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Overview of the System

The Mobile Tool Assistant is an autonomous robot designed to follow a user within a short range while carrying small tools or materials. It uses Ultra-Wide Band (UWB) based localization to maintain a consistent distance from an authorized user and integrates onboard sensing and control logic to navigate safely in an indoor environment.

The system consists of a mobile base with drive motors, embedded processing hardware, and sensors for environmental awareness. Its primary function is to automatically follow a user while carrying a payload and taking actions to avoid obstacles. The robot operates entirely autonomously once it starts and would alert the user when the battery level drops below 10%.

The system architecture emphasizes modularity: a tracking subsystem estimates the user's relative position, a control subsystem computes motion commands, and a power subsystem manages energy distribution and charging. All components communicate through a central processing unit that ensures real-time response and safety compliance.

The proposed solution satisfies the project requirements by:

- Maintaining autonomous, reliable short-range following feature using UWB distance estimation.
- Providing safety through automatic obstacle avoidance and controlled motion.
- Supporting energy-efficient operation and charging features.

This high-level design provides a balance between practicality, cost, and technical feasibility while ensuring the robot can operate within the constraints outlined in the requirements specification.

Functional Block Diagram

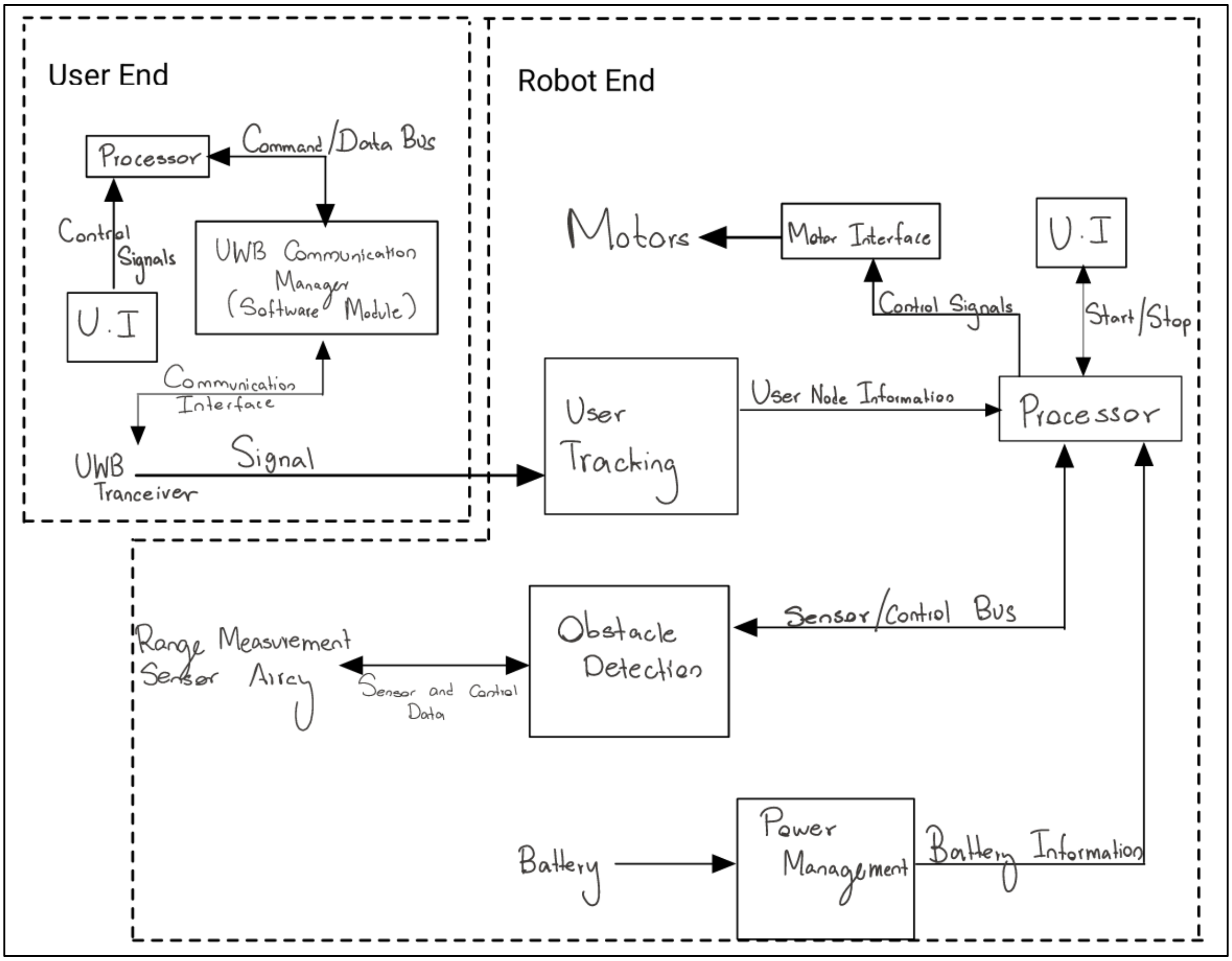

Figure 1: Functional Block Diagram

Functional Description

The system is divided into six main subsystems that collectively achieve user following, motion control, and operational safety.

1. **User Tracking Subsystem**
Determines the user's relative position using UWB distance data.
Inputs: UWB range signals.
Outputs: Estimated relative user position and movement direction.
Requirement: Maintain continuous communication within ~10 m range with minimal delay.

2. **Navigation Subsystem**
Collects environmental data to detect obstacles.
Inputs: Range sensor data.
Outputs: Distance/Proximity flags.
Requirement: Provide timely updates for collision-free motion.

3. **Motion Control Subsystem**
Convert data into drive commands.
Inputs: Desired following distance, obstacle data.
Outputs: Motor and steering signals.
Requirement: Achieve stable, smooth, and responsive movement.

4. **Processing and Communication Subsystem**
Acts as the core controller for coordinating all subsystems.
Inputs: Data from tracking, sensors, and user controls.
Outputs: Status updates, and telemetry.
Requirement: Perform real-time decision-making with efficient data handling.

5. **Power Management Subsystem**
Regulates and distributes electrical power to system components.
Inputs: Battery supply.
Outputs: Stable voltage lines to other subsystems and battery information.
Requirement: Ensure safe operation and adequate runtime.

6. **User Interface Subsystem**
Provides manual control and feedback to the user.
Inputs: Buttons or wireless control signals.
Outputs: Indicators for mode, status, and battery level.
Requirement: Offer simple, reliable interaction during operation.

System Test Plan

Table 1: Functional Tests

Test ID	Requirement	Test Objective	Test Method / Procedure	Expected Result
F1	Follow distance: 1 m ± 0.5 m	Verify the robot maintains proper following distance from the user node.	Place the user node at varying distances (0.5–2 m). Measure and record actual following distance over time.	Robot maintains an average distance of 1 m ± 0.5 m in all trials.
F2	Follow speed: 5 km/h ± 1 km/h	Verify the robot's ability to follow a moving user within specified speed.	Move the user at incremental speeds up to 6 km/h. Measure robot's response lag and following accuracy.	Robot maintains tracking and motion synchronization within the specified speed tolerance.
F3	Payload: 5 kg capacity	Validate payload-carrying capability during motion.	Place payloads of up to 5 kg on the platform and repeat follow tests.	Robot moves smoothly without mechanical strain or loss of control.
F4	Obstacle detection	Verify obstacle detection and avoidance.	Place static obstacles within 1.0 m in robot path. Record detection and response.	Robot detects obstacle ≥1.0 m away and responds accordingly.

Table 2: Hardware Tests

Test ID	Requirement	Test Objective	Test Method / Procedure	Expected Result
H1	Payload Size limit: 30×20×15 cm	Confirm ability to carry payload of given dimensions	Measure payload dimensions.	Robot moves smoothly without mechanical strain or loss of control.
H2	Surface navigation	Validate navigation on flat indoor surfaces.	Operate robot on a smooth surface.	Robot navigates without slipping, stalling, or losing balance.

Table 3: User Interface Test

Test ID	Requirement	Test Objective	Test Method / Procedure	Expected Result
UI1	Start/stop interface	Validate user control of operation.	Activate robot via user interface. Observe response.	Robot starts and stops following reliably upon user input.

Table 4: Power and Charging Tests

Test ID	Requirement	Test Objective	Test Method / Procedure	Expected Result
P1	Charging input and time	Verify charging operation with 120 V AC supply.	Connect charger to standard outlet, measure total recharge time.	Full charge achieved within 6 hours.
P2	Battery runtime	Validate operating duration.	Fully charge battery, operate continuously in follow mode.	Robot operates for ≥2 hours on a single charge.

Table 5: Non-Functional tests

Test ID	Requirement	Test Objective	Test Method / Procedure	Expected Result
NF1	Indoor-only operation	Verify safe and reliable operation indoors.	Test operation in different rooms and lighting conditions.	Robot functions stably indoors; avoids failure under typical lighting.
NF2	Temperature tolerance	Validate operation in standard indoor range.	Run robot in environments between 20–25°C.	Normal operation within temperature range; no performance degradation.
NF3	Noise compliance	Measure sound level during operation.	Use sound meter during motion.	Noise level ≤ 50 dB.
NF4	Data privacy	Verify no user data stored.	Inspect firmware and logs for any visual/audio capture.	No personal data stored or transmitted.
NF5	Authorized pairing	Verify restricted pairing behavior.	Attempt to connect unauthorized devices.	Robot accepts only pre-authorized user node connections.

APPENDIX I: SYSTEM ALTERNATIVE

APPENDIX A: Aditya Ramakrishnan (Alternative-1)

Overview

A Mobile Tool Assistant that autonomously follows the user using a vision-based tracking system, detects and avoids obstacles with LiDAR. The onboard camera continuously tracks the designated user using a visual marker, while the LiDAR module provides real-time mapping for safe navigation.

Key Features

- Vision-Based Following: Tracks the user through real-time image processing and maintains a consistent following distance using camera-derived position data.
- LiDAR Navigation: Real-time LiDAR scanning allows precise obstacle detection and local path planning.
- Processing: The processing unit fuses vision and LiDAR data to plan paths and control the drive system.
- User Interface: Simple start/stop and mode control via smartphone.
- Safety and Reliability: Obstacle detection and navigation, low-battery alerts.

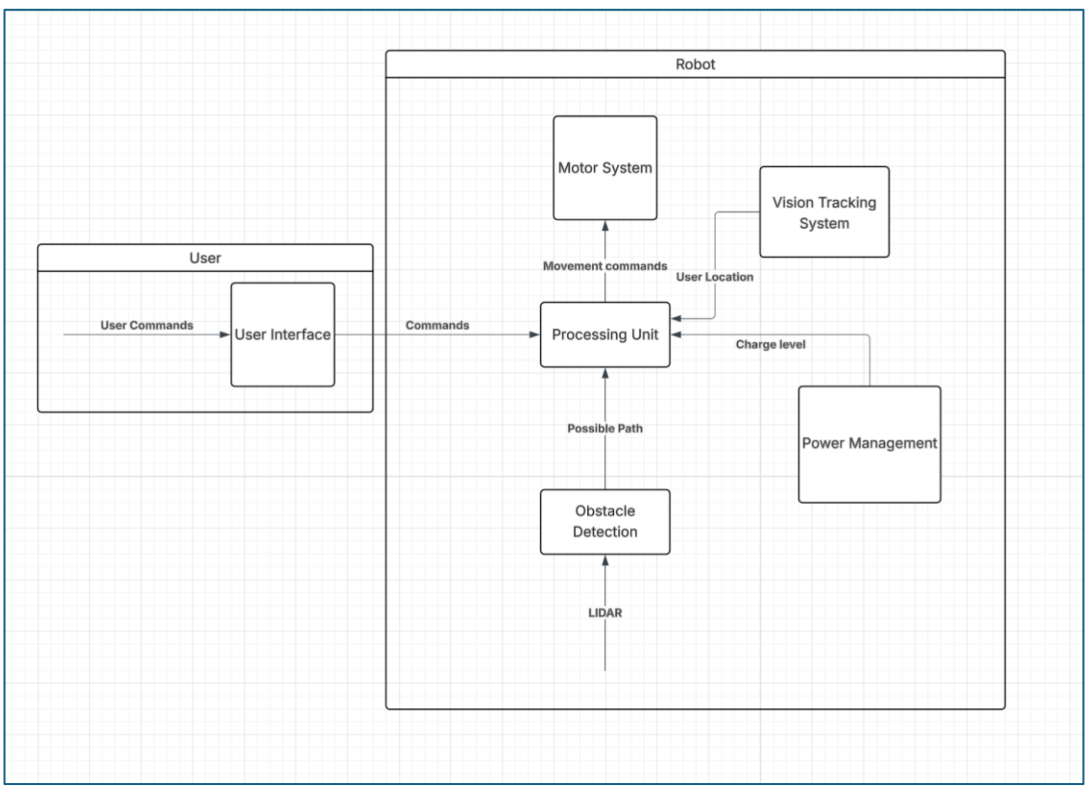

Figure 2: Alternative 1 - Block Diagram

APPENDIX B: Ethan D'Almeida (Alternative-2)

Overview

The system is an autonomous robot designed to follow a user carrying a small BLE transmitter while navigating safely in its environment. It combines BLE tracking, sensor-based obstacle detection, and autonomous movement.

Key Features

- BLE based tracking using Direction Finding (Bluetooth 5.1 and above) and RSSI.
- Obstacle detection sensors for close-range obstacle detection along with stereo cameras for long-range obstacles with depth sensing.

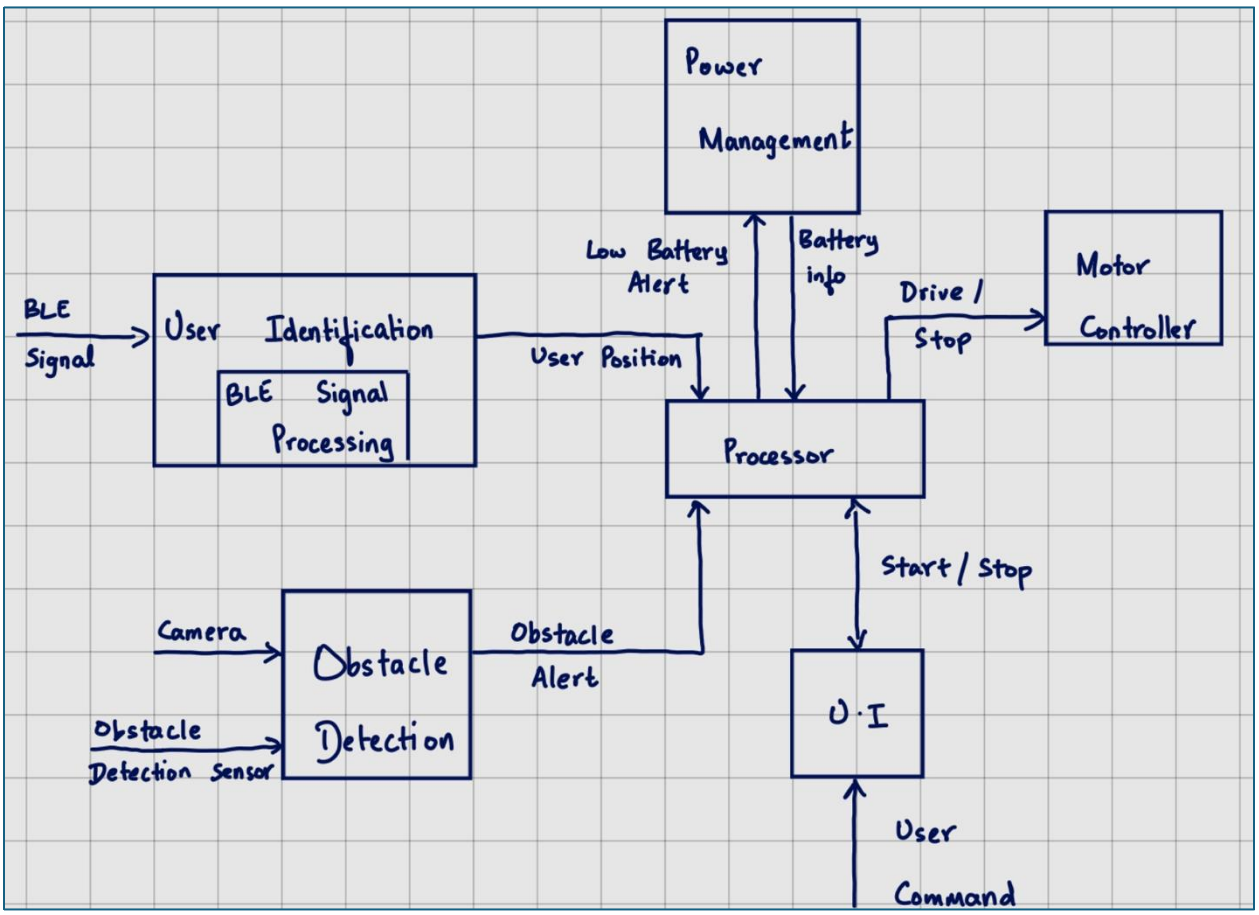

Figure 3: Alternative 2 - Block Diagram

APPENDIX C: Chidubem Emeka-Nwuba (Alternative-3)

Overview

The system is an autonomous mobile assistant designed to follow a user wearing a BLE-based wearable device while navigating safely through its environment. It combines BLE communication with IMU-based motion data to track the user's movement and orientation, while onboard sensors handle real-time obstacle detection and avoidance. The robot platform interprets incoming data to adjust its path and maintain smooth, safe following behavior.

Key Features

- BLE-Based User Tracking: The wearable user node continuously broadcasts motion and orientation data, allowing the robot to interpret user direction and movement in real time.
- Obstacle Detection: Integrated sensing enables the robot to detect obstacles in its path and recover from displacement while maintaining stable navigation.
- Autonomous Motion Control: A central processing unit interprets user and sensor data to control the robot's motors and execute movement decisions.
- Safety Features: The system identifies potentially unsafe conditions, such as ramps or stairs, to prevent accidental falls or collisions.
- Power Management System: Manages and distributes power across system components and communicates with the processor to report battery status and initiate power-saving actions.
- User Interface System: Software interface that allows the user to start, stop, and monitor operation, utilizing information received from the user node for control.

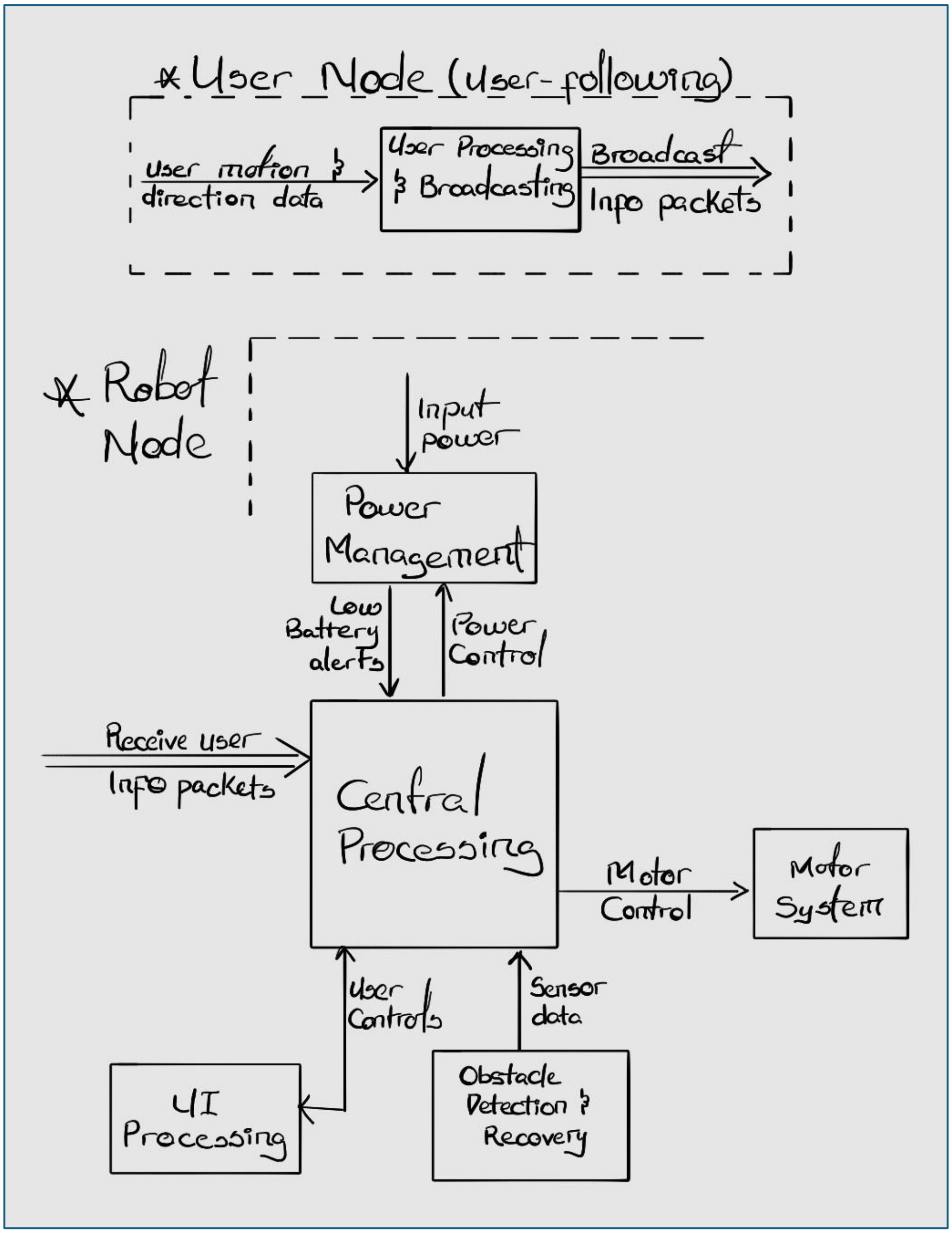

Figure 4: Alternative 3 - Block Diagram

APPENDIX D: Aneek Mohamed Ruksan (Alternative-4)

System Overview

The system is an autonomous mobile assistant designed to follow a user carrying a UWB transceiver while navigating safely through its environment. It combines UWB-based tracking, sensor-driven obstacle detection, and autonomous motion control for reliable operation.

Key Features

- UWB-based User Tracking: Reliable short-range communication for user identification and distance estimation.
- Obstacle Detection: Range sensor array for real-time environment scanning and collision avoidance.
- Autonomous Motion Control: Processor-driven motor interface for path following and maneuvering.
- Dual User Interfaces: Remote (wearable) and onboard UI for control options.

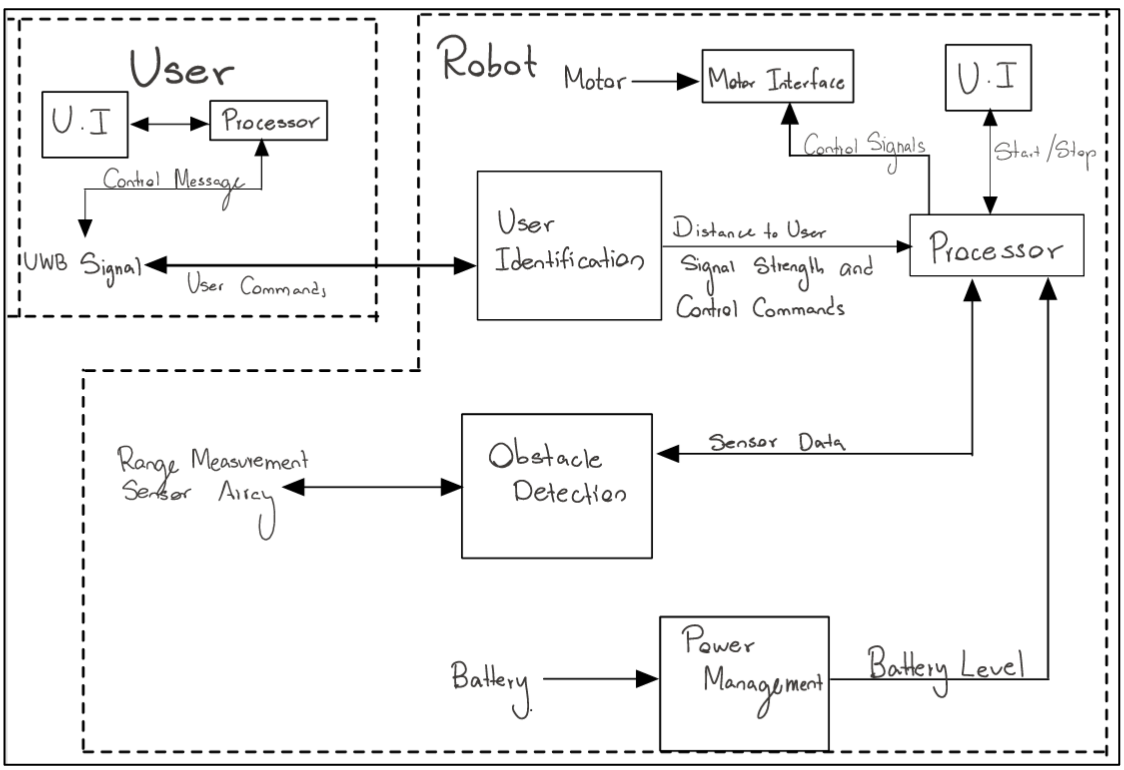

Figure 5: Alternative 4 - Block Diagram

APPENDIX 2: ANALYSIS OF SYSTEM ALTERNATIVES

Table 6: Decision Matrix

Criteria	Weight	Alt-1	Alt-2	Alt-3	Alt-4
Hardware Cost	4	6	7	9	8
Development Time	5	4	4	5	4
Power Consumption	4	3	7	8	8
Ease of Use	3	6	6	7	8
Reliability	5	4	8	5	4
Scalability	4	8	6	4	5
Final Score		126	158	155	137

Each proposed system alternative was analyzed based on its ability to meet the project's technical, economic, and operational requirements. The key evaluation criteria included hardware cost, development time, power consumption, ease of use, reliability, and scalability. Each criterion was weighed on a scale of 1 to 5 according to its importance, and the alternatives were scored out of 10 based on performance under each category. The resulting weighted scores provided an objective comparison of overall feasibility.

From the analysis, Alternative 4 (UWB-based system) achieved the highest overall score (158), demonstrating the best balance between technical performance and practicality. UWB communication offers superior distance accuracy and reliability compared to BLE and vision-based tracking, while maintaining moderate cost and power usage.

Alternative 3 (BLE + IMU system) followed closely with 155 points, offering excellent power efficiency and affordability but with limited positional precision due to RSSI fluctuations. Alternative 1 (Vision + LiDAR system) and Alternative 2 (BLE + stereo vision system) provided strong technical capability but were less economical and more power-intensive, making them less suitable for a compact, low-cost prototype.

In summary, Alternative 4 was selected as the final design due to its high reliability, strong technical accuracy, and overall balance across all weighted criteria. It best meets the project's objectives while remaining feasible for further development and integration.