[TechBatch]

Conceptual Design Report

Version 0.0
[31.12.2023]

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Project Start Date:
[03/11/2023]

Project End Date:
[14/06/2024]

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Executive Summary

While taking precautions against disasters is crucial, there are instances where disasters may be unavoidable despite all necessary measures. In such situations, establishing effective and prompt communication during search and rescue operations is the core issue. Efficient communication serves as the cornerstone for well-coordinated rescue efforts, mitigating the impact of the crisis. The allocation of rescue resources, the transmission of critical information, and the execution of a cohesive response all rely on effective and swift communication. This uninterrupted and rapid communication boosts the efficiency of response efforts and substantially diminishes the overall severity of the disaster's consequences.

TechBatch presents an innovative solution: an ad hoc communication system tailored for disaster relief scenarios. This initiative involves the simulation of a wireless communication environment using solely infrared frequencies. Within this endeavor, a rescue team is formed, comprising three mobile units and a base unit. These mobile units are adept at swiftly identifying targets and assembling on disaster sites, enabling uninterrupted communication with the base unit to ensure effective response coordination. In the simulation area, we will meticulously examine real-world challenges such as Non-Line-of-Sight (NLOS), Line-of-Sight (LOS), and scenarios involving multiple disaster areas individually.

TechBatch is determined to provide innovative and eco-friendly project solutions through teamwork. We aim to broaden knowledge, create a flexible learning environment, and offer practical solutions for real-world challenges. By promoting effective communication, tapping into each team member's expertise, and consistently improving our approach, we aim to develop a project that meets academic standards and industry needs. Our team is diverse, with individuals skilled in signal processing, communication, electronics, and computer technology. Our knowledge and experience make us confident in bringing our vision to life – to innovate and implement cutting-edge solutions.

This design report initiates an overview of the project's general information. Subsequently, it outlines the fundamental objectives and requirements, along with their justifications, forming the foundational framework for the project's design. The report then explains the solution approach, detailing the design and interconnections of sub-systems. This comprehensive explanation provides a clear visualization of the overall solution for the entire system.

Introduction

From the beginning of the term, our primary focus has been on thoroughly understanding our project, encompassing its desired outcomes and the procedural steps for its resolution. After almost three months of concerted efforts, we now possess a clear comprehension of the issue we aim to address and the methodologies we plan to employ. This Critical Design Report delves into the project selection criteria, complete with their respective weights, as well as detailing the requirements, objectives, subsystems devised to fulfill these requirements, and the deliverables intended for the final customer. As we currently engage in testing individual subsystems, this report serves as a comprehensive guide outlining our strategies for the next five months, all geared towards the overarching goal of improving the quality of search and rescue process during a disaster.

Within our Conceptual Design section, readers will discover details about the fundamental aspects of our project's subsystems, a flowchart depicting the operational principles of the device, 3D visuals enhancing the product's understanding, a timetable highlighting completed and upcoming tasks, and a risk analysis addressing potential challenges in integrating the subsystems and attaining the final product.

Motivation of the project

In the field of disaster relief, it is vital to acknowledge that unforeseen challenges and issues may arise despite precautionary measures. The primary hurdle revolves around ensuring efficient communication in the midst of crises, particularly in search and rescue operations. The ad hoc communication system is designed to address the challenges encountered in disaster relief efforts.

Literature/Market Survey (State of the Art)

The literature review and research conducted to conceive the project yielded some results. These findings revealed significant differences between the requirements of the intended project and the features of current research and products. While the use of RF signals for communication is common in recent research and products, this project requires the use of IR signals for communication. This makes the project somewhat more challenging because IR signals are not as effective in communication as RF signals. A similar situation exists in the process of MU (Mobile Unit) determining its own location and planning its movement. Normally, technologies like GPS are used for location tracking in such projects and products, but in this project, MUs are required to determine their own location without external information. There is no information transfer requested from MUs in this regard, adding complexity to the project. Despite providing a general idea, the literature and product research could not contribute significantly at the desired level due to variations in applications.

Current status of your project work

Regarding our project, we have lastly done the Test Demo stage. We have tested 2 subsystems of our project. These subsystems were IR communication and MU's Movement Algorithm. Although the subsystems were successful during the Test Demo, they are still open to changes and adjustments. Now, we are at the stage of Conceptual Design Report. We are writing the report to give information about our possible overall system design. After this stage, we are going to present our works that we have done until now and works that we are going to do until the end of the project.

Scope and organization (of the report)

This report contains the requirement analysis section of the conceptual design report for our partners. Within this section, we outline various requirements either specified by our partners or deemed essential for our project, influencing the design objectives. Subsequently, we present the solution, which encompasses preliminary ideas about the submodules currently undergoing implementation in our project. These submodules comprise crucial subsystems expected to feature prominently in our final project demonstration. Additionally, the report introduces the project's deliverables, accompanied by 3D models.

Problem Statement

Ensuring effective communication in disaster scenarios is crucial for coordinating a swift and organized intervention effort. Challenges arise from disruptions or inefficiencies in communication channels, hindering the exchange of vital information and causing delays in mobilizing and organizing rescue teams. The need for reliable communication is fundamental in this project, as communication will be provided through IR signals, requiring overcoming certain challenges to establish this reliable communication. To achieve effective and reliable communication with IR signals, the distances and alignments between the receiver and transmitter must be carefully adjusted. Since this project involves mobile units, failure to resolve alignment issues effectively will result in unreliable communication, impeding search and rescue activities. Additionally, the movements of mobile units and their communication with the Base Unit (BU) must be synchronized. Otherwise, communication cannot be reliably and effectively established, jeopardizing the successful completion of the main mission.

In addition to communication issues, the requirement for mobile units to determine their own locations poses a localization problem. Due to the limitations of IR signals, communication throughout the entire disaster area is not feasible, necessitating mobile units to determine their locations during their movements. Units providing incorrect location information may lead to unwanted accidents and collisions in the disaster area. Furthermore, without knowing their locations and destinations, mobile units cannot conduct a healthy search and rescue operation, resulting in mission failure.

Objectives and Requirements

Objectives:

- **Reliable Communication:** The communication system must provide reliable communication and coordination to achieve detection and rescue processes, especially in disaster scenarios where lives are at danger.

- **Efficient Search Algorithm:** Search algorithm for target detection should work correctly to avoid extending the path.

- **Usability:** The GUI should be user-friendly and provide a clear representation of the system's status.

- **Mechanical Robustness:** The system should handle unexpected results and errors successfully, such as collisions.

- **Correct Operation of the Search Algorithm:** MUs should not leave their paths.

- **Error-free Detection of the Target Location:** MUs should detect target tile correctly by reading RFID card on the tile.

- **Fast Disaster Relief Movement:** MUs should move fast sufficiently not to delay the search and rescue process.

Requirements:

1. **Communication and Coordination:**

   ● The MUs are randomly located initially.
   ● The BU must communicate with all MUs and coordinate their moves according to the messages it receives.
   ● The BU does not know where the MUs are initially.
   ● MUs can communicate with the BU and each other.
   ● The BU must receive and process location information from MUs once communication is provided and direct them.

2. **Target Detection and Rescue:**

   ● MUs can identify targets if they are located on or near the corresponding target tile.
   ● Once an MU identifies a target, it must inform the BU.
   ● The BU must call all other MUs to gather at the location the first MU that found the target.
   ● MUs should gather in the tiles next to the target.

3. **Obstacle Handling:**

   ● Obstacles may block line of sight communication from MUs to the BU.
   ● The MUs must consider obstacles when creating route to provide communication and connectivity.

4. **Collision Avoidance:**

   ● The MUs must form their movement path according to the information about where the obstacles are to avoid collisions with obstacles.
   ● The MUs must avoid collisions with each other to complete their missions.

5. **Additional Features:**

   ● The target may be mobile, changing its location to side tiles every 10 seconds.
   ● Multiple targets may be formed in the search area.
   ● The GUI must provide real-time information to the BU about the status and location of MUs.

System Design

Overall System Description

Considering the problem statement, the project requirements, and design objectives, the main purpose of our system is to detect a disaster area and direct the mobile units to that location. The base unit will be the guiding unit in the system that will give the necessary commands to implement disaster relief movement. Therefore, the following overall system is designed. The block diagram for overall system description can be seen in *Figure 1*.

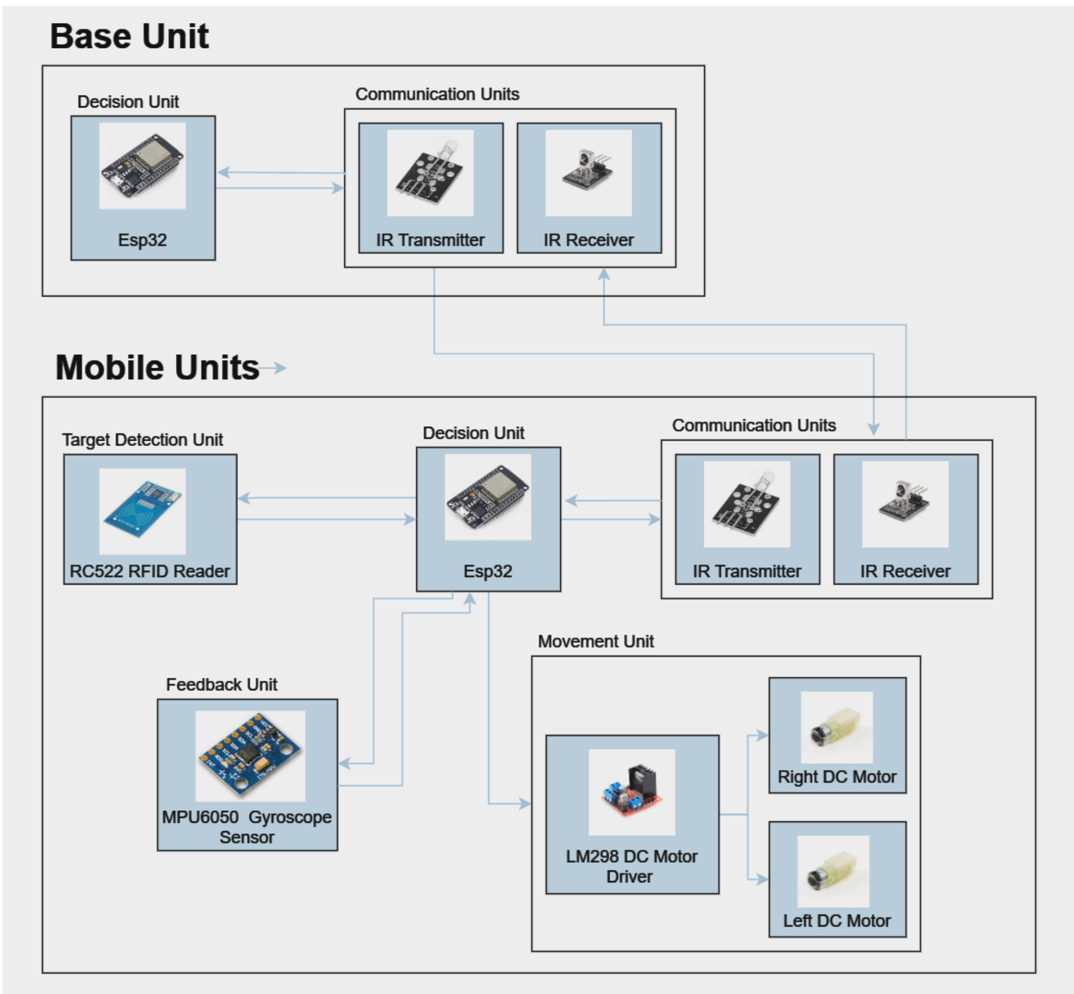

Figure 1: Block diagram for overall system description.

The system starts with the initialization of the base unit and mobile units. The base unit and mobile units will communicate with IR communication protocol NEC via their transmitters and receivers. Each unit consists of 1 receiver and 1 transmitter. Mobile units are able to communicate with the base unit only when they are in the communication range which is the indicated tiles below. This range is determined with RFID tags on the tiles. Mobile units will move in a particular path that is explained in detail in the movement algorithm subsystem sec. 2.1 . This movement will be continuous and will be interrupted if a mobile unit finds a target. The target will be indicated by another RFID tag. The unit that finds the target will go to the communication range of the base unit and transmit the information about the target location. The other units will be informed about the target by the base unit when they come to the communication range and will be guided directly to the target area. After that, the important objective is reaching the disaster area without collision and as fast as possible. Collisions will be avoided by rooting each unit in the non-overlapping paths. This overall functioning is illustrated in the flowchart in Figure *2*.

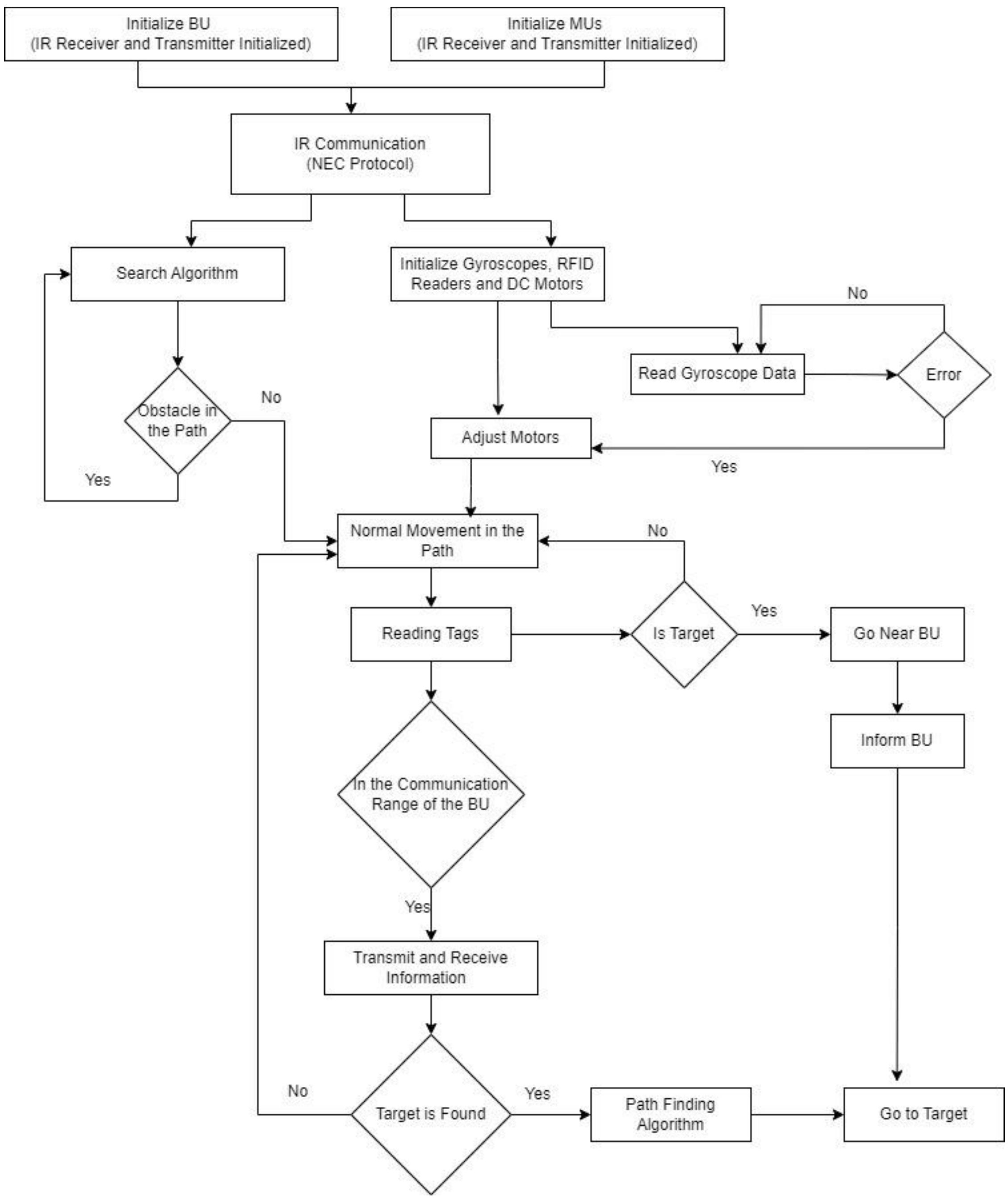

Figure 2: Flow Chart for overall system.

Considering this general schema, we divide the whole system into three main subsystems:

1. Mobile Units Movement Sub-System
2. IR Communication Sub-System
3. Movement Algorithm Sub-System

Moreover, we divide each main sub-system into their subsystems as well.
Requirements and solutions of each subsystem are explained in the sub-sections below.

The overall physical system is designed as a map with a grid on it. The base unit will be stationary in the middle of the lower side and the mobile units will be moving in the non-overlapping paths. The map consists of (8x8) a total of 64 tiles that have a 12.5 cm edge length. The 3D model of the system can be seen in *Figure 3*.

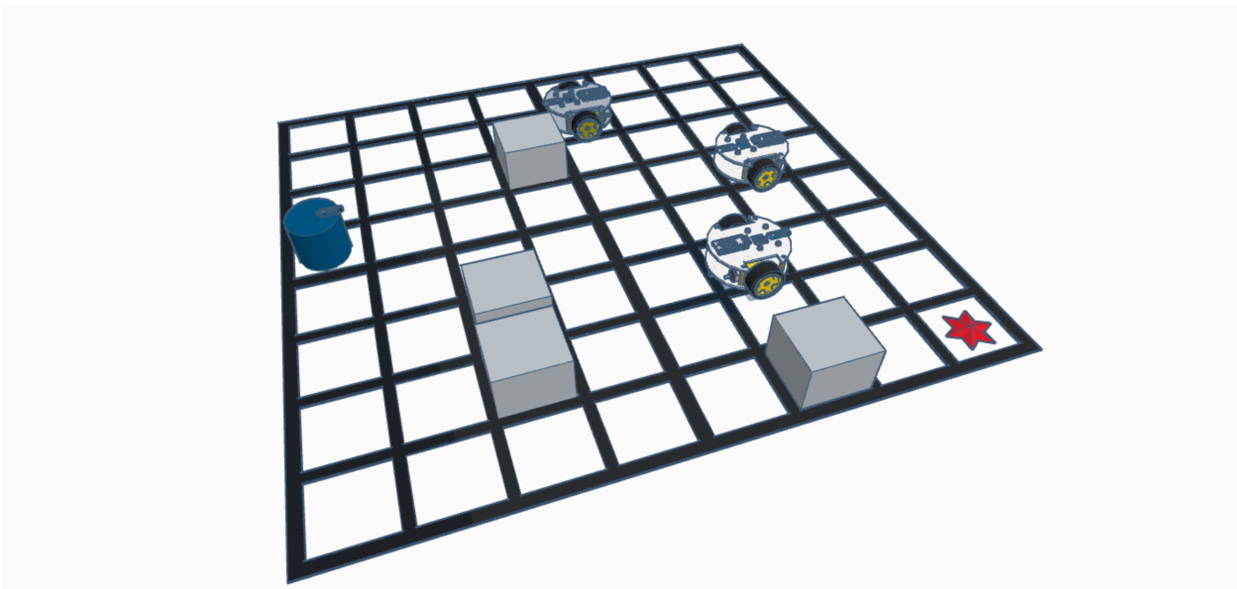

Figure 3: 3D model of overall system design.

Considering datasheets of the components we calculated the total weight and dimensions of our mobile unit which is provided in *Table 1* below.
Moreover, according to the voltage that is supplied to each component and the current they use, the power consumption of each unit is estimated. One can see these estimations in *Table 2*.

Table 1: Expected weight and dimension table.

Expected Weight	783 gr
Expected Dimension	15cm x 10cm x 13cm (LxWxH)

Table 2: Expected power consumption of each component.

Component	Current	Power
Esp32	160-260mA	1W
MPU6050	0-10mA	33mW
Motor Driver	0-36 mA	324mW
Motors	2A	20W
RC522	13-26mA	66mW
IR receiver	40 μA	200 μW
IR transmitter	5mA	25mW

The flow chart and block diagram that is proposed are generated by the light of the weighted objective tree that is obtained considering system requirements. The objectives are determined as reliable communication, error-free detection of the target location, efficient and correct operation of search algorithm, fast disaster relief movement, and mechanical robustness of all systems.

Mobile Units Movement Sub-system

The aim of this sub-system is to find the target in the area in a robust way. Since commands are taken from the base unit, this system communicates via the IR communication sub-system. According to the commands from the base unit and movement algorithm, the mobile units are adjusted to arrive at the destinations. This process is

The mobile units movement sub-system consist of these components:

- Microcontroller ESP32
- 2 x DC Motors
- 2 x Wheels
- Motor Driver LM298
- RFID Reader RC522
- Gyroscope MPU6050
- Chassis
- Power Source Li-Ion Battery

In this section, the design and selection process of these components and also the operation of the sub-system will be explained in the section which are localization and accurate movement. A 3D model of the one MUs can be seen in *Figure 4*.

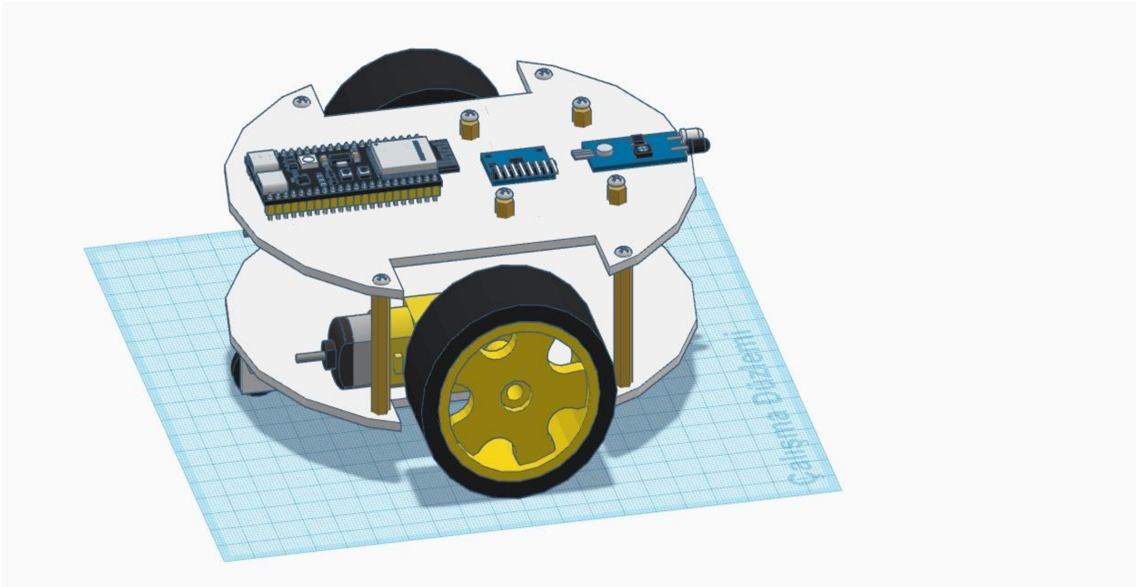

Figure 4: 3D model of Mobile Unit.

Localization:

The movement of the mobile units will be directed by the base unit. In order to determine their positions and give directives to navigate them to specific locations RFID tags are used. Each tile consists of an RFID card with a unique ID and each mobile unit has a RFID reader on their bottom. The directives are given by the base unit based on these IDs. For instance, in order to turn a mobile unit to the left in a specific tile, the turning left function is activated in the code when that ID is detected.
RFID Cards and Reader:
Each card consists of a unique ID which is encoded in the code and assigned a name that corresponds to tiles on the map such as A1, A2, B1...
The readers that are attached to the bottom of the mobile unit can only read those IDs when they are on top of them.

To be more specific, firstly in order to navigate each unit in their search path specific tile IDs are determined. When the system is initialized the base unit will transmit those locations and related commands. Moreover, targets will be specified with those RFID tags too. For instance, if one of the units finds the target it will transmit that ID to the base unit, and the base unit will transmit that key and go to that tile command to other units.

Movement:

Although in the ideal case, straight movement of the mobile units is easy to construct, in reality, this simple act is very prone to distraction because of the environment and non-ideality of the components. Moreover, MUs not only move straight, but they must also turn right and left to keep track of their path. Therefore, to ensure an accurate movement without error, a feedback system must be established. The components used in this section are DC motors, motor driver, microcontroller, Li-Ion battery and gyroscope.

a. Microcontroller

Our design needs a system on a chip microcontroller to process the information from a gyroscope sensor and control the motors accordingly. We choose to use ESP32. Important factor for the selection of the microcontroller is being economical and powerful. Motors are driven by the analog output pins of the microcontroller that can adjust the speed of each motor separately by controlling the RPM of motors.

b. Motor Driver and DC Motors

Motors are the main component of the system that enables the MUs to move to any specified direction. Each motor is connected to wheels. The speed of the motors is governed by the given RPM from our algorithm. RPM is related to the voltage between the pins of the DC motors that is controlled by the motor driver that regulates the given voltage.

c. Gyroscope

Gyroscope senses the orientation and angular velocity of the MUs in real-time. This sensor serves as a pivotal component of our design, contributing to units' navigational capabilities. Similar to motors, the gyroscope is linked to the algorithmic framework, ensuring coordination with the overall control system. This enhances the precision and stability of the MUs movements whether it is in a straight path, or rotation to the right or left. Output of the sensor is a fundamental input for the algorithm, ensuring dynamic control of the system.

d. Li-Ion Battery

The selection of lithium-ion (Li-ion) batteries for our project is driven by their characteristics that align with our requirements. Li-ion batteries offer a rechargeable solution, ensuring cost-effective use in our application. The high energy density of Li-ion batteries allows for efficient power storage in a compact and lightweight format, good for our project's need for portability without compromising performance. Moreover, the extended lifespan of Li-ion batteries contributes to reduced maintenance and operational costs over the project's lifecycle.

Overall Sub-system design:

Our system must be very robust not to miss the decided path. Therefore, errors in movement must be calculated in real-time and active feedback systems must be constructed accordingly. Our solution is to use a gyroscope sensor to sense the heading by processing the angular velocity data. Our algorithm can be explained in these steps:

1. Initialization:
   MUs stand still to calibrate the gyroscope for determination of the heading. Initial right and left motor RPM values are written to motor speed pins via analog outputs of ESP32.
2. Movement Start:
   Digital output pins for the direction of rotation of motors are written so that motors start to operate.
3. During Movement:
   Even though RPM values are adjusted so that each wheel is spinning in the same velocity, little fluctuations and misadjustment may badly affect the MU's heading in the long run. Thus, RPM values of each motor are corrected with the information of angle of route deviation, for example if MU is heading towards the right, then left RPM value is increased to adjust the heading.
4. Rotation to right or left:
   By the search and rescue algorithm, when the specified RFID card is readed, MUs must be rotated. When rotation to any direction, the motor on the turning side is stopped completely, and only the opposite side operates. By the heading angle information, both motors stop when the target angle is reached. However, because of the non-ideality, there may be some disorientation, and this is corrected via starting only one motor backward and forward until the target angle is reached.

Considering the project design objectives, the corresponding sub-system requirements were determined as in *Table 3*. One can also see the relation of sub-system requirements to overall system objectives.

Table 3: Sub-system Requirement relations with design objectives.

Sub-System Requirement	Requirement Description	System Requirement Relation	Design Objectives
Going Straight in a Path	MU should move strictly in the required tiles	MUs shouldn't collide with each other and also avoid obstacles	Mechanical Robustness
Going Straight in a Path	MU should move strictly in the required tiles	MUs should stay in the specified tiles	Correct operation of the search algorithm
Reliable Localization	Detecting the RFID tags in the tiles	MUs shouldn't miss the card positions	Error-free detection of the target location
Reliable Localization	Detecting the RFID tags in the tiles	MUs should read the RFID tags to communicate with the BU	Reliable Communication

Alternative Solution:

An alternative solution involves the integration of motor encoders. These encoders provide a more accurate measure of the MUs' spatial displacement, addressing the cumulative errors associated with relying solely on gyroscope data. By combining the strengths of both gyroscope and motor encoder data, our system aims for a more robust and reliable approach to navigation, minimizing the risk of errors and enhancing the overall effectiveness of the MUs.

Search and Rescue Algorithm Sub-System

The search and rescue algorithm sub-system aims to determine the strategy for searching the target in the regions for mobile units to search more efficiently and fast. The search algorithm should avoid collisions and obstacles during movement.

Table 4: Sub-system Requirement relations with design objectives.

Sub-System Requirement	Requirement Description	System Requirement Relation	Design Objectives
Target Detection	Once the target is detected, MU should inform the base.	Once an MU identifies a target, it must inform the BU.	Fast Disaster Relief Movement
Return to the Base	MUs should check the BU to learn whether the target is found.	BU must call all other MUs to gather at the location of the first MU that found the target.	Fast Disaster Relief Movement
Return to the Target	Each mobile unit should return to the target after the target is found.	MUs should gather in the tiles next to the target.	Fast Disaster Relief Movement
Shortest Path	Each MU should return to the base and target in shortest path	Search algorithm for target detection should work correctly to avoid extending the path	Efficient Search Algorithm
Obstacle avoidance	When there is an obstacle MU should find another path to arrive at its destination.	The MUs must consider obstacles when creating routes to provide communication and connectivity.	Reliable Communication
Infinity weight of obstacles	The weights of obstacles in the undirected weighted graph should be infinity to increase the path's cost concerning other paths.	The MUs must form their movement path according to the information about where the obstacles are to avoid collisions with obstacles.	Efficient Search Algorithm
No collisions	Mobile units should not collide when searching for a target or returning it.	The MUs must avoid collisions with each other to complete their missions.	Mechanical Robustness

Determine the search regions for each mobile unit

The Figure 5 shows the setup for the base unit and searching regions. Green dots represent the communication regions where mobile and base units can communicate. Three different search regions are indicated with different colors. Each mobile unit is responsible for its own region, and if the target is not detected, they are not allowed to move to another region. Each region has a tile next to the base to ensure communication between a mobile unit and the base unit.

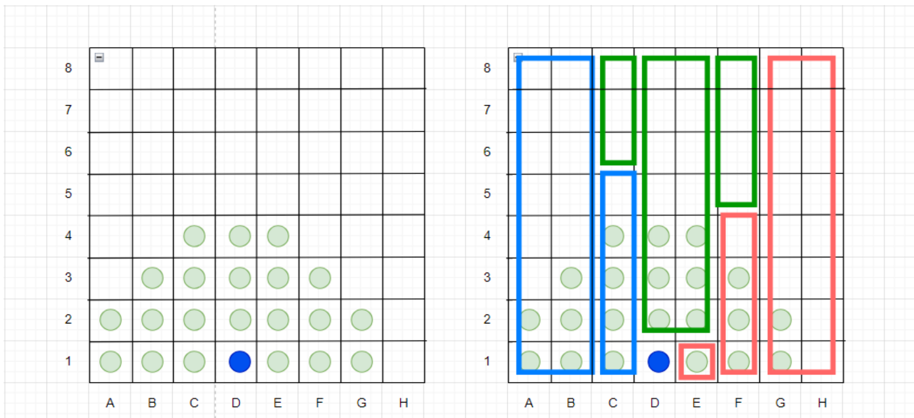

Figure 5: The base set up and search regions of each MU.

Movement in the search region: avoid obstacles

The main structure of the algorithm is based on graph theory. Each node in the graph can represent a location or a tile on the 8x8 grid where RFID tags are placed. The grid cells are the nodes, and edges connect neighboring cells. If two cells are adjacent (horizontally, vertically, or diagonally), there is an edge between them. Each edge has weight, which determines the cost of the movement from one tile to another. In Figure 6, the weights are shown for one tile and its adjacent tiles. It can be seen that diagonal tiles are not connected. The weight of a diagonal move is double the vertical or horizontal move costs since the mobile unit is not able to move diagonally.

When an obstacle is placed in a tile, the weight of edges that connect the tile with the adjacent tile becomes infinity. The movement of the grid depends on these weights. When a mobile unit encounters an obstacle, it can find a low-cost path to avoid it.

Each sub-grid is represented in a graph to each MU responsible for the sub-grids. Therefore, it prevents the MUs from crossing sub-grids of other MUs. This solution ensures that MUs do not collide while searching.

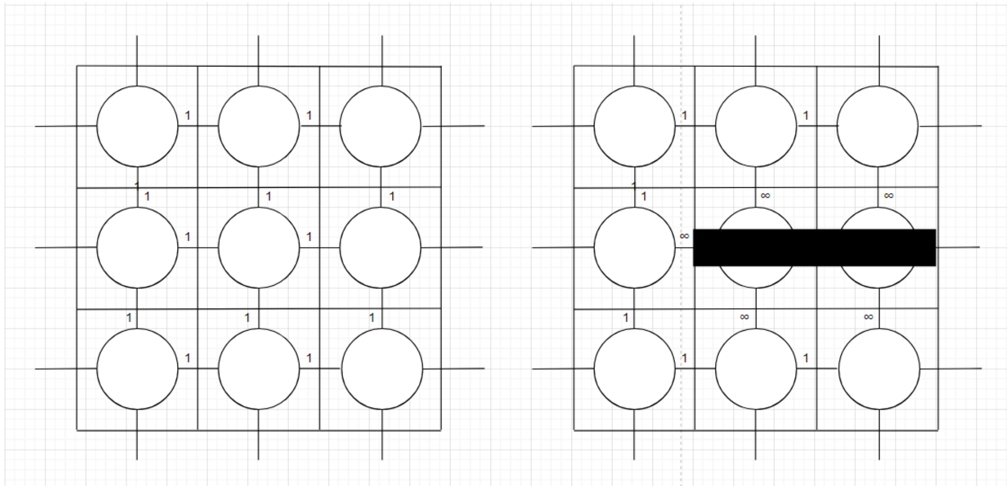

Figure 6: Undirected weighted graph representation of grid with and without obstacles.

Return to the Base Unit

Once the target is detected or the search is finished, Dijkstra's path-finding algorithm is applied to navigate the mobile units from the target location or mobile unit's current location to the base unit while considering the structure of the graph, edge weights, and any constraints.

Dijkstra's algorithm can be explained as follows:

Initialization:

- Start with a source node.
- Assign a distance value of 0 to the source node and infinity to all other nodes.
- Mark all nodes as unvisited.

Iterative Process:

- Select the unvisited node with the smallest tentative distance.
- For the selected node, consider its neighbors and calculate their tentative distances through the current node.
- Compare the newly calculated tentative distance to the current assigned value and update if the new distance is smaller.

Mark as Visited:

- Once all neighbors of the current node have been considered, mark the current node as visited.
- A visited node will not be rechecked.

Repeat:

- Repeat steps 2 and 3 until all nodes are visited, or the destination node is reached.

Result:

- The algorithm produces the shortest path from the source to all other nodes in the graph.

Return to the Target

After a mobile unit finds the target, it goes to the base and informs the base that the target has been found and the location of the target. The base unit calculates the path that goes to the target, and the path is transmitted from the base to the mobile unit, and the path is marked as visited to avoid collision. This procedure is repeated for each mobile unit, and unmarked shortest paths are calculated by the base using Dijkstra's algorithm and transmitted to mobile units.
Mobile units should check the base when they are not in the communication region unit to see whether the target is found. According to the time elapsed and where they are, they check base if there is information about the target.

Alternative Solution

An alternative solution to pathfinding is using other algorithms such as A* and RRT. A* algorithm, an informed search approach, guarantees optimality when an admissible heuristic is employed. A* is particularly effective in pathfinding tasks, leveraging heuristic information to guide exploration. Meanwhile, Rapidly-exploring Random Tree (RRT), a probabilistically complete algorithm, lacks a guarantee of optimality but excels in motion planning, especially in robotics applications.

Another alternative solution to determine the search regions for each mobile unit is to place the base unit in the middle of the area and increase the communication region. However, this solution needs another application and algorithm, such as rotating the base around itself; for mobile units to communicate with the base correctly, they must wait for the base to turn towards them.

IR Communication Sub-System

The IR communication sub-system plays a crucial role in facilitating reliable communication between mobile units and the base unit. Its primary responsibility involves performing encoding and decoding operations. That is, messages are encoded, comprising an 8-digit hex number, and subsequently decoded to extract meaningful data. The decoded message is then transmitted to the designated unit, specifically the microcontroller, in order to perform necessary actions.

Table 5: Sub-system Requirement relations with design objectives.

Sub-System Requirement	Requirement Description	System Requirement Relation	Design Objectives
Encoding Message	A message should be encoded to an 8-digit hex number. (4 Bytes)	The BU must communicate with all MUs and coordinate their actions according to the messages it receives.	Reliable Communication
Decoding Message	Encoded messages should be decoded to the meaningful data.	The BU must communicate with all MUs and coordinate their actions according to the messages it receives.	Reliable Communication
Assigning addresses to the units	Each unit (MUs and BU) should have predefined addresses to receive and transmit messages.	MUs should communicate with BU.	Reliable Communication
Communication in range of transmitter	MUs should be in the range of the transmitter of the BU.	MUs should communicate with BU.	Reliable Communication

Encoding and Decoding the Data

In IR communication, data is represented by an 8-digit hex number. Specifically, a 4-digit segment is allocated for the address, a 2-digit for the command, and the remaining 2 digits serve the purpose of indicating the protocol. The protocol segment is computed based on the chosen protocol.

There are several protocols in IR data transmission. Our choice is the NEC protocol since it is widely used and gives confident results in our experimental trials. Within the NEC protocol, the 2-digit protocol code is determined by obtaining the 1's complement of the command. An illustrative example of data representation in the NEC protocol is provided in Figure 7 below.

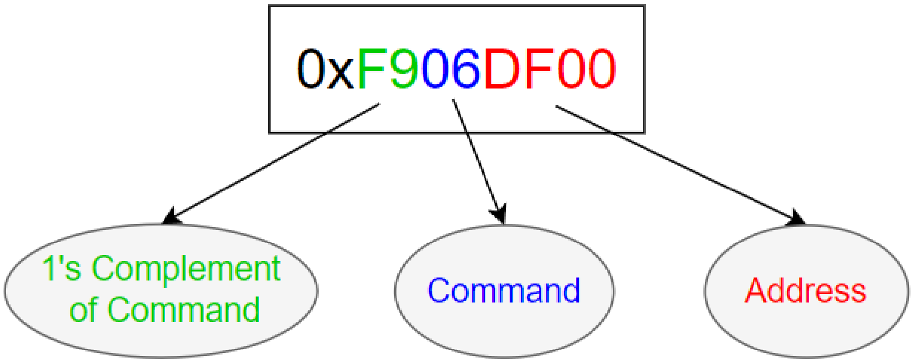

Figure 7: Data Representation in NEC Protocol

In this example, the address belongs to the originating unit sending the data and the command represents the intended action. The first two digits are nothing but the 1's complement of the command, a distinctive characteristic indicating the use of the NEC protocol.

In IR communication, the essence of data transmission lies in conveying this 8-digit hex number. Consequently, it requires encoding various messages and commands into a 2-digit hex number, constituting the command segment, as illustrated in Figure x. Each command is uniquely associated with a specific action. An example of this encoding process is shown below.

"I found the target"	-> 0xF3 (2-digit hex command)
"I haven not found the target yet"	-> 0xF4 (2-digit hex command)

For instance, if the MU1 which has the address 0x2222, wants to send the command 0xF3 then the data it should send is: 0x0CF32222

After the transmission of the 8-digit hex data, the receiver unit should also be able to decode the data to a meaningful message. For this, each mobile unit and the base unit have the information of messages and their corresponding data as well as the address information of other units.

Assigning Addresses to the Units

To create a reliable IR communication between MUs and BU, each unit should know who the message comes from. To achieve this, four predefined addresses are assigned to the units. Units decode the received messages and process them according to the address information. Assigned addresses to the units are like below:

0x1111 —> BU
0x2222 —> MU1
0x3333 —> MU2
0x4444 —> MU3

Assigned addresses are in the form of hexadecimal numbers because the protocol we used contains the address information directly in the message.

Communication in Range of Transmitter

Transmitter range of the BU is limited; therefore, messages that are sent from the BU do not reach all points in the disaster area. For this reason, MUs have to arrive at the tiles which BU can transmit the messages. After the arrival, reliable communication is realized.

Alternative Solution

If the angle of sight would not be sufficient, we can consider turning the BU periodically to provide point to point alignment between transmitter and receiver of different units.

Test Results

Movement Algorithm Sub-System Test:

In order to test the Mobile Units Movement subsystem we determined two types of test. The first test is moving straight in a line which is crucial considering even a small bend in the movement can cause the mobile unit to leave its correct path. We determine the steps of this test as 1, 3, 5, and 7 tiles. Considering that the edge of our map is 8 tiles this test range is sufficient. The criteria for success is achieving the correct tile at the end. Each test step is tested 5 times and the mobile unit can be considered as passed from this test as one can see from the results.

The second test is moving in a square path of different edge lengths. This test requires the mobile unit not only to move straight but also to turn strictly 90 degrees when needed. It is also important since even a small deviation from 90 degrees will cause mobile units to end up in the wrong place again.
Considering the correct operation of the search algorithm, going to the target location algorithm, avoiding the obstacles, and preventing possible collisions, the results of these tests are crucial.

The results of these tests are important as they show that a unit can move in its search path without going out of it, thus possible collisions with the other units and obstacles will be prevented and the search algorithm as well as going to the target location algorithm will operate precisely. Consequently, the system requirements of mechanical robustness and precise operation of the search algorithm can be satisfied.

As can be seen in Appendix-2, considering our test results, MUs didn't satisfy the second part of the test. To be sure of the headings of MUs, a gyroscope is very useful. However, there are still some issues to be solved. Mainly, using gyroscopes, MUs can be in the one heading, i.e. looking in the zero angle, but the time passed to this status creates an error in the x-y location. Although MUs adeptly reach their target headings swiftly, minor deviations in horizontal space can result in unintended consequences, such as failing to read RFID tags. This oversight disrupts the adherence to the search algorithm and may lead to collisions.

Main reason these initial instabilities occurred was the power source, and non-ideality of the motors. In the test demo, we were using a 9V alkaline battery, which was not powerful enough to feed our system. Power source was running out after a few iterations and this affected the performance of our motors significantly. Determined stable RPM values for each motor was changing with the power sources situation. Also, non-chargeability was an issue for the cost. That’s why we decided to use a Li-Ion battery in our final design. Furthermore, the engine’s starting instances were also different. This creates a necessity for better hardware than we used in the test demo.

IR Communication Sub-System Test:

In the evaluation of the IR communication sub-system, our focus was on two critical aspects: distance and angle. Understanding the limits of the IR receiver and transmitter is crucial in designing the core of our IR communication system, constituting a pivotal element in the overall project.

In the distance test, we opted to measure distance in terms of the number of tiles rather than traditional centimeters. This metric aligns seamlessly with our use of RFID technology embedded in each tile. By leveraging RFID cards in software, we effectively constrained our communication range to specific RFID tags. The results of our distance test demonstrated impeccable performance consistently parallel to our anticipated expectations. This reassures us of the system's reliability across varied ranges. It's noteworthy that this test, despite increasing distances, maintains a point-to-point communication paradigm.

Meanwhile, in the angle test, our objective was to gauge communication effectiveness across different angles. Notably, some discrepancies were observed at specific tiles, such as A3 and A4, as detailed in the test document in the Appendix. These errors stemmed from the actual communication performance surpassing our initial expectations. However, these deviations are not a significant concern, given the system's ability to reliably communicate across various angles and extended distances. This outcome presents an opportunity to optimize our system by considering a stationary base instead of a rotational one, given the system's demonstrated capability to perform effectively at diverse angles.

Planning

In the remaining part of the fall semester, we have a presentation to deliver. Following this presentation, our team has outlined a flexible roadmap for the upcoming semester, detailing our tasks. Our immediate focus post-presentation will be on intensively working on the search and rescue algorithm under Eda's leadership. We plan to scrutinize and refine the algorithm, incorporating new elements and adjustments to approach perfection. Mustafa and Hasan will create and test a simulation of this algorithm using MATLAB, and based on the simulation results, necessary enhancements will be implemented.

Once we conclude our work on the search and rescue algorithm, we will divide into groups again to address other subsystems. Hasan, Tuana, and Eda will concentrate on mobile units movement subsystems and make necessary improvements. We had initially used batteries to power the mobile units until we realized it was insufficient. The most crucial development needed for mobile units movement subsystems is to find a more effective power source and integrate it into our mobile units. After this integration, we will increase the number of tests during the Test Demo to assess the effectiveness of our improvements. We will observe whether our mobile units move smoothly in the disaster area and decide on our next steps.

While Hasan, Tuana, and Eda handle this subsystem, Mustafa and Mustafa Kemal will work on the necessary enhancements for IR communication. The most significant development in this area that will propel us forward is coding the encoding and decoding messages processes for the units. Mustafa and Mustafa Kemal will define approximately 70 to 80 messages and integrate their codes into the units. Once this coding is complete, tests similar to the Test Demo will be conducted to ensure correct parsing of received messages through Arduino IDE.

Upon completion of all tests and improvements, before transitioning to integration, our entire team will collaborate on designing the mobile units. According to our current plans, the body of our design will be 3D printed to minimize the size of our mobile units. After unveiling our design, we will proceed to integrate all subsystems and thoroughly test our prototype. If the prototype fails to function properly and meet requirements, we will consider it unsuccessful and return to the development stage. Once we deem our prototype successful, we will build upon improvements such as mobile unit design and disaster area design. Subsequently, we will incorporate the schedule we devised and conclude the project. Additional details can be found in the Gantt chart that we have created.

Deliverables

- 3 mobile units
- The base unit
- The GUI
- The disaster area

Detailed Cost Analysis

- 5 ESP32 as the brain of the units -> 207.33 x 5 = 1036.65 TL
- 6 DC motors for wheels of the MUs -> 90.16 x 6 = 540.96 TL
- 65 RFID cards -> 8.40 x 65 = 546 TL
- 4 IR transmitter and receiver ->10 x 4 = 40 TL
- 4 9V Li-ion battery ->190 x 4 = 760 TL
- Other components ->400 TL

Total cost is 3323.61 TL which equals $112.74.

Ethical Concerns

As TechBatch company, we believe that our project Ad Hoc Network Communication System for Disaster Relief will make a significant impact, especially when used in countries prone to frequent disasters like our own. We understand that natural disasters are inevitable, but we also recognize the crucial role that accurate and prompt search and rescue operations can play in saving lives after such events. Therefore, during the project development phase, we have dedicated extra efforts to ensure that we deliver the best possible solution.

Touching people's lives and making a positive impact is the core value of our company. In addition to the contributions our project will make to individual lives, we also consider the societal benefits it will bring. Once our system is put into use, it has the potential to reduce the financial burden on governments dealing with economic challenges in the aftermath of disasters, reflecting positively on the overall situation. Moreover, the more organized and rapid search and rescue operations facilitated by our product will prevent further hardships for disaster victims, whose lives are already difficult.

Schedule

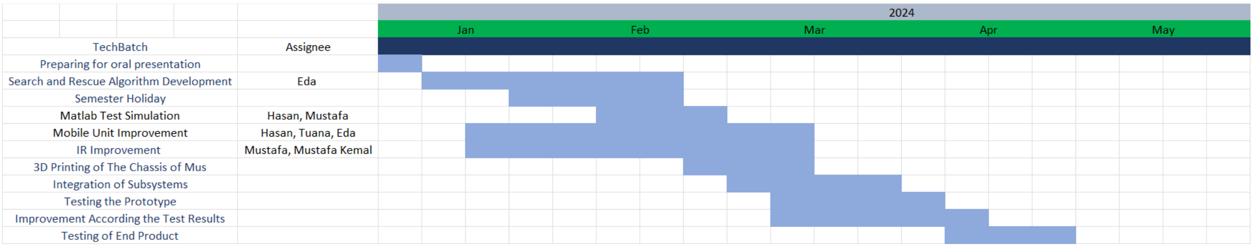

Figure 8: Updated Gantt chart based on the team's progress.

Risk Analysis

Table 6: Risk analysis of plan A.

Technical Risks	If reliable communication is not provided, the project completely fails.
Cost Risks	There are no cost risks.
Timeline Risks	There are no timeline risks.

Table 7: Risk analysis of plan B.

Technical Risks	Same risk is valid, if reliable communication is not provided, the project completely fails.
Cost Risks	There are no cost risks.
Timeline Risks	There may be some timeline risks because the new design causes us to spend more time.

Conclusion

This conceptual design report introduces the project's statement, outlines its current status, and provides insights into the implementation and test procedures. Design objectives and requirements are articulated, offering a comprehensive overview of our company's intentions and the project's general impression, substantiated by justifications. The overall system solution and relationships with other sub-systems are concisely explained.

The main solution of the first sub-system, the Mobile Units Movement Sub-System, is localization with high accuracy and precise movement with a gyroscope. For high-accuracy localization, RFID tags are used; therefore, each MU has a chance to update its location in every tile. For precise movement, a gyroscope is used to measure the heading (yaw) angle and angular speed of the MU to make it go straight and make a complete 90-degree turn. As an alternative solution to this sub-system, motor encoders can be used to measure the MUs' spatial displacement accurately and adjust the RPM values of the motors for precise movement.

The main solution of the second sub-system, the Search and Rescue Algorithm Sub-System, is to use graphs to represent the grid. Firstly, the grid is divided into three equal search areas and each area is assigned a MU. Avoiding obstacles and returning to the base and target is based on the same path-finding algorithm, Dijkstra's algorithm. This algorithm provides the shortest path between source and destination tiles. To prevent collision between MUs, returning the path to the target is calculated by BU and transmitted MUs. When a MU's path is calculated, this path is marked as visited, not to be used in the other MU's path to avoid collisions. Different path-finding algorithms in the literature, such as A* and RRT, can be used, and the location of the base unit and partition of the grid can be changed as an alternative solution to this sub-system.

The main solution of the third sub-system, the IR Communication Sub-System, is encoding and decoding data with the NEC protocol due to its widespread usage and consistent, reliable results in our experimental trials. Each unit has been allocated a specific address, ensuring that the received messages are decoded and processed based on the provided address information. If the angle of sight is insufficient, we can periodically rotate the base unit around itself to provide point-to-point communication as an alternative solution.

Then, the test procedure and results are provided to explain the performance of the project and the basis for the design decisions. According to the test results, it is concluded that the system is in a good status, but further improvements are needed for the Mobile Units Movement Sub-system.

Subsequently, an assessment of the upcoming work and the allocation of tasks among company members, constituting the overall company schedule, are disclosed. A comprehensive risk analysis is conducted in terms of plans, and contingency solutions for potential challenges are outlined to prevent any disruptions in the project's progress.

Appendix 1: Weighted Objective Tree

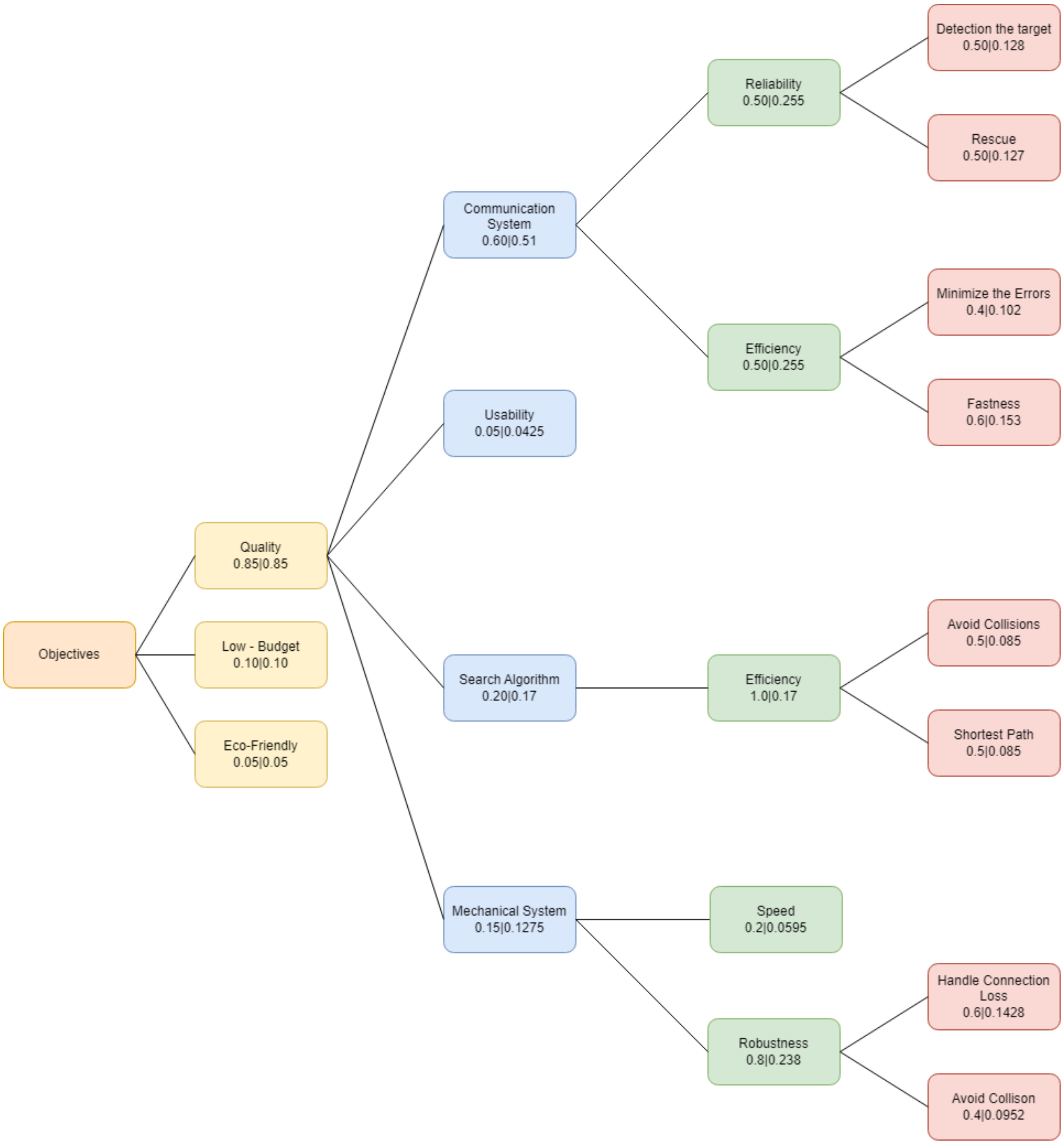

Figure 9: Weighted objective tree.

Appendix 2: Test-1: Movement Algorithm Sub-System Test

Location	EE Building D-125	
Date	20 December 2023	
Time	18:00	
Description	This test document is designed for an ad hoc network communication by TechBatch to test movement algorithm sub-system, collect the results and publish them.	
Aim	This test guide aims to show if the base unit can monitor the mobile unit for it to move in specified routes.	
Expected Outcome	It is expected to show that the mobile unit is able to move in different paths according to the directions that are predefined.	
Participants	Eren BALEVİ, Eda ÖZKAYNAR, Hasan Said ÜNAL, Mustafa ÇELİK, Mustafa Kemal ÖZDEMİR, Tuana MERDOL	

1. Map

Test will be done on a map which contains an 8x8 grid. Mobile unit will be placed on this map.

Calibration: Each tile is adjusted as 12.5 cm x 12.5 cm and it is verified with a ruler.

Test Environment

The test environment for this subsystem will be the map that the base unit and mobile unit will be placed on. This map will be a grid with 1 m^2 area, and it is divided into 8 x 8 square tiles. Each row is named as (A, B, C, D, E, F, G, H), and each column is named as (1, 2, 3, 4, 5, 6, 7, 8). A robot car (mobile unit) will be placed on the starting tile and a computer with an Arduino IDE will be used to send commands for the movement on the specified route.

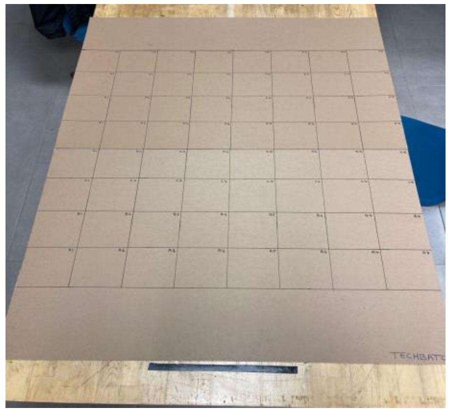

Figure 1: Test environment.

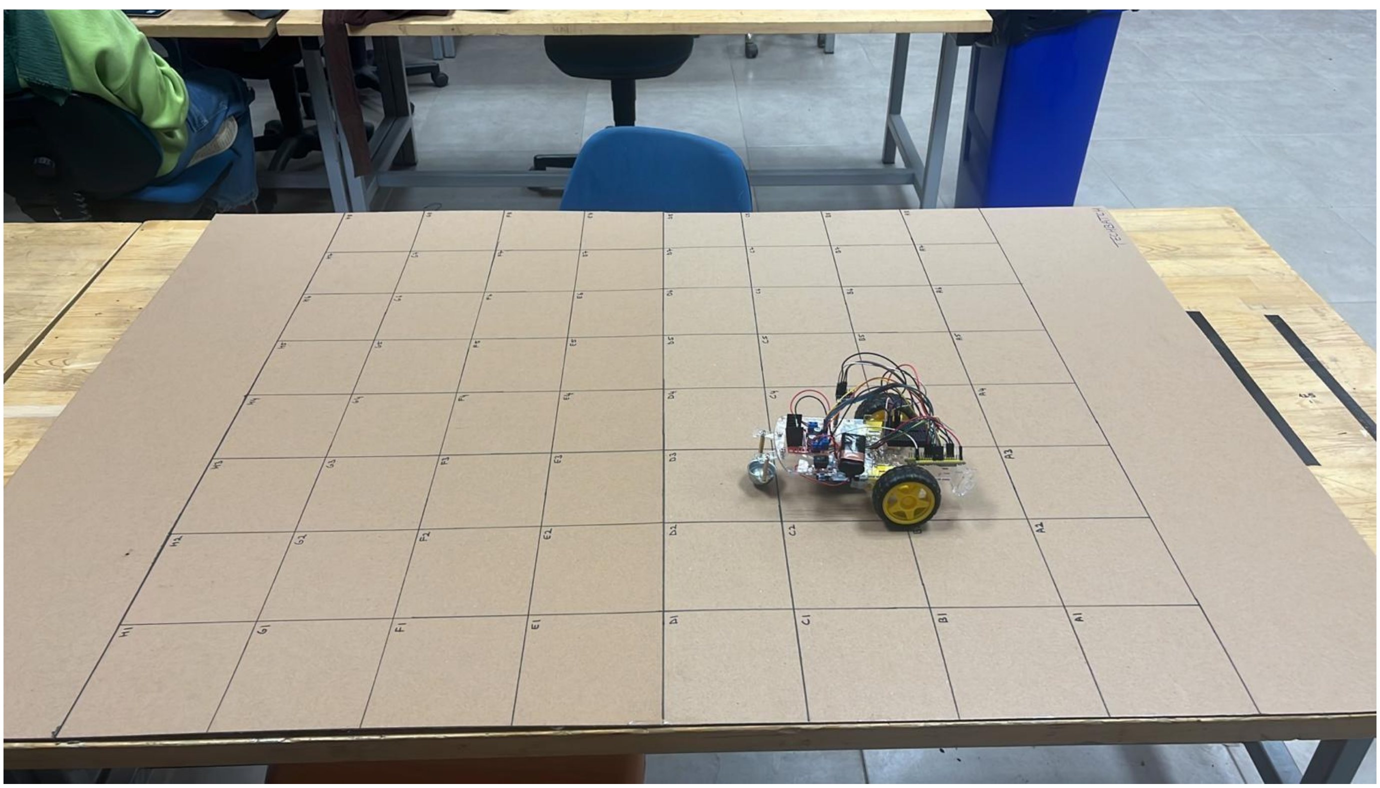

Figure 2: Test environment with MU.

Test Parameters

Parameter	Range	Step Size	Number of Measurements
# of tiles MU traverses in direct path	1-7 tile	2 tile	4
# of tiles in a side of the square MU traverses in square path	4-6 tile	1 tile	3

1. Test Procedure

1. Movement algorithm test for direct path in different distances is planned. The procedure is as follows:

1. The MU is powered on.
2. The ESP32 microcontroller on the MU will be connected to a phone via Bluetooth, using the Dabble application the connection is established.
3. The mobile unit will be placed on a predetermined tile and directions which is indicated in Figure 3. The paths below will be repeated for 5 times. The command is sent to the MU to start the movement. For navigating MU in the specified paths commands in below must be sent:
    a. 1: Go straight for 1 tile
    b. 3: Go straight for 3 tiles
    c. 5: Go straight for 5 tiles
    d. 7: Go straight for 7 tiles
    e. 4: 4x4 square path
    f. 6: 5x5 square path
    g. 8: 6x6 square path
4. Error is defined as whether or not the MU is stopped at the target tile. If it didn't stop then this trial would count as a failure.

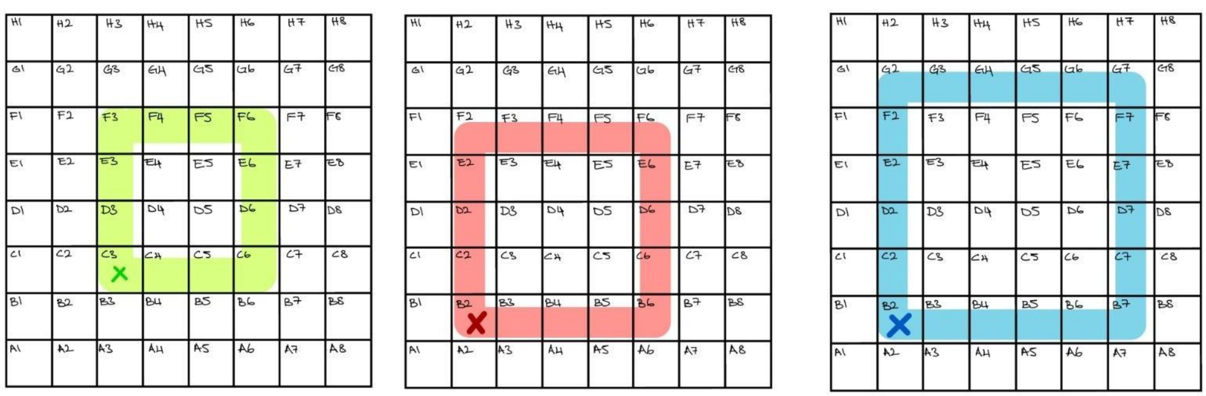

Figure 3: Test paths for square movement.

Test Data

Table 1: # of tiles MU traverses in direct path

Parameter Value	Actual Performance	Expected Performance	Error
1	5/5	5 successful missions out of 5 trials	
3	5/5	5 successful missions out of 5 trials	
5	4/5	4 successful missions out of 5 trials	
7	4/5	4 successful missions out of 5 trials	

Table 2: # of tiles in a side of the square MU traverses in square path

Parameter Value	Actual Performance	Expected Performance	Error
4	2/5	4 successful missions out of 5 trials	
5	2/5	3 successful missions out of 5 trials	
6	2/5	3 successful missions out of 5 trials	

Data Analysis

(To be filled after the test)

Determine appropriate methods for analyzing and presenting the test data (plots, diagrams, tables, etc.). Provide meaningful statistical analysis.

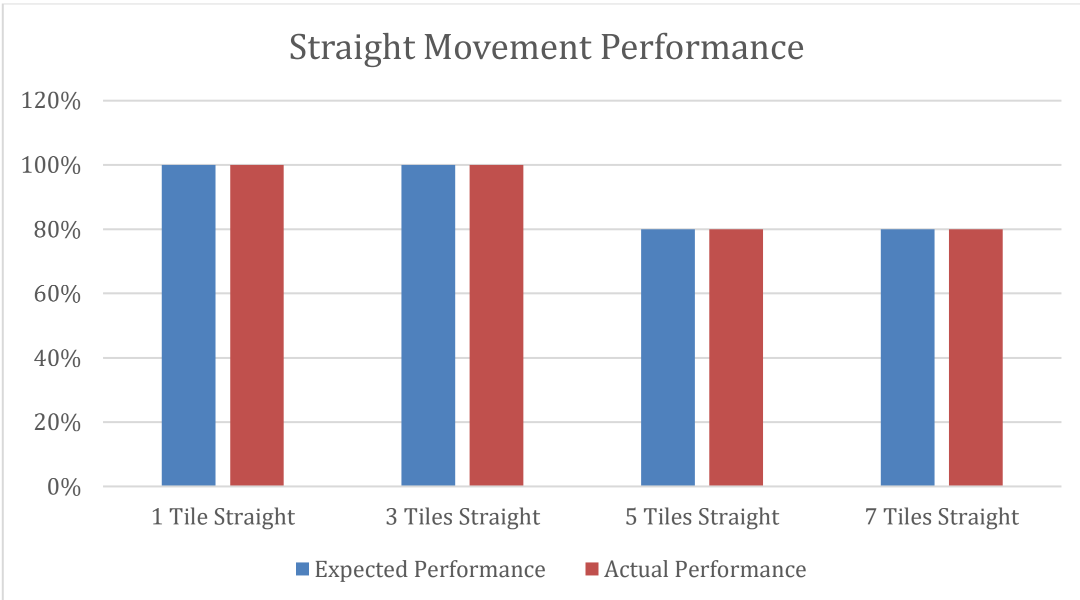

Figure 4: Straight Movement Performance Table.

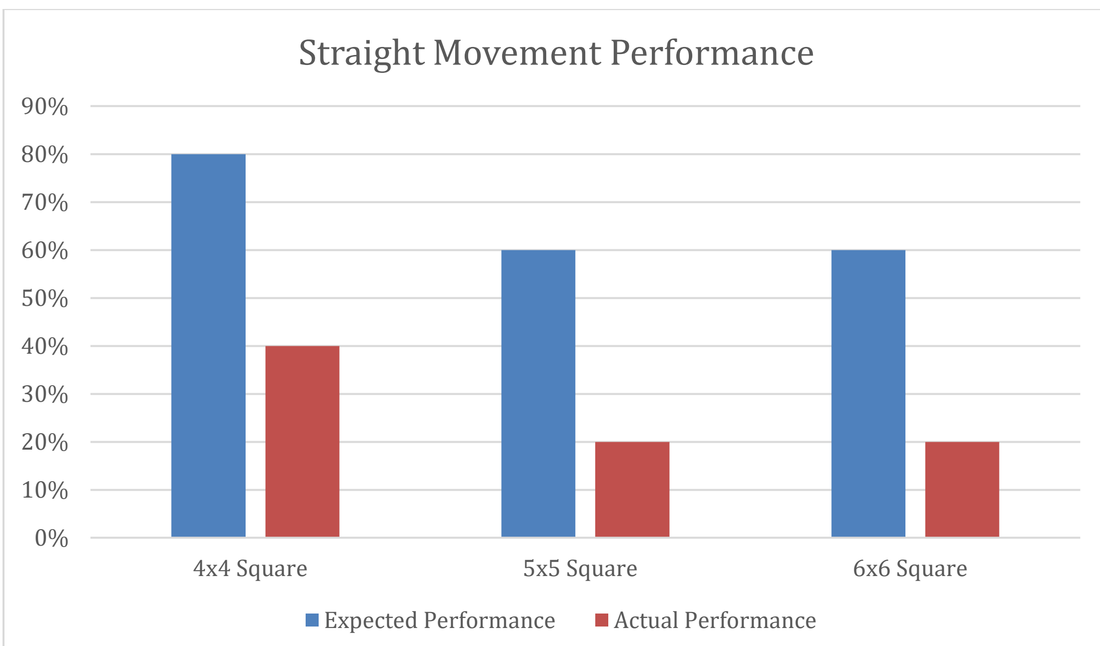

Figure 5: Straight Movement Performance Table.

Results and Discussion

Going Straight Test
In the distance test, we successfully achieved the expected performance at each distance, as illustrated in the related graph. This result shows that the base unit can move in a straight path without any deviation. It ensures that our units can move between the required tiles without unconnecting RFID cards. Moreover, movement algorithms can be operated with minimal error.

Turning Square Test
In this part of the test mobile units failed in some parts due to reasons mentioned clearly in the test results part. The main reasons are about power source and non-idealities of the motors as well as the gyroscope algorithm. Corresponding improvements were determined and will be implemented in the following weeks.

Appendix 3: Test-2: IR Communication Sub-System Test

Location	EE Building D-125
Date	20 December 2023
Time	18:00
Description	This test document is specifically crafted for evaluating ad hoc network communication within TechBatch's IR communication system. The primary objective is to conduct comprehensive tests, systematically collect the results, and subsequently publish a detailed report.
Aim	This test guide is formulated to validate the sub-system's ability to accurately transmit and receive data signals from the IR transmitter and receiver under diverse conditions.
Expected Outcome	Reliable communication is expected for different angles and ranges between Base Unit (BU) and Mobile Unit (MU). Communication will be corrupted when the MU is out of range.
Participants	Eren BALEVİ, Eda ÖZKAYNAR, Hasan Said ÜNAL, Mustafa ÇELİK, Mustafa Kemal ÖZDEMİR, Tuana MERDOL

Test Devices & Tools

1. Ruler

Ruler will be used to measure the distance between the base unit and the mobile unit.

Calibration: The precision and the accuracy of the ruler can be tested with another ruler. Intervals of the ruler are accepted as a true reference for dimension measurements.

2.Computer with Serial Window of the Arduino IDE:

As long as the base and mobile unit communicate 'Message is Received' message will appear in the serial window of the Arduino IDE.

Calibration: Serial window is reset for each test. Reset process can be done by the button which is on the top right corner of the serial window of Arduino IDE.

2. Protractor

Calibration: To check the protractor one can use a known reference angle to compare the reading on the protractor with the actual angle. For example, one can use a 90-degree wall or a 180-degree angle ground.

Test Environment

The testing environment for this subsystem is a part from the main map of the system. First five rows and columns of the map (tiles marked from A to E and 1 to 5) will be used to show that the mobile unit and base unit communicate until the 3 tile distance. A unit that contains an ESP32 microcontroller, a transmitter and a receiver which represents the **base unit** will be placed at the beginning of the map (tile A1), and another unit with an ESP32, a transmitter and a receiver that represents the **mobile unit** will move between A1 and A4. A computer screen will be used to track the communication.

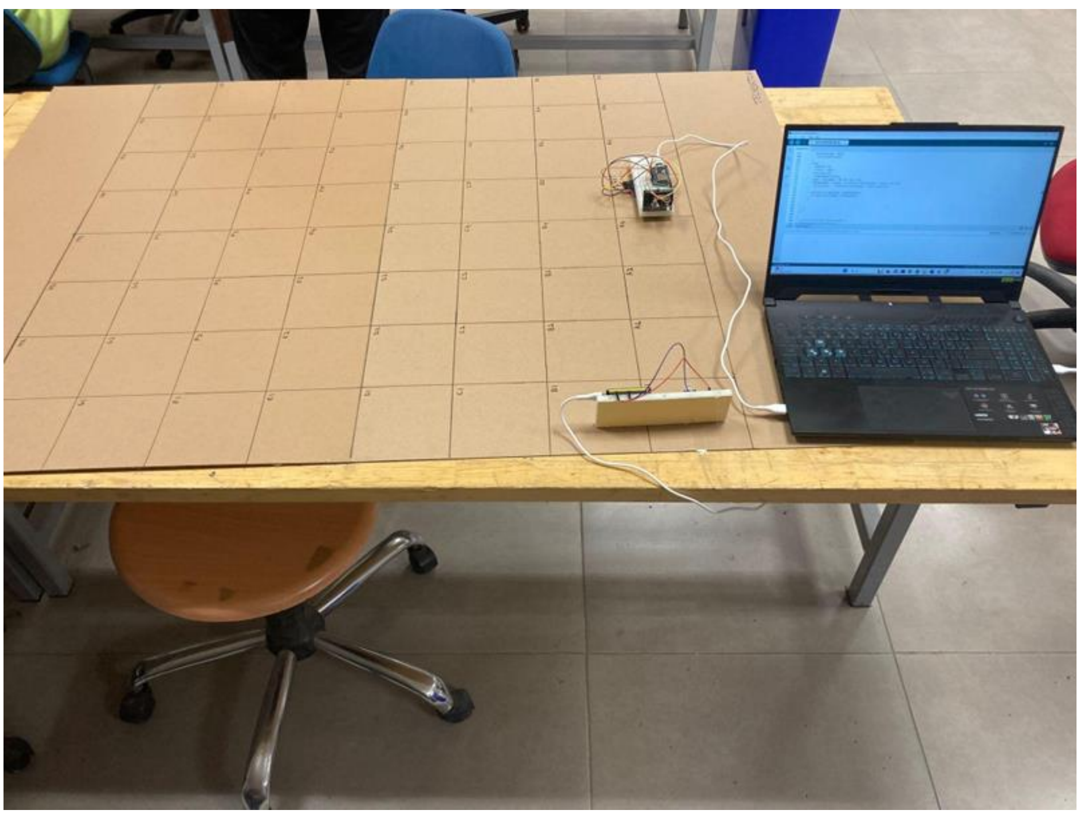

Figure 1: Test environment for IR communication.

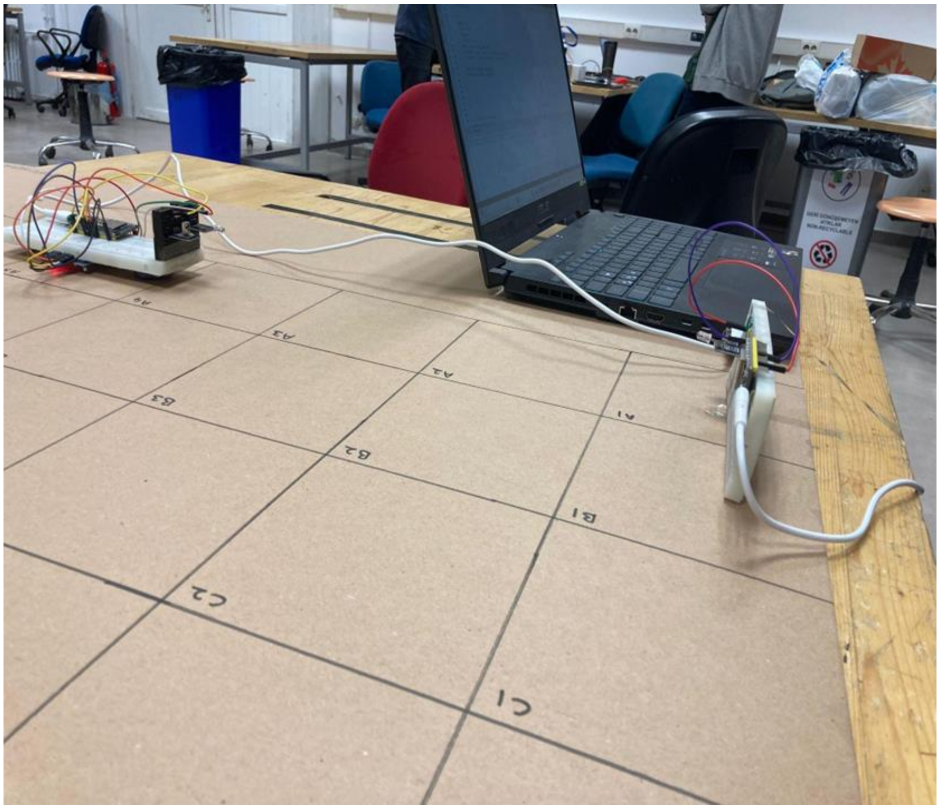

Figure 2: Test environment for IR communication.

Test Parameters

Parameter	Range	Step Size	Number of Measurements
Distance between emitter and transmitter	2-5 tiles	1 tile	4
Angle of the transmitter	0-180°	30°	7

1. Test Procedure

1. **IR communication test for different distances between the mobile unit and base unit is planned. The procedure is as follows:**

    1. Units that represent base and mobile units are connected to two different computers through their ESP32 microcontrollers.
    2. The files named **"BU.ino" and "MU1.ino"** are opened and the programs in the files are loaded to the ESP32 microcontroller of the base and mobile units.
    3. The base unit is placed on the center of the A1 tile as seen in figure above.
    4. The mobile unit is placed on the tile A2.
    5. To check for communication, we will verify there is reliable communication between the base and mobile unit by printed messages on the serial monitor of Arduino IDE.
    6. **"Message is received from BU/MU: " ,"MU/BU sent the message: "** messages will be seen on the screen if the two side communication occurs, and if the communication cannot sustain received messages won't be seen.
    7. The mobile unit will stay in each tile for a while and the serial monitor will be tracked to record how many of the first 20 messages that are sent and received were delivered successfully or not.
    8. The same measurement will be performed on each tile.

2. **IR communication test for different angles between the emitter and transmitter is planned. The procedure is as follows:**
    1. Units that represent base and mobile units will be connected to two different computers through their ESP32 microcontrollers.
    2. The files named **"BU.ino" and "MU1.ino"** are opened and the programs in the files are loaded to the ESP32 microcontroller of the base and mobile units.
    3. The base unit is placed on the center of the A1 tile as seen in figure above.
    4. The mobile unit is placed on the tile A2.
    5. Mobile unit is rotated from 0 degree to 180 degree with a 30 degree step size .
    6. To check for communication, we will verify there is reliable communication between the base and mobile unit by printed messages on the serial monitor of Arduino IDE.

7. **"Message is received from BU/MU: " ,"MU/BU sent the message: "** messages will be seen on the screen if the two side communication occurs, and if the communication cannot sustain received messages won't be seen.
8. The mobile unit will stay in each step for a while and the serial monitor will be tracked to record how many of the first 10 messages that are sent and received were delivered successfully or not.

9. If 8 of 10 messages are unsuccessful, communication is considered as failed.

10. After the measurement, the process is repeated in the following tile until tile A4 for the angle ranges specified on the tables below.

Test Data

Table 1: Distance (@ 0 degree)

Parameter Value	Actual Performance	Expected Performance	Error
1 tile	100%	>95% reliable communication	0%
2 tiles	100%	>90% reliable communication	0%
3 tiles	100%	>85% reliable communication	0%
4 tiles	100%	>80% reliable communication	0%
5 tiles	0%	<10% reliable communication	0%

Table 2: Angle (@ A2)

Parameter Value	Actual Performance	Expected Performance	Error
0	100%	>90% reliable communication	0%
30	100%	>90% reliable communication	0%
60	100%	>90% reliable communication	0%
90	100%	>90% reliable communication	0%
120	100%	>80% reliable communication	0%
150	100%	>80% reliable communication	0%
180	100%	>70% reliable communication	0%

Table 3: Angle (@ A3)

Parameter Value	Actual Performance	Expected Performance	Error
0	100%	>90% reliable communication	0%
30	100%	>90% reliable communication	0%
60	100%	>80% reliable communication	0%
90	100%	>70% reliable communication	0%
120	100%	<20% reliable communication	80%
150	100%	<20% reliable communication	80%
180	99%	<10% reliable communication	89%

Table 4: Angle (@ A4)

Parameter Value	Actual Performance	Expected Performance	Error
0	100%	>90% reliable communication	0%
30	100%	>80% reliable communication	0%
60	100%	>70% reliable communication	0%
90	100%	<50% reliable communication	50%
120	100%	<30% reliable communication	70%
150	100%	<20% reliable communication	80%
180	10%	<10% reliable communication	0%

Data Analysis

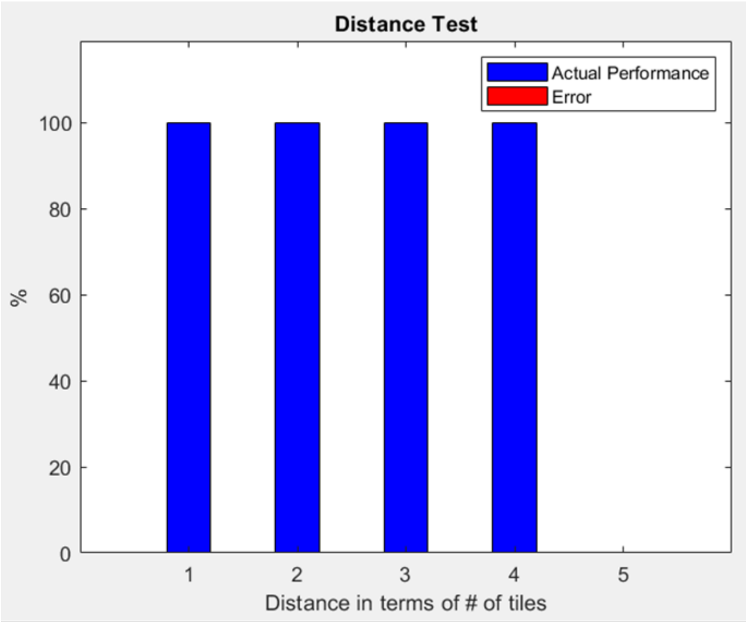

Figure 3: Distance Test Results

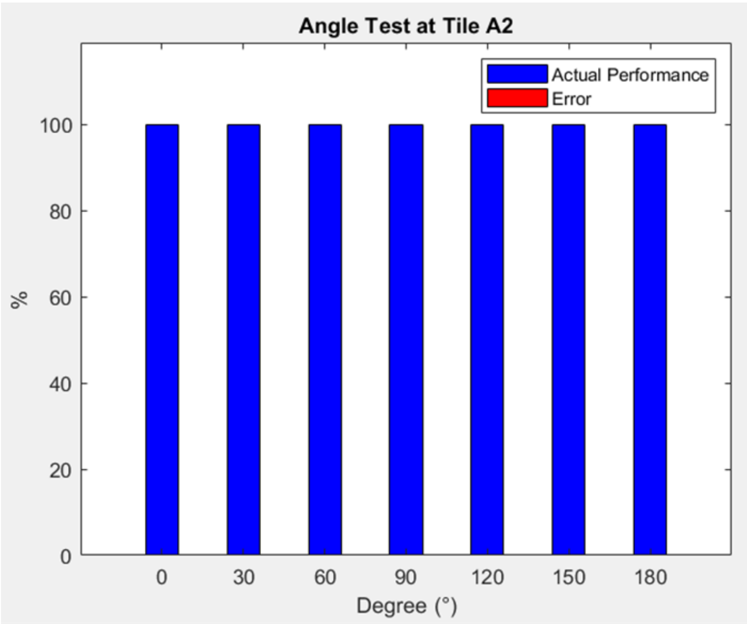

Figure 4: Angle Test Results at Tile A2

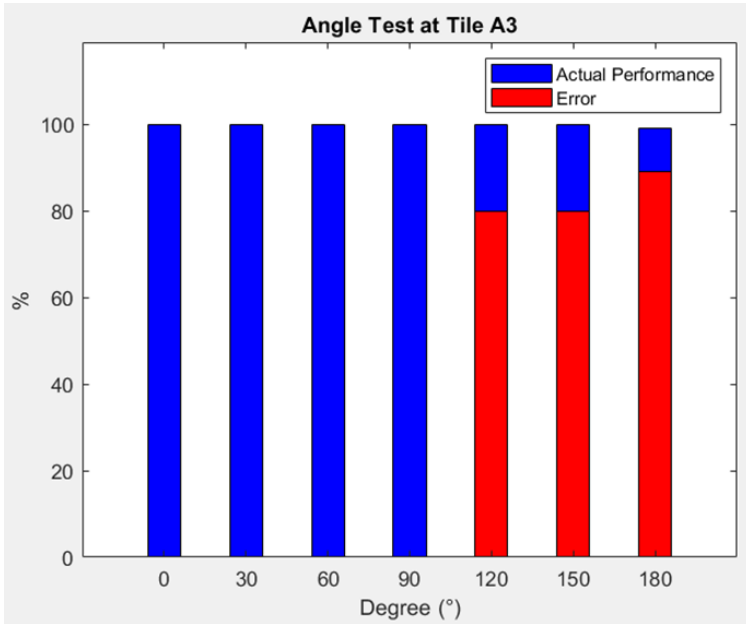

Figure 5: Angle Test Results at Tile A3

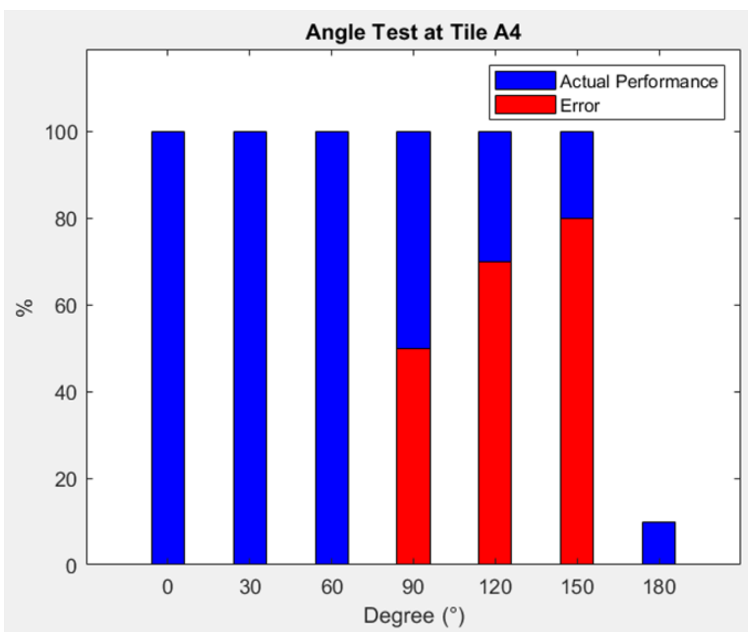

Figure 6: Angle Test Results at Tile A4

Results and Discussion

Distance Test

In the distance test, we successfully achieved the expected performance at each distance, as illustrated in the accompanying graph. This outcome affirms our accomplishment in establishing reliable communication between the base unit and mobile unit within the specified distances. Consequently, it ensures dependable communication at the prescribed range limit of the base unit.

Angle Test

During the angle test, discrepancies were observed in some angles, particularly at tiles A3 and A4. These errors can be attributed to an unexpectedly high communication performance at certain angles, surpassing our initial expectations. However, this anomaly does not pose a significant challenge. On the contrary, it presents an advantage by facilitating communication over a wide range of angles, notably up to 180 degrees in most cases. This promising result opens the possibility of employing a stationary base unit instead of one that requires rotation, simplifying the communication setup between the base unit and mobile units.