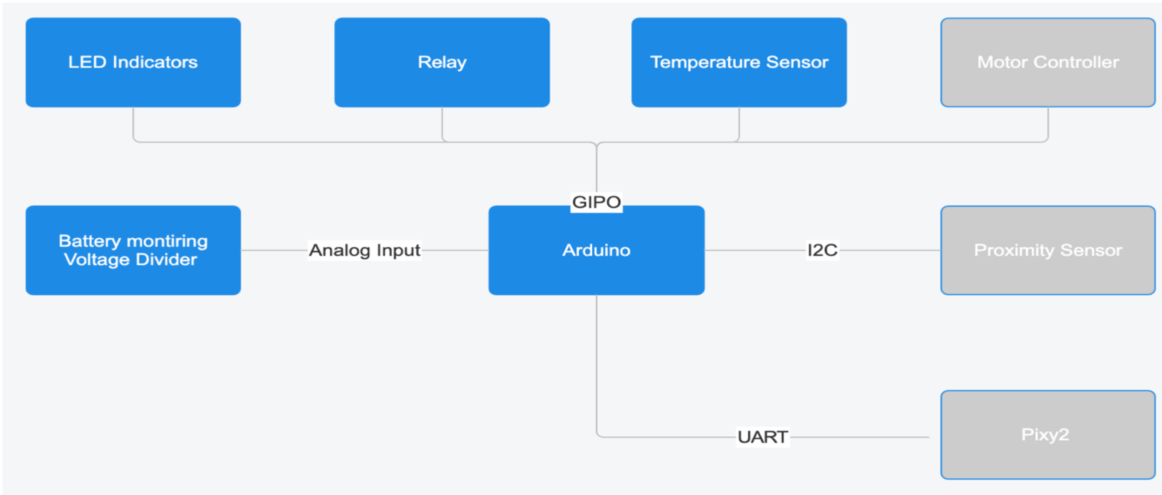

Figure 18. Internal Communications Diagram. (explained in section 2.3)

5. External Interfaces

External systems that interact with the BID4R system include pre-existing components such as sensors, cameras, motor controllers, and DC motors. These components play critical roles in the rover's operation and interface with the Arduino Nano. While their functionality remains unchanged and independent of BID4R-specific enhancements, they are essential for the project's success.

5.1. Hardware Interface Architecture

The BID4R system integrates pre-existing hardware components to achieve navigation and mobility. These components include:

- Proximity Sensor (VCNL4010):
  - Function: Measures distance to nearby objects, providing data for docking alignment and collision avoidance.
  - Communication: Two-way communication with the Arduino over I2C.
- Pixy2 Camera:
  - Function: Detects objects using color and shape recognition, aiding navigation and alignment.
  - Communication: Two-way communication with the Arduino via SPI.
- Motor Controller:
  - Function: Controls the DC motors based on Arduino signals, enabling precise movement and direction control.
  - Communication: Receives one-way commands from the Arduino through GPIO.
- DC Motors:
  - Function: Provide mobility for the rover by responding to motor controller commands.
  - Communication: Controlled indirectly by the Arduino via the motor controller.

5.2. Hardware Interface Detailed Design

This section consolidates the technical details and interactions between the BID4R system and external hardware components:

- Proximity Sensor (VCNL4010):
  - Uses IR-based detection to measure distances in millimeters.
  - Data Flow: Sends real-time data to the Arduino for processing.
- Pixy2 Camera:
  - Transmits object detection data in structured packets (e.g., coordinates, dimensions).
  - Data Flow: Continuously monitors surroundings and sends object details to the Arduino.
- Motor Controller:

    - Adjusts motor speed and direction based on digital signals from the Arduino.
    - Data Flow: Processes one-way commands to control rover movement.
- DC Motors:
    - Executes movement commands as directed by the motor controller.
    - Data Flow: Operates directly under motor controller input.

5.3. Software Interface Architecture

The BID4R system's software interfaces enable efficient communication between the Arduino and external components. Each interface handles specific data flows:

- Pixy2 Camera Interface:
    - Protocol: SPI for high-speed communication.
    - Data Flow: Transfers object detection data to the Arduino.
- Motor Control Interface:
    - Protocol: GPIO for direct motor control.
    - Data Flow: Arduino sends HIGH/LOW signals for motor adjustments.
- Proximity Sensor Interface:
    - Protocol: I2C for regular distance measurement updates.

Data Flow: Arduino queries proximity data for docking alignment

5.4. Software Interface Detailed Design

5.4 Software Interface Detailed Design
Details for each software interface include data formats, protocols, and error management:

- Pixy2 Camera:
    - Data: Transmits structured object data packets.
    - Error Handling: Retries transmission if communication fails.
- Motor Controller:
    - Data: Receives HIGH/LOW signals for speed and direction control.
    - Error Handling: Defaults to stopping motors on signal loss.
- Proximity Sensor:
    - Data: Sends distance values in millimeters.
    - Error Handling: Retries data requests if no response is received.

5.5. Internal Communication

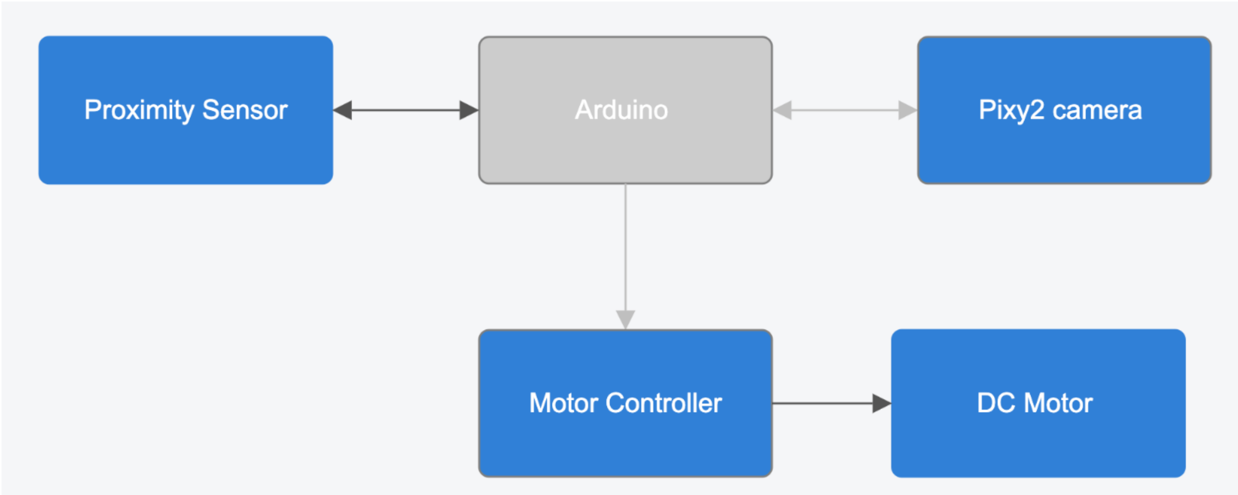

Figure 19: Overview of Component Interactions
This diagram illustrates the interaction pathways between components and the Arduino, highlighting its dual role of operating the robot's systems and managing the battery system.

- Proximity Sensor ↔ Arduino:
  - Two-way communication.
  - The sensor provides alignment data to the Arduino, which processes the input.
- Pixy2 Camera ↔ Arduino:
  - Two-way communication.
  - The camera sends object data to the Arduino, which processes it for alignment tasks.
- Arduino → Motor Controller:
  - One-way communication.
  - Sends control signals for movement.
- Motor Controller → DC Motor:
  - One-way communication.
  - Directs motor speed and direction as instructed by the Arduino.

The faded Arduino in the diagram highlights its dual role: operating the robot's systems (sensors, camera, and motor control) and managing the battery system simultaneously.