System Specification: Indoor Localization Device

Group: Group 5

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1 The Concept

Contributed by Dominic Bertolo

1.1 Overview

The intended system is a device that implements indoor localization techniques to aide in navigating a user within indoor spaces. The primary target audience for this device is users with visual impairments or unfamiliarity with the indoor environment they wish to navigate. The intended device aims to bridge the accessibility gap created for those with visual impairments in unfamiliar areas with audio cues that guide a user towards a destination that they have inputted.

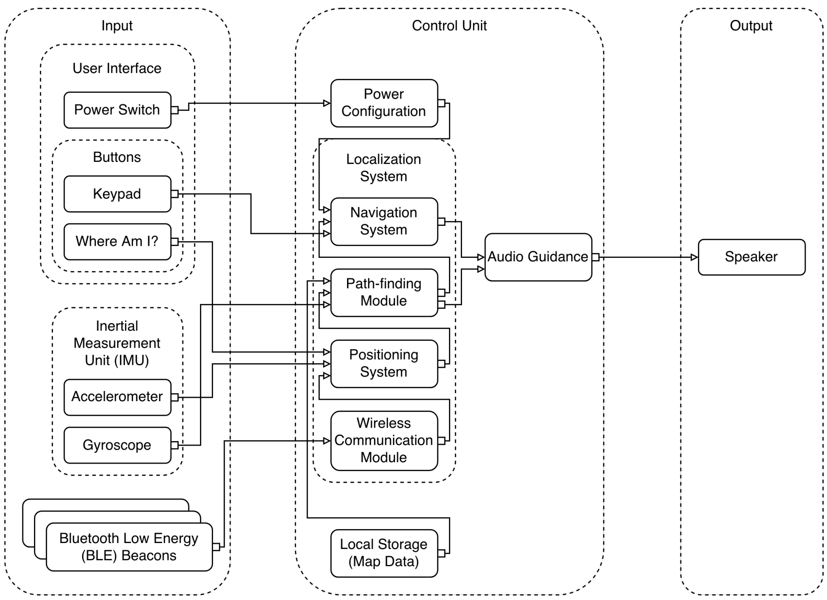
1.2 Changes from Original Specification

Compared to the original requirements specification, the device has changed in its user positioning system. In the original iteration, the user-position system was to be a hybrid system consisting of a Pedestrian Dead Reckoning (PDR) system and a WiFi Fingerprinting system. The new system design keeps the PDR system but replaces the WiFi Fingerprinting with Bluetooth Low Energy (BLE) Fingerprinting, favoring the use of BLE beacons as sources of signal instead of WiFi access points.

2 Inputs/Outputs and System Block Diagram

Contributed by Dominic Bertolo

2.1 Block Diagram



Group Block Diagram

2.2 Inputs/Outputs

Clearly specify the inputs and outputs for each block in the system. This should include both data and signals, as appropriate.

2.2.1 Inertial Measurement Unit (IMU)

The Inertial Measurement Unit (IMU) is a module that consists of an accelerometer and a gyroscope. The accelerometer takes in an input of the user's movement and provides an output of raw acceleration data. Similarly, the gyroscope takes an input of the orientation of the user based on a fixed reference point and provides an output of an orientation offset relative to its fixed reference point.

2.2.2 User Interface

The User Interface comprises of a power switch and a four-by-three keypad. The power switch has an input of the boolean state the user has set. Based on the state of the power switch, a signal will be outputted that represents the boolean state it is in. Each button of the four-by-three keypad will take an input of the boolean state of being pressed down or not. A signal from each button will be outputted to indicate the boolean state of whether it is pressed or not. The "Where Am I?" button is separately listed in the block diagram as primarily, the keypad buttons are used for inputting a destination to navigate towards. The "Where Am I" button is separate in its purpose and use compared to the other keypad buttons, but it is the same as the other keypad buttons for the input it receives and the output it provides.

2.2.3 Bluetooth Low Energy (BLE) Beacons

The Bluetooth Low Energy (BLE) Beacons are one of the few components to the system that do not take an input. They have a preconfigured setting for their unique identifier, aside from this configuration, there is no input provided to the beacons. Their output is a signal containing the unique identifier of the beacon.

2.2.4 Power Configuration

The power configuration determines whether the device should continue to process data. It takes an input of the signal provided by the power switch, and does not provide an output to be processed, but instead outputs the action of toggling the state of the remaining systems of the device to reflect the power configuration.

2.2.5 Local Storage

The data that is locally stored on the device does not take an input as it is preconfigured and static. This data is a source of information for systems in the device to operate based on. Due to this, it can be representing as having an output that correlates to the data being accessed. In the case of the block diagram, the data being accessed is specifically the preconfigured map data to be used by the pathfinding system.

2.2.6 Wireless Communication Module

The signals emitted from the BLE beacons needs to be processed in order to be interpreted by the remaining systems. Within the block diagram, this processing is visualized by taking an input of the available signals from the nearby BLE beacons, and an output of a processed form of this signal data. For this device, the processing of the signal data will be a "fingerprint" in the form of a vector containing the unique identifier attached to each signal alongside the signal strength of each signal.

2.2.7 Positioning System

The positioning system is a hybrid system and takes an input from primarily two sources, the Wireless Communication Module, and the IMU's raw data in the form of acceleration and orientation. Additionally, the positioning system takes in an input of the "Where Am I?" button, providing the user's position when this button is pressed. The positioning system outputs the estimated position of a user in regards to estimated distance between reference points within the preconfigured map data.

2.2.8 Path-finding Module

The path-finding module takes in input in the form of a user's estimated position, and target destination. The sources from this target destination can come from either the navigation system or the local storage containing the preconfigured map data. The position of the user is provided by the positioning system. The path-finding module outputs a "path" of the reference points needed to arrive at the destination, along with guidances that will guide the user to each reference point.

2.2.9 Navigation System

The navigation system takes an input from primarily three sources, power configuration, path-finding module, and user keypad presses. The power configuration dictates whether or not the navigation system should be active and processing data. The path-finding module provides information on how the navigation system is to guide the user to reach the destination inputted by the keypad. The output of the navigation system is the corresponding guidance needed to be provided to the user.

2.2.10 Audio Guidance

The audio guidance module takes an input from the navigation system as to which guidance needs to be provided to the user for that moment in time. The output of this module is the corresponding audio file to be played to the speaker.

2.2.11 Speaker

The speaker takes an input of the corresponding audio file and plays the sound for the user to hear.

3 Specification of the Blocks

Contributed by Dominic Bertolo

3.1 Functionality

3.1.1 User Interface

The user interface is the collection of user input sources, including the following: a power configuration switch, "Where Am I?" button, "Current Selection" button, "Start Navigation" button, and eight keycode modifiers corresponding to four columns, each with an increment and decrement for each column. The user interface along with the speaker are the primary user-facing features of the indoor navigation device. By setting the power configuration switch to either boolean state of on or off, the system's software will be started or terminated. By pressing any of the keycode modifiers, the user's current selection of a destination will change along with directing the audio guidance manager to indicate the new updated value via an audio cue. By pressing the "Current Selection" button, the user is able to receive an audio cue that presents the entirety of the current destination selection. By pressing the "Start Navigation" button, the current keycode selection will be passed to the navigation system to obtain the needed audio guidance cues to provide to the user via the speaker in order to arrive to their desired destination. By pressing the "Where Am I?" button, at any point regardless of state of navigation, the user can here an audio cue that presents the most likely reference point to which a user is closest.

3.1.2 Inertial Measurement Unit (IMU)

The Inertial Measurement Unit (IMU) is a module that contains three-axis accelerometer and a three-axis gyroscope. Based off of the movement of the module, and by extension the movement of the user, it provides the raw acceleration data in each of the three axes measured alongside the raw orientation data in each of the three axes measured. This data is then passed to the Positioning System in order to be filtered, processed, and interpreted.

3.1.3 Bluetooth Low Energy (BLE) Beacons

The Bluetooth Low Energy (BLE) beacons are a collection of preconfigured BLE sensors that emit a static signal that contains their unique identifier. They are configured to all emit a signal at the same desired strength

3.1.4 Power Configuration

The power configuration is the authority for whether the other systems on the device should be running such as the navigation system, positioning system, wireless communication system, and audio guidance system.

3.1.5 Nagivation System

The navigation system acts as the central controller that determines which audio guidance messages should be delivered to the user. It receives the current user position from the positioning system, the calculated route from the path-finding module, and user input from the keypad interface. Its primary role is to interpret these inputs and select appropriate instructions such as “turn left,” “continue straight,” or “you have arrived.” During navigation, the system continuously updates the guidance based on real-time position changes. If the user presses “Start Navigation,” the system initializes a new navigation session; if “Where Am I?” is pressed, the system temporarily interrupts navigation to provide the user’s current location.

3.1.6 Path-finding Module

The path-finding module computes an optimal path from the user’s current estimated location to a specified destination. Using preconfigured indoor map data from local storage, the module identifies reference nodes (hallways, intersections, doorways) and determines the shortest or most accessible route. It also generates step-by-step guidance instructions corresponding to each segment of the path. This module ensures that routes avoid restricted areas and remain consistent with accessibility considerations.

3.1.7 Positioning System

The positioning system fuses data from the IMU and BLE fingerprinting module to estimate the user’s real-time position. IMU acceleration and orientation values provide dead-reckoning estimates, while BLE fingerprints provide environmental calibration points. The system an Extended-Kalman Filter to reduce accumulated PDR drift. When the “Where Am I?” button is pressed, this system outputs the closest known reference point based on current estimates.

3.1.8 Wireless Communication Module

The wireless communication module processes incoming BLE signals gathered by the device’s receiver. It identifies all beacon transmissions in range, extracts each beacon’s unique identifier, and measures its signal strength (RSSI). These values form the BLE fingerprint vector forwarded to the positioning system. This module handles all low-level BLE communication protocols and filtering of sporadic, noisy, or irrelevant signals.

3.1.9 Local Storage

The local storage module contains static, preconfigured information necessary for navigation. This includes indoor map topology, node labels, distances between reference points, and audio file mappings. The module outputs this data when requested by the path-finding module or navigation system. It remains read-only during normal operation.

3.1.10 Speaker

The speaker outputs the audio cues selected by the navigation system. It functions as the final output interface for user guidance, converting the selected digital audio file into sound waves. Audio cues include button confirmations, directional instructions, destination confirmations, and location announcements.

3.2 Technical Specifications

3.2.1 Power Requirements

The Raspberry Pi 5, according to the Raspberry Pi documentation, requires a minimum 5V/5A power source for maximum achievable performance. The BLE beacons, according to the Fermion specifications, each require a 3.3V power source, with the recommendation of a CR2032 battery. General power consumption will depend on the boolean state of the power configuration in addition to the frequency of audio cues provider through the speaker module.

3.2.2 Communication Protocols

The IMU to be used communicates through the I^2C communication protocol for its raw accelerometer and gyroscope data. The BLE beacons will emit a 2.4 GHz bandwidth signal and be read by the wireless communication module.

3.2.3 Data Flow and Processing

The IMU will constantly be receiving and emitting data, as well as the BLE Beacons. When the power configuration is set to run the navigation and other relevant systems, the device will process this data to be interpreted. The accelerometer and gyroscope data will be used to calculate an estimated stride length, step count, and heading direction of the user. This processed data is then interpreted by the positioning system to determine an estimated progress along the desired path. The wireless communication module will occasionally produce an update wireless fingerpint based on the raw signal strength of each BLE beacon. This fingerprint will then be interpreted alongside the estimated position based on the pedestrian dead recknoning prediction. Wireless fingerprinting can additionally be received on an event-based call to allow the user to obtain an accurate estimate of a position relative to a reference point. In the context of this device, this feature exists for the implementation of the "Where Am I?" button.

3.3 Inputs/Outputs

A more detailed explanation for the following inputs and outputs can be found in the earlier section of "Inputs/Outputs and System Block Diagram".

Navigation System

- Inputs
  - Path instructions from path-finding module
  - User inputs from keypad
  - Power configuration signal
  - Real-time user position
- Outputs
  - Guidance instructions → Audio Guidance module

Path-finding Module

- Inputs
  - Estimated position
  - Destination keycode
  - Map data from local storage
- Outputs
  - Reference-point path
  - Segment-by-segment guidance cues

Positioning System

- Inputs
  - IMU acceleration and orientation
  - BLE fingerprint vector
  - "Where Am I?" button press
- Outputs
  - Estimated user coordinates
  - Closest map reference node

Wireless Communication Module

- Inputs
  - Raw BLE signals
- Outputs
  - Processed BLE fingerprint vector (ID + RSSI)

Local Storage

- Inputs
  - Access requests from path-finding and navigation modules
- Outputs
  - Node definitions
  - Audio file index lookup

Speaker

- Inputs
  - Digital audio file
- Outputs
  - Audible Sound

4 System Description

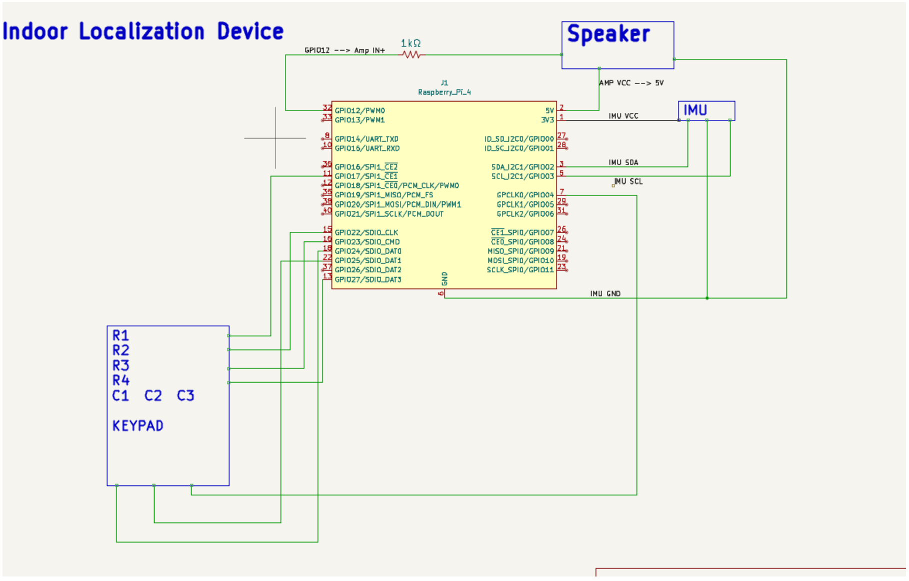
Contributed by Dominic Bertolo

4.1 Block Interaction

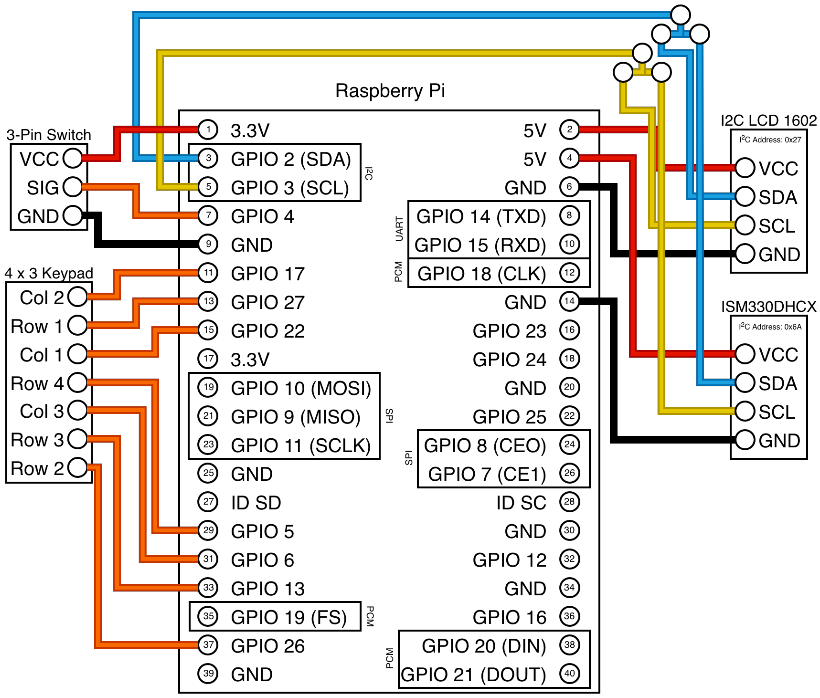
The system operates as a sequential pipeline that incorporates real-time feedback from various sources. While the power configuration is set to enable to device, the system forms a closed loop where user position estimates are contiuously made in order to provide proper guidance until destination is reached.

1. User Input → Navigation System
   - User powers device on using the power switch
   - Keypad inputs define destination or request location information
2. BLE Beacons + IMU → Wireless Communication + Positioning System
   - IMU constantly streams raw acceleration/orientation data
   - BLE receiver collects beacon identifiers and RSSI values
   - Positioning systems both data streams to estimate user's location
3. Position Estimate + Destination → Path-finding Module
   - When a destination is entered, the path-finding module accessess map data from local storage
   - Computes optimal path across reference nodes from position estimate to destination
4. Path + Position Updates → Navigation System
   - Navigation system selects appropriate instructions as the user moves
   - Handles interuptions such as the "Where Am I?" request
5. Instruction → Audio Guidance → Speaker
   - Guidance is converted into audio playback and delivered through the speaker

4.2 Schematic Diagram



A schematic representing the circuit connections of the hardware components



A schematic representing the visual wiring connections of the hardware components

5 System Analysis

Contributed by Alejandro Armenta

5.1 Testing and Results

The planned testing process for TIRE will begin once the team acquires all hardware components and integrates them into the Raspberry Pi. The initial testing environment will be an empty classroom, and if successful, testing will move into a larger and more dynamic environment such as hallways and additional classrooms. The primary objective of TIRE is to reliably guide a user to a specified destination with minimal deviation from the intended target location.

Key Elements to Test

- Conduct group test trials to reach designated destinations using TIRE, with accuracy measured as the distance between the fixed target point and the actual arrival point.
- Test performance during high-traffic periods to determine whether signal congestion affects localization accuracy.
- Have each team member independently navigate to destinations to gather baseline travel time and positional data for comparison with TIRE-assisted navigation.
- Evaluate the effect of different device holding positions on gyroscope accuracy.
- Measure battery longevity by operating the device continuously to determine expected run-time per battery pack.

5.2 Analysis and Key Metrics

To determine whether TIRE meets design specifications, the following performance metrics will be evaluated:

Specification	**Planned Target**
Localization Accuracy	Less than or equal to 1.5 meters (5 feet) deviation from the target location in a classroom environment.
Power Efficiency	Device must run continuously for a minimum of 4 hours, with an ideal target of up to 24 hours.
Output Cue Latency	Audio cue latency must be less than 0.5 seconds from the trigger event, ideally between 0.2–0.5 seconds.

These metrics represent the minimum acceptable performance for TIRE to be considered a successful navigation aid for students in school environments.

5.3 Problem Areas and Recommendations

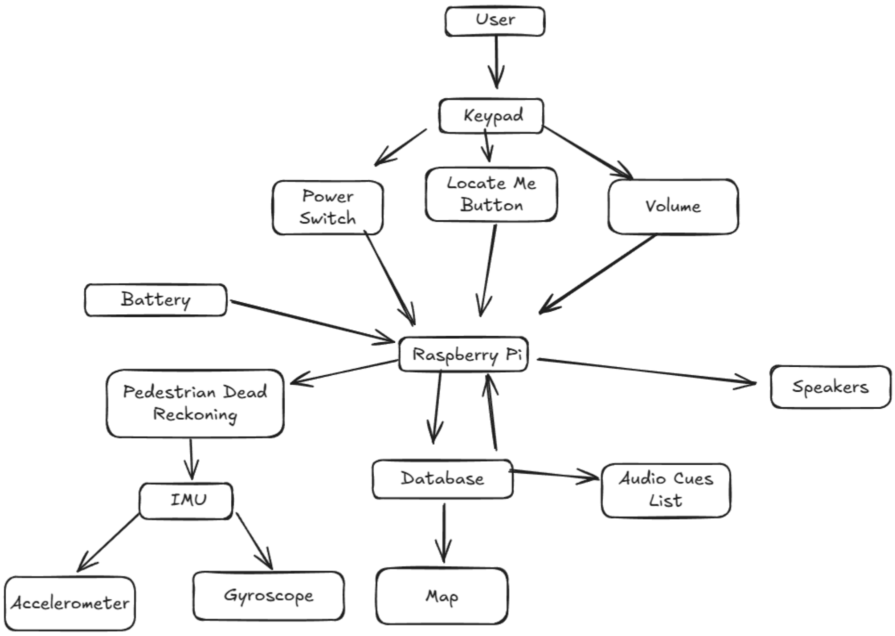
Problem / Issue	Recommendation for Improvement
Beacon placement and power supply: Achieving high accuracy requires optimal beacon spacing and stable power. Poor placement may result in dead zones or inconsistent signals.	Mount beacons on classroom ceilings, spaced no more than 10 meters apart. Use RSSI mapping to validate coverage. For battery-powered beacons, establish a regular maintenance schedule.
Detection of obstacles: Classroom furniture or crowds may interfere with navigation cues.	Position beacons along paths with minimal obstacles. Adjust navigation algorithms to account for dynamic environmental changes.
Sensor bias and prioritization: Incorrect device orientation may cause gyroscope errors, leading to inaccurate guidance.	Implement filtering algorithms such as the Kalman Filter to prioritize critical sensor inputs. For example, BLE, accelerometer, and map constraints may be weighted more heavily than gyroscope data when inconsistencies are detected. Conduct comparative testing to determine which sensors are essential and which can be deprioritized.

5.4 Summary

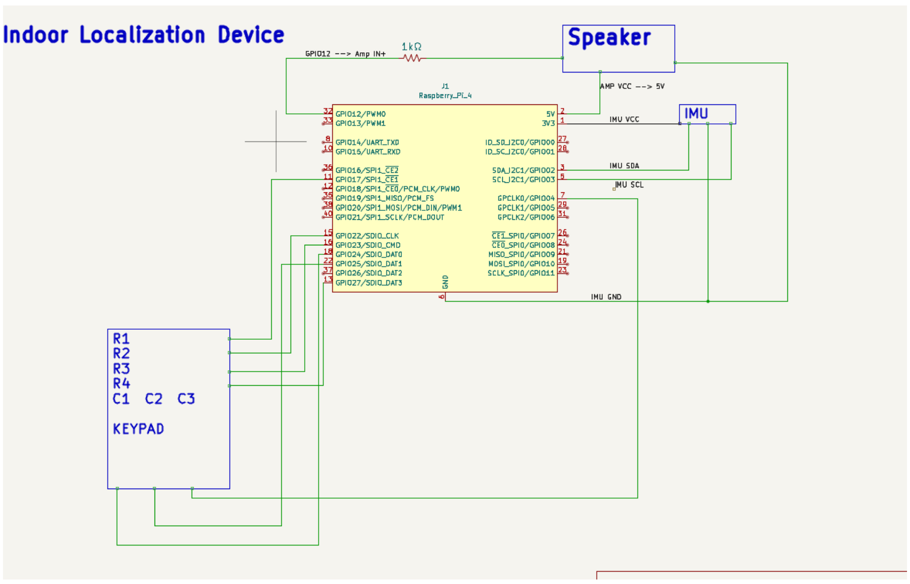
The testing plan for TIRE emphasizes accuracy, reliability, and usability in real-world university and school environments. By systematically evaluating localization precision, power efficiency, and audio latency, the project aims to ensure that TIRE meets its intended specifications. Anticipated challenges—including beacon placement, environmental obstacles, and sensor bias—will be addressed through iterative testing and targeted design improvements.

6 Individual Block Diagrams and Schematics

6.1 Francisco Alvarez

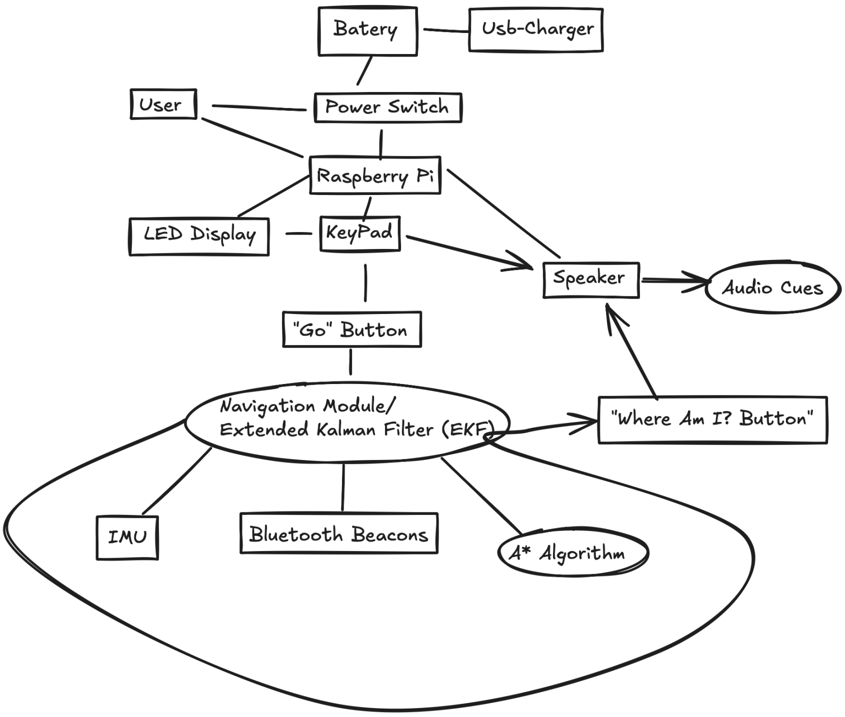


Francisco Alvarez's Block Diagram

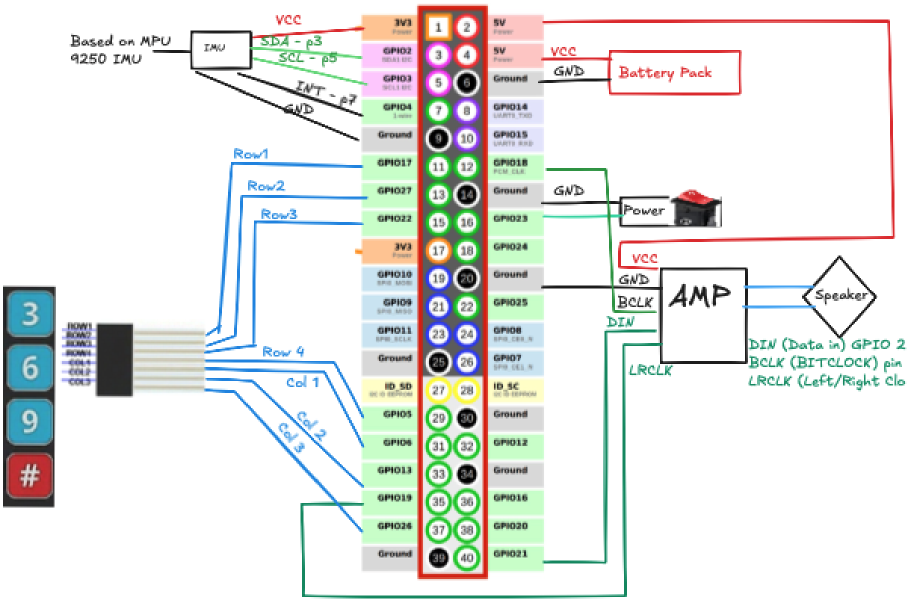


Francisco Alvarez's Schematic Diagram

6.2 Alejandro Armenta

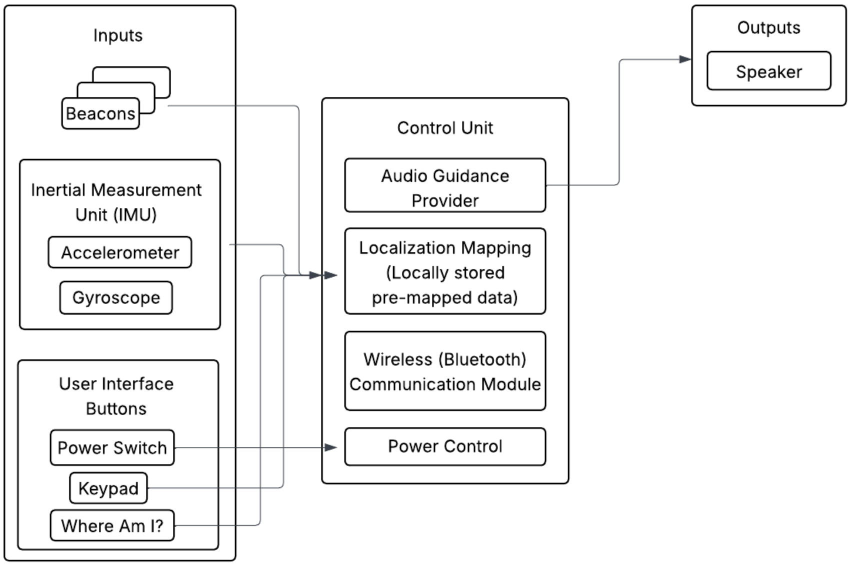


Alejandro Armenta's Block Diagram

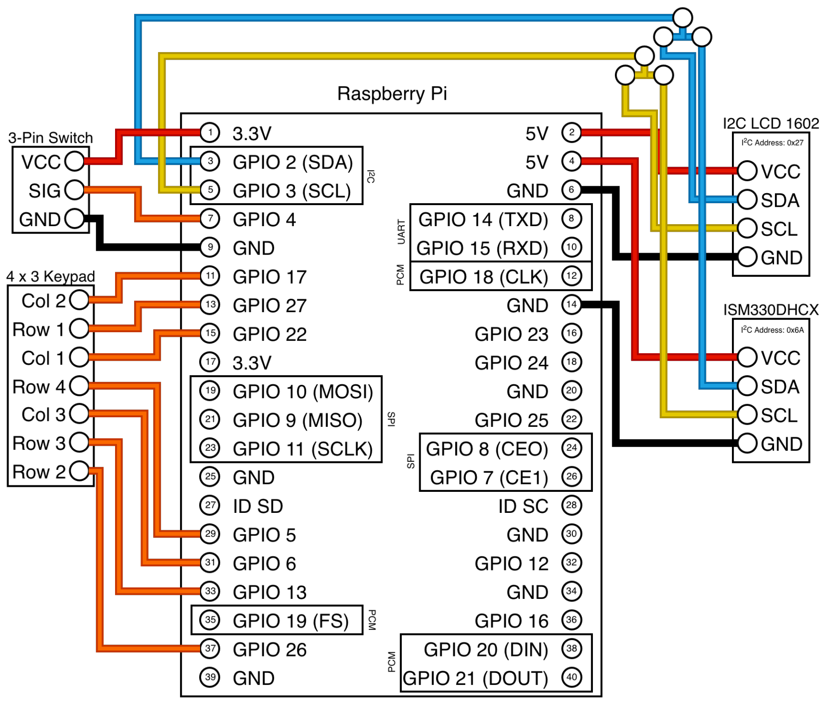


Alejandro Armenta's Schematic Diagram

6.3 Dominic Bertolo

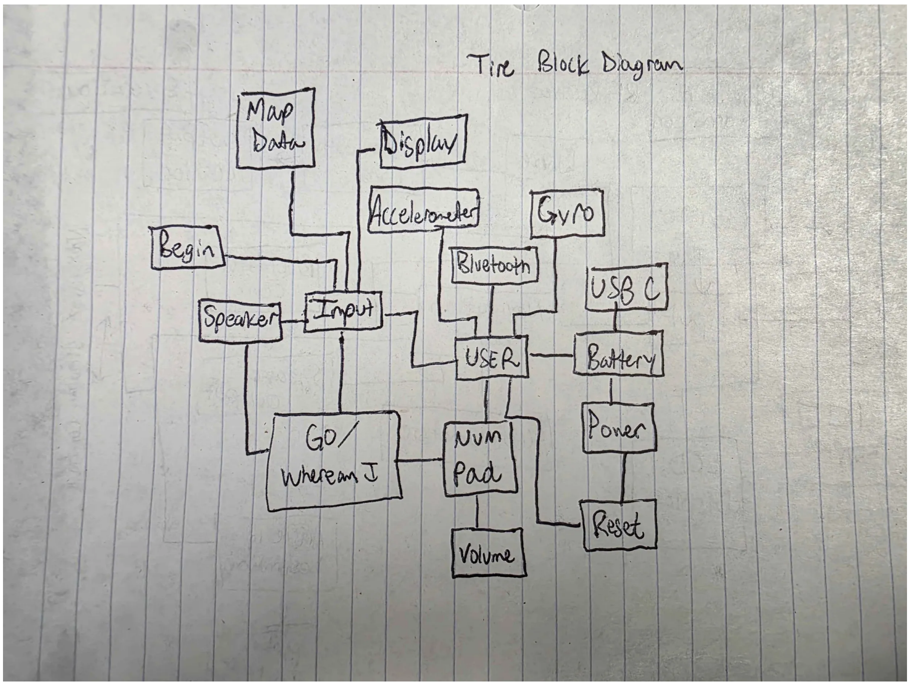


Dominic Bertolo's Block Diagram

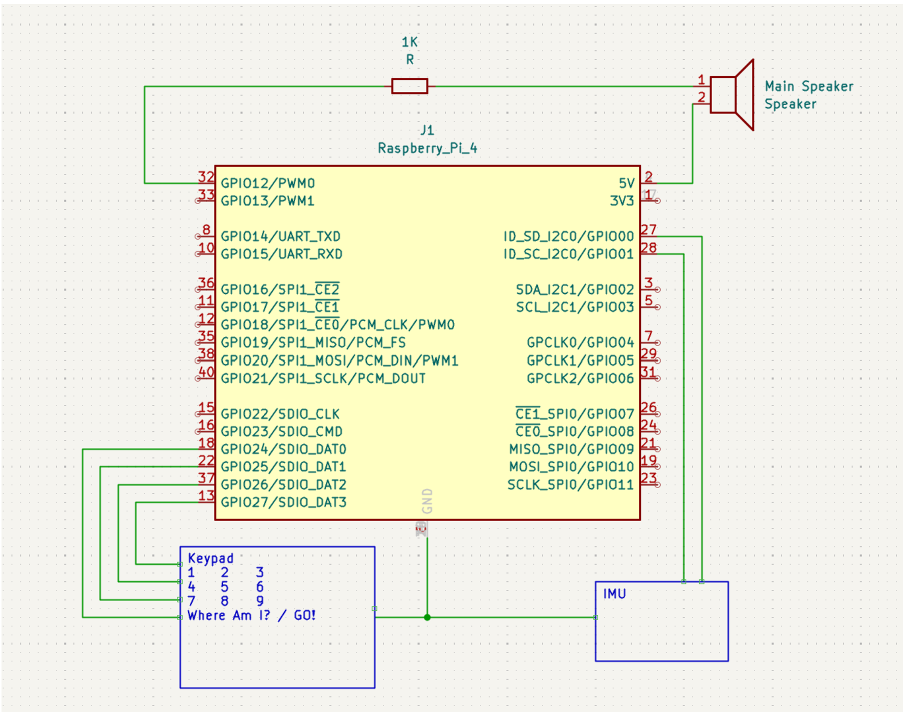


Dominic Bertolo's Schematic Diagram

6.4 Carlos Gomez

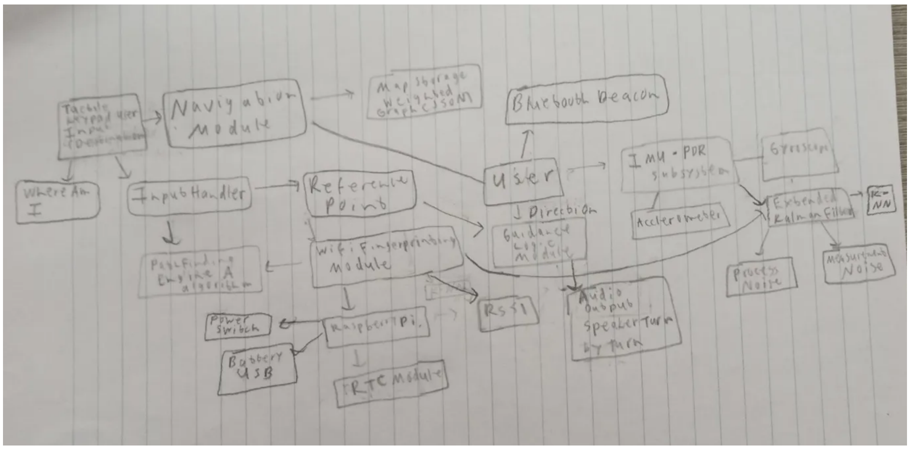


Carlos Gomez's Block Diagram

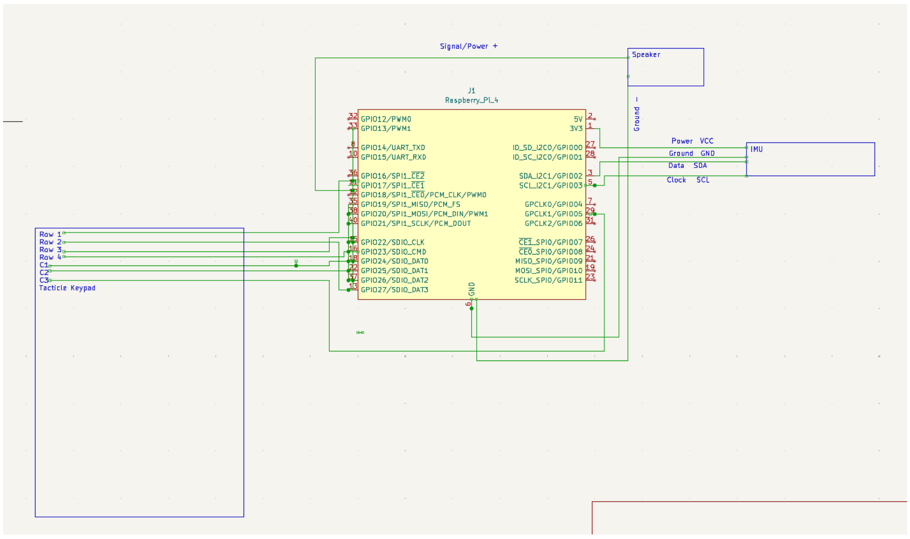


Carlos Gomez's Schematic Diagram

6.5 Isaac Spann

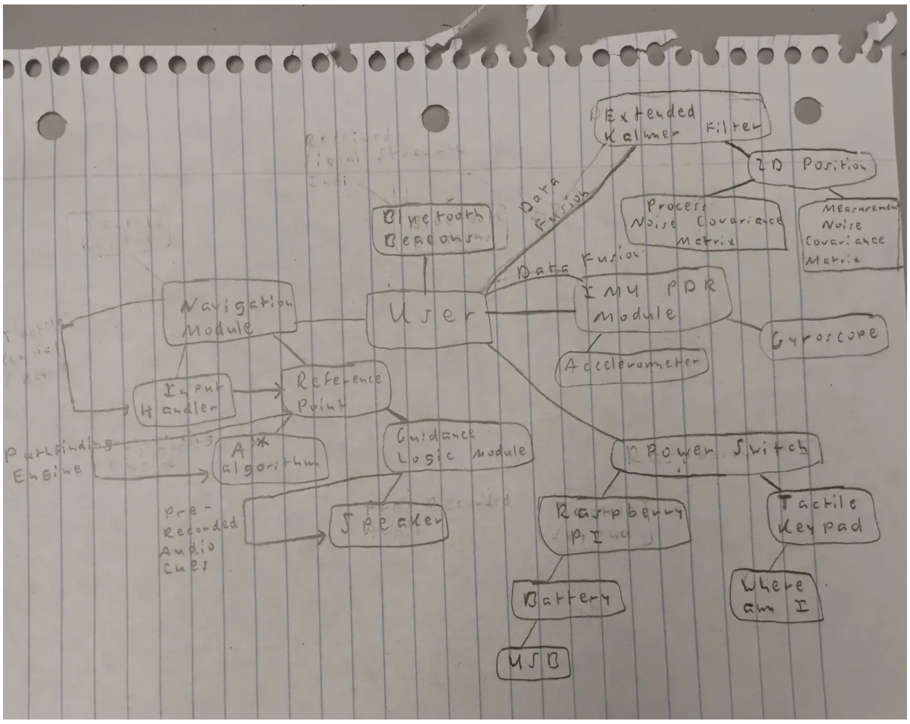


Isaac Spann's Block Diagram

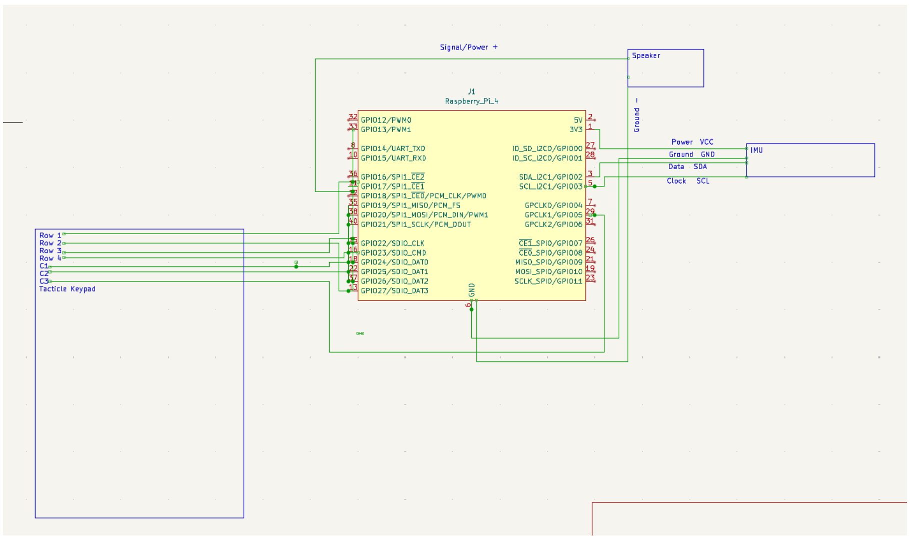


Isaac Spann's Schematic Diagram

6.6 Josiah Spann



Josiah Spann's Block Diagram



Josiah Spann's Schematic Diagram