SIGHT

# Final Report

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# Executive Summary

Founded in June 2023 by 6 highly motivated Electrical and Electronics engineers from Middle East Technical University (METU), SIGHT Inc. is a cutting-edge R&D company. Since the day of our founding our main drive and motivation has been creating outstanding products that can help the world become a better and safer place. In our pursuit of this vision, we have been working relentlessly on coming up with new and creative ideas that could have an impact on human-life itself, more specifically a system that could aid rescue teams during disasters such as wildfires, earthquakes and more.

Disasters and more specifically natural disasters are an inescapable truth of our lives. Before faced with a disaster, it is important to have the required infrastructure and resources to manage the possible negative after effects they could cause. Especially the last earthquake in Turkey, back in February 2023, has reminded us of how important it is to be prepared. Maintaining robust communication in the midst of a disaster scenario is one of the most crucial parts of search and rescue efforts, especially when communication through usual networks is damaged or completely ceases to function. This crucial fact has inspired us to come up with a communication system that can help relief teams in case of possible disaster scenarios.

Our solution plan provides an ad-hoc communication system that is tailored for disaster relief scenarios. During emergencies such as earthquakes and fires, it enables efficient coordination and communication between search and rescue teams. This system consists of a base unit (BU) and mobile units (MUs) that utilize infrared frequencies for communication between each other. With these properties, our system allows for near real-time information sharing and rescue coordination within a designated area. The system optimizes the rescue operations by locating targets accurately in as little time as possible, reduces response times, utilizes collaboration among various mobile units and cleverly addresses challenges such as signal interference and obstacles

This project acts as the foundation for an Ad-Hoc Network Communication System designed for disaster relief where communication is vital for search and rescue efforts. Any investment in this foundational stage will pave the way for the development of the fundamental communication infrastructure to be used in real-life disaster scenarios. Making use of the scalability of this technology will ultimately enable us to improve the efficiency of disaster response efforts.

Our deliverables for the project are a base unit (BU), 3 mobile units (MUs) and a test area. The total budget for this project is estimated to be around $240 where the expenses are detailed categorically in the cost analysis of subunits if applicable, and in the Planning section of the report.

Our team consists of multi-talented engineers, specialized in 4 different fields of Electrics and Electronics Engineering. The versatility of our team and its collective expertise and knowledge ranging from power electronics to communication networks ensures the successful and efficient execution of the Ad-Hoc Disaster Relief Communication project. This well rounded team will not only meet the requirements and objectives, but also promises exceeding them.

# Introduction

In this report, the Ad Hoc Communication System for Disaster Relief project will be discussed. First, the motivation, the current status of the project, and the scope of the report are discussed. Then, objectives and requirements, system analysis and solution ideas, test results and the plan of progress are given.

## Motivation of the project

In the unfortunate event of the earthquake that struck Turkey on February 6th, the critical importance of reliable communication in disaster situations was harshly evident. The disaster not only resulted in profound trauma for the affected communities but also revealed significant challenges. Search and rescue teams encountered difficulties in reaching certain cities. Simultaneously, the affected regions witnessed the collapse of vital communication infrastructures, rendering effective coordination and information dissemination exceptionally difficult. Moreover, the task of detecting disaster victims proved to be a formidable challenge for the rescuers, marking the urgent need for innovative solutions that can address these critical issues and enhance the efficiency of disaster response efforts.

## Literature/Market Survey (State of the Art)

This study aims to showcase the latest advancements in robotics in disaster relief situations, with a focus on cooperative communication and target search among robotic units. Research on self-governing robots demonstrates their efficiency in accomplishing target search assignments in crisis situations, illustrating their usefulness in maneuvering, and reaching hazardous or difficult-to-reach locations that could prove problematic for human rescue personnel. Furthermore, the understanding of swarm intelligence enhances robotic units' capacity for real-time coordination and communication. Leading robotics businesses' industry publications highlight the useful applications of communication characteristics for efficient platform cooperation. Present-day developments in the topic focus on incorporating communication functionalities into robotic systems, specifically using swarm intelligence to improve real-time coordination. Developing adaptive communication protocols to enable smooth cooperation between diverse robotic teams presents opportunities for innovation. The results, especially regarding the effectiveness of autonomous robots in target search missions, will guide the conceptual design in the following sections by filling in the gaps and leveraging new developments in the dynamic field of robotics in disaster relief.

## Final status of your project work

Concerning our project, we have evaluated all available mechanisms and selected the most effective option for each unit. These subsystems, namely the decision, communication, sensing, power, and motion units, have been elaborated on in the Final Report. Notably, in the motion unit, we've utilized the line-follower sensor for both linear movement and rotation operations of our two-wheel mobile units. In the communication unit, we have implemented the "Sensory Approach." This design strategy involves placing 8 transmitter and receiver pairs around the robot to achieve signal coverage. Moreover, we have utilized a custom protocol for data transmission. This data protocol and design approach will be discussed further in this report. For the sensing unit, RFID is the chosen method for the final design. In the decision unit, our final strategy is Plan B, which involves a predetermined division of the 9x9 search area into three sections for each mobile unit to find the target.

## Scope and organization

The report begins by offering a detailed description of the requirements and objectives of the system. In this part, we highlight a set of features considered important for meeting customer expectations or perceived as necessary by the project team during the planning or development phase. Then, we will move forward with system design where we discuss our solutions as rough drafts of systems and subsystems. Then, we will go through our test results regarding the performance of these solutions. The following segment details the expected results, offering a comprehensive description of the anticipated project outcomes. Finally, the report wraps up by presenting the key discoveries and insights gathered from the entire proposal report.

## Problem Statement

This project consists of a stationary base unit (BU) and three mobile units (MUs) whose aim is to find the location of the desired target as quickly as possible and enable coordinated action among other mobile units to reach the identified target. A wireless communication between units with infrared frequencies is implemented to enhance the process of locating the target. How the information is transmitted, received, and processed is the main concern of the project. In order to transfer information between units, the distance between them should not be greater than R. The primary objective of a mobile unit is to scan the tiles on its path to check whether the target is located there and transmit its acquired information to other units if they are in communication range. Enabling the smooth movement of the mobile units without colliding with each other plays an important role in an effective search. After finding the target, the mobile unit notifies the base unit so that the other mobile units can gather around the target. While the base unit does not take part in active search, it plays an important role in facilitating information flow between mobile units.Transmission and reception at the base unit can be omnidirectional. While each mobile unit knows its initial position, the base unit does not have mobile units initial location information. Its information is updated after every communication establishment with mobile units. While mobile units can communicate with the base unit, they can also communicate with each other after a connection is established.

The search area is designed to be 2.5 Rx2.5 R m2 which consists of NxN square tiles where N has to be bigger than seven. Values of R and N are decided according to the dimensions of the mobile units and search algorithm proposals. Additionally, obstacles within this area have the capacity to obstruct both the movement of the mobile units and communication between them. While obstacles can be one or two tiles long, there are at most three obstacles in the area.

# System Design

Our project is segmented into distinct units, namely communication, decision, motion, sensing, and power units. In the communication unit, our main goal is to transmit information data in condensed packets between mobile units (MU) and the base unit (BU) utilizing IR LED's and receivers, all the while maintaining package integrity. The Decision Unit is tasked with determining the next movements of the mobile units by utilizing current information on the search status, the information gathered autonomously through a search algorithm or gathered by other MU's and BU. It also makes decisions on what information to transmit to the communication unit for distribution to the other mobile units. The Motion Unit is dedicated to managing motors, their control algorithms, hardware, and feedback mechanisms to achieve the desired movements. The Sensing Unit is designed to facilitate the tracking of mobile units to determine their respective locations and tracking the target location in the playground (search field) at the same time. The Power Unit oversees the management of the battery, its charging process, and performs DC/DC conversions.

In the following sections each unit is examined in detail.To identify the optimal solution idea for each unit, an evaluation is conducted based on the weighted objective tree under each unit header. For the overall solution, we have decided to utilize Radio-frequency Identification (RFID) in the sensing unit to scan each tile of the rescue field. In the communication unit, we are using an electronic rotating system to cover all of the angles. In this system, there are 8 transmitters and receivers with only one of them is turned on at a time and the turned on one rotates. We are using a custom-made protocol to define the communication. The explanation in detail is in the Communication Unit Section. In the Decision Unit, our current algorithm is the

Plan B algorithm discussed in CDRR, where the grid is divided into 3 areas and every MU has its own area to search. At the start, they move on to their corresponding region and scan there until the target is found or another unit comes with this information. For more detailed information, refer to the Decision Unit section. In the Motion Unit, we have transformed our mobile unit into a line following robot in order to overcome the straight path challange.Now our robot moves on a grid with lines connecting the RFID tags. More detailed information is given in the motion unit section.

The general operational flow of the project is depicted in the block diagram (see Figure 2). In the Sensing Unit, MU's determine their locations by scanning each tile in the rescue field using the RFID technique. Subsequently, the mobile unit gathers information, including the scanned tiles, its current location, and the target's location (if it reaches the target and scans the target tile). This process culminates in a data information array about the rescue field. The Decision Unit utilizes this data array to determine the next movement of the mobile unit. For instance, in our solution approach, to find the target as soon as possible, the MU avoids scanning the tiles that have already been scanned by itself. Owing to the Communication Unit, MU's can gather information from other mobile units or the base unit. Therefore, the decision unit also considers the information based on data coming from the Communication Unit. Once the robot decides on its next destination, the Decision Unit instructs the Motion Unit, which, in turn, commands the driver, motor, and ultimately the wheels to take the necessary action. For the next destination, the same flow occurs.

The base unit comprises decision and communication units as well. However, the Decision Unit does not give commands to a Motion Unit; its role is solely to determine the information the BU shares with the MUs.

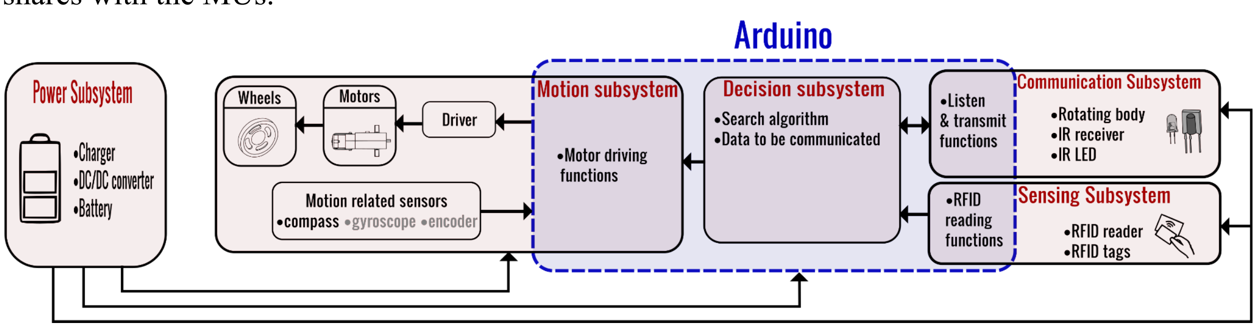



*Figure 1: Previous Block Diagram of the System Flow from the CDRR*

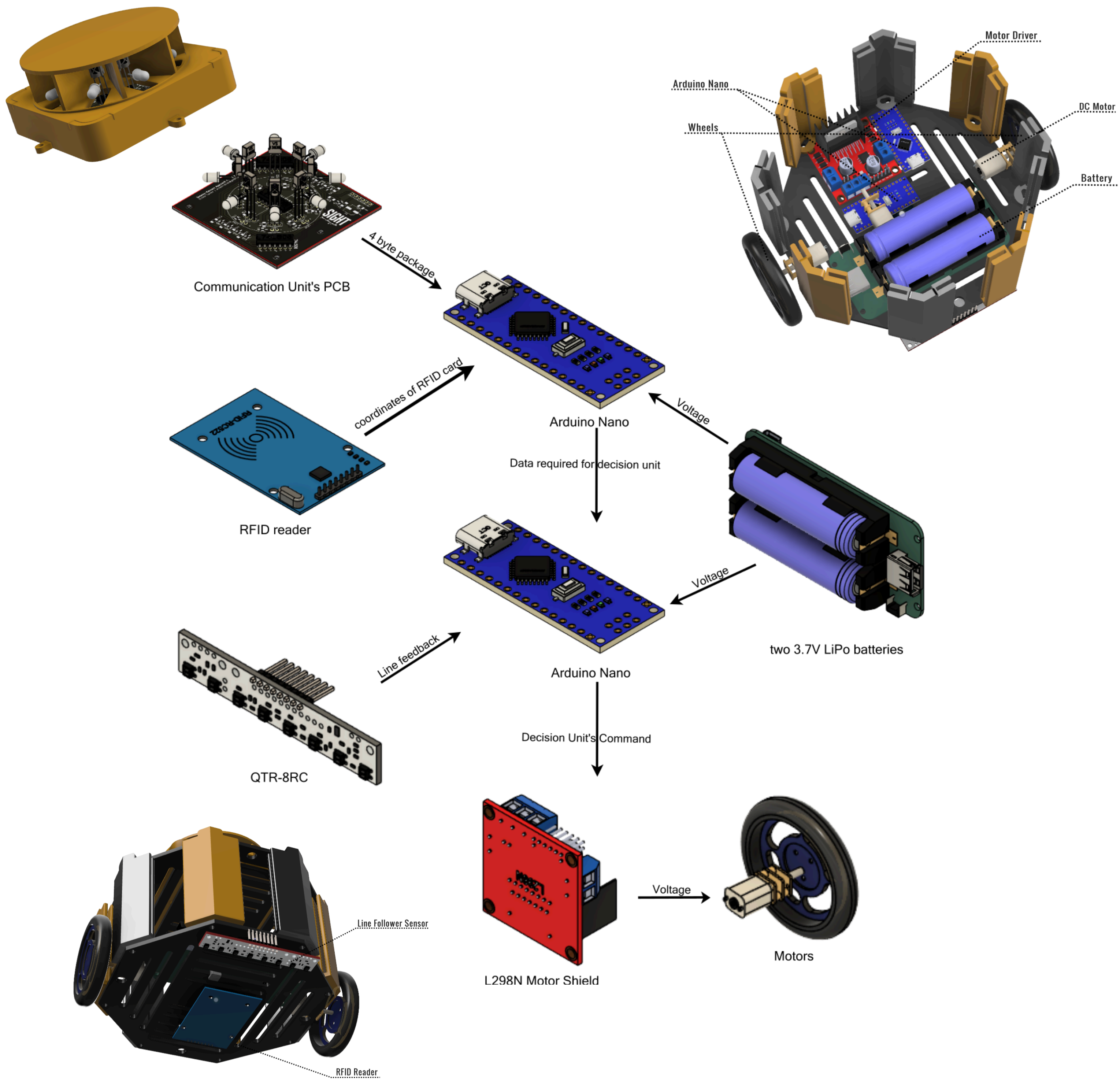



*Figure 2. Flow Chart of the A Mobile Unit*

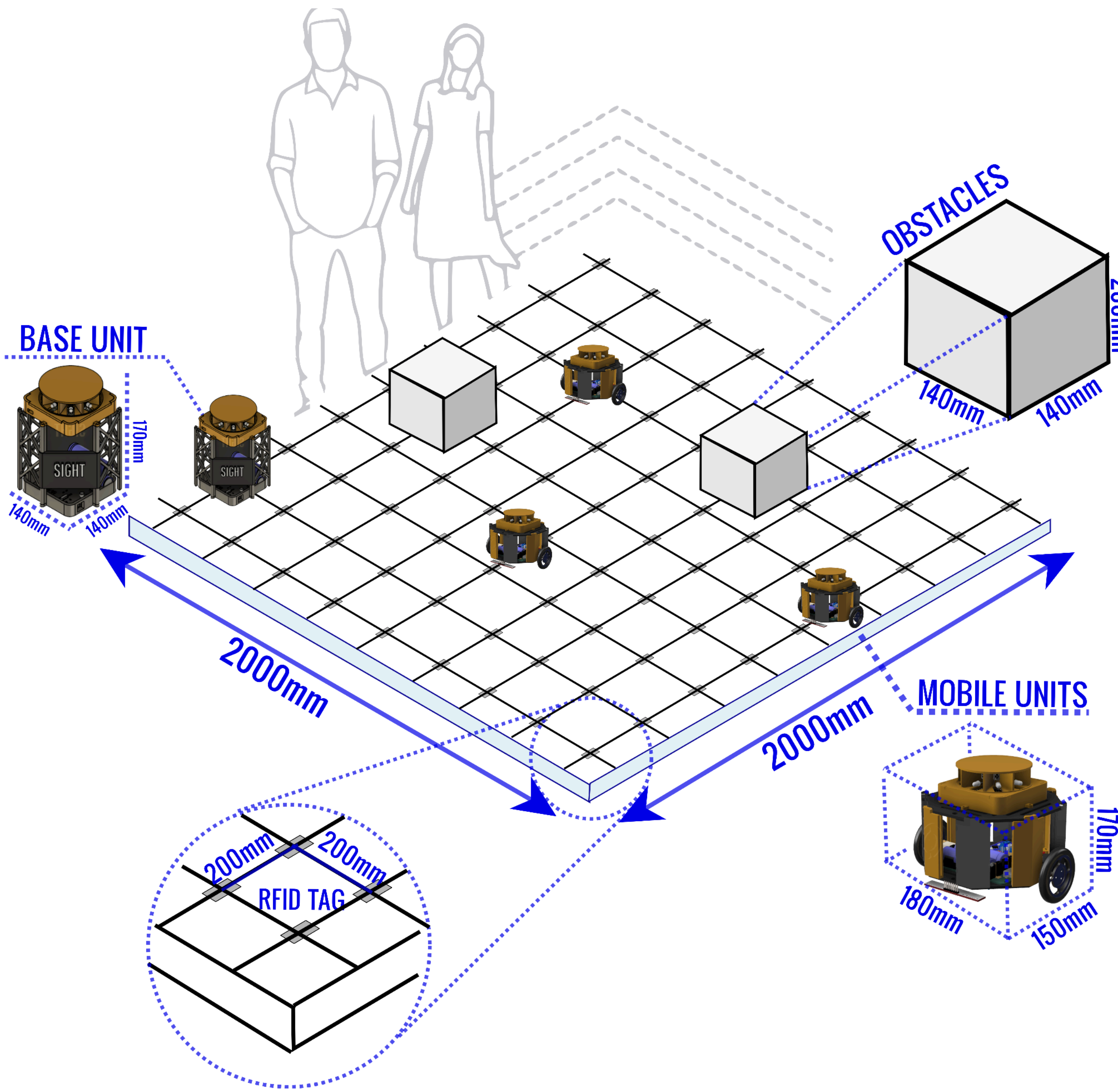



*Figure 3. Overall System*

Figure 3 illustrates the final design of our project. The anticipated dimensions for our rescue field are 2000X 2000 mm, with each tile approximately the dimension of 200 mm. The mobile unit we are using has dimensions of 180x150x170 mm and a power consumption of around 15W. We project that our obstacles will have dimensions of 140x140x200 mm, effectively covering an entire tile. The base unit is stationary, apart from velocity, its other parameters closely resemble those of the mobile unit.

## Communication Unit

In this unit, our main goal is to transmit information data in condensed packets between mobile units and the base unit utilizing IR LEDs and receivers, all the while maintaining package integrity. This unit is divided into hardware and software components. The software part will run on an Arduino Uno. Initially, we will present the subsystem level requirements. Then, we will present a summary of the hardware and software elements that constitute this unit.

The communication unit requirements and their relation to overall system requirements are as follows:

| Communication Unit Requirement | Corresponding System Requirement | Solution |
|---|---|---|
| The communication subsystem should have the functionality of communicating the units, it should deliver the messages on the target location and call the other MU’s. | Communicating with Other MUs and BU, Reporting Target Location, Calling the MUs | Using sensory approach solution, MUs are able to communicate with each other |
| The communication should be carried out in Infrared Frequency. | Infrared Frequency | Infrared transmitter and receivers are used |
| The system's communication range should cover 90 cm. | Having a Range of Communication | Communication range is adjusted as 90 cm via coding |
| %95 of the data should reach the communicated unit, and the analysis of whether the departing data is corrupt should be carried out with 100% success. | Reliable Communication | CRC technique is used |

# Hardware

### IR Receiver

The selected IR receiver sensor is the **VS1838B**. In its idle state, the receiver outputs a high signal. The experimental results of another IR receiver (i.e. **AA3P TK19**) showing similar characteristics to the **VS1838B** shown in Fig.4 and Fig. 5. Upon receiving a 38kHz IR signal burst, as depicted in Fig. 4, the output signal transitions to low and remains low for a duration equal to the burst duration. Fig. 5. To elaborate further, the burst pattern consists of one period of transmission followed by two periods of no transmission, concluding with another burst period. This sequence at the receiver side results in the reception of b'0110'.

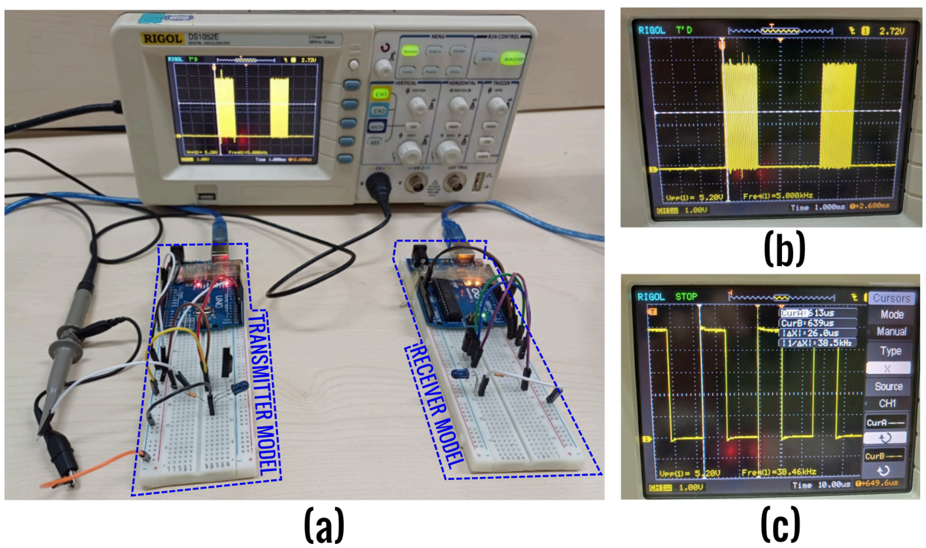



*Figure 4: Experimental Setup for Investigating AA3P TK19 IR Receiver Sensor Functionality with (a) overall configuration, (b) oscilloscope snapshot of the burst, and (c) close-up burst view at 38kHz frequency*

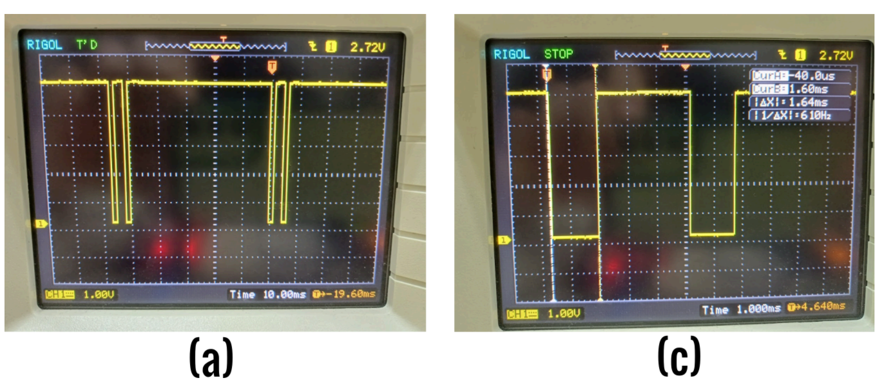



*Figure 5: AA3P TK19 IR receiver sensor output for a "0110" data stream with a 50ms delay (a) overview and (b) close-up views*

An important factor to consider is the burst length. To keep things simple, when we increase the number of cycles in each burst, we can send more bytes in a package, but the rate at which data is transferred slows down. After deciding on 60 cycles per burst, with each cycle lasting 26 microseconds, it takes 1.56 milliseconds to send one bit. This means the data transfer rate is 650 bits per second. Therefore, a burst length of 60 cycles meets our requirements without needing further improvements.

There are three main issues with the transmission that are not ideal. The first issue is with the burst frequency, which is very close to 38kHz but not exactly. The second issue is assuming that the output from the receiver stays low for the same time as the burst, which in practice, always has some differences. These differences are due to the step-by-step nature of the algorithm and imperfections. The third issue is that the transmitter might send a signal that doesn't perfectly match with T. When sending a small number of bits, these mistakes might not matter much. However, as the size of the data package grows, these mistakes add up and become significant. For an ideal burst duration of T, a mismatch at the receiver side T', the number of bits sent N, the difference in transmitting duration δ, and the difference in receiver output duration ζ per bit; the total mistake E at the receiver side for a package can be described with a formula.

$$T_i' = T + \delta_i + \zeta_i$$

$$E = \sum_{i=1}^{N} \delta_i + \zeta_i$$

The expression (δ + ζ) often shows a pattern of leaning towards either positive or negative values, leading to its gradual build-up. For the package to be accurately received, it is essential to maintain the value of E significantly lower than that of T. We have determined that when E reaches half the value of T, our sampling algorithm fails to function properly. Our algorithms are specifically designed to ensure that the condition E << T is met for complete package sizes of up to 16 bytes.

### IR LED

Not much consideration is needed for the IR LED, as the options mainly differ in their power ratings. We opted for a common through-hole IR LED with a forward voltage drop of 1.5V and a continuous current capability of 75mA. The signal applied to the LED has a peak value of 5 volts, and it is applied over a 330-ohm resistor, resulting in 10mA of current. It can be assumed that the total flux is more or less proportional to the applied current, provided it is moderate. In our testing, it was revealed that even 10mA of current is more than sufficient. It's important to note that there is still a safe margin to strengthen the light signal up to five times safely.

### Controller Circuit

With eight receivers and eight transmitters, there are sixteen devices to manage at any given time. The LEDs need to be activated, the receivers should be read, and there should be an idle state where no action takes place. Since using 16 different digital pins to control these devices is impractical, we employed an 8-Bit Serial-In-Parallel-Out Shift Register, specifically the **74LS164**. The pinout and internal structure of the IC are illustrated in Fig. 6.

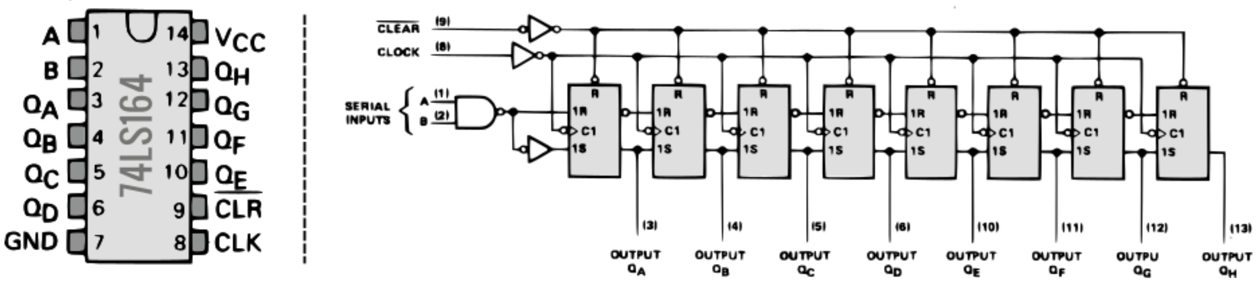



*Figure 6: Pinout and Internal Structure of 74LS164 IC*

In our setup, the Vcc and GND pins of the shift register are connected to the Arduino's 5V power supply and ground, respectively. The A and B input pins of the shift register are tied together and linked to a data signal originating from the Arduino. The CLR (clear) pin (which is connected to Vcc, rendering it inactive for our purposes. The CLK (clock) pin is connected to a clock signal generated by the Arduino. With each rising edge of the clock signal, the current data value is fed into the first SR-latch, and all subsequent bits are shifted one position to the left. By design, Qa and Qh outputs are considered the least significant and most significant bits, respectively. To ensure proper operation, only one of the outputs should be active (set to 1) at any given time. An illustration of the sequence of IC pin states required to select the sixth device (i.e., Qf) is presented in Fig. 7.

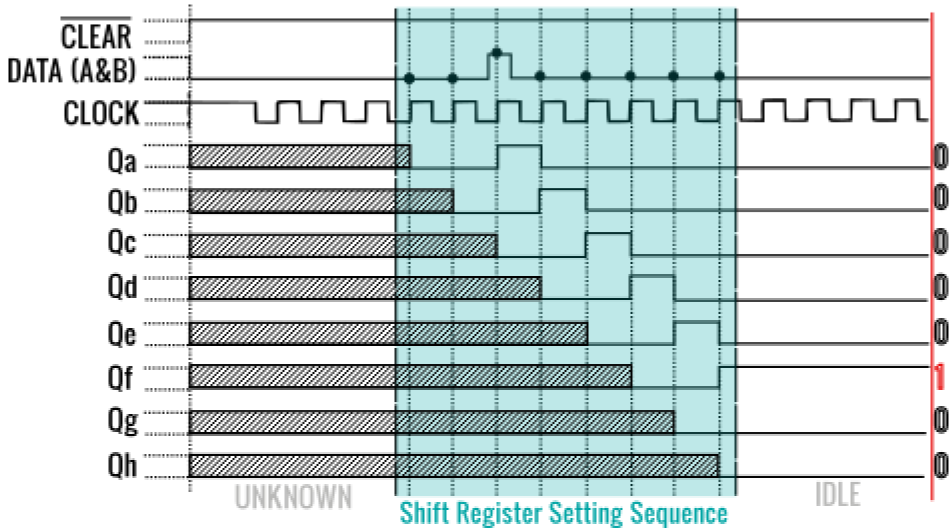



*Figure 7: Pin states sequences w.r.t time so that device related to $Q_f$ is selected.*

The outputs from the shift register, labeled as Qis, play a crucial role in selecting both receivers and transmitters. In other words, each Qi output is associated with a pair consisting of a receiver and a transmitter. To dictate whether the system is in a transmitting or listening mode, an additional pin from the Arduino, aptly named "transmit," is employed. The state of each transmitter (i.e., whether transmitter i is actively transmitting) can be determined by a specific logic equation.

$$Is\ i^{th}\ transmitter\ emitting\ burst\ =\ Transmit\ AND\ Q_i$$

The hardware realization of this logic is given in Fig. 8.

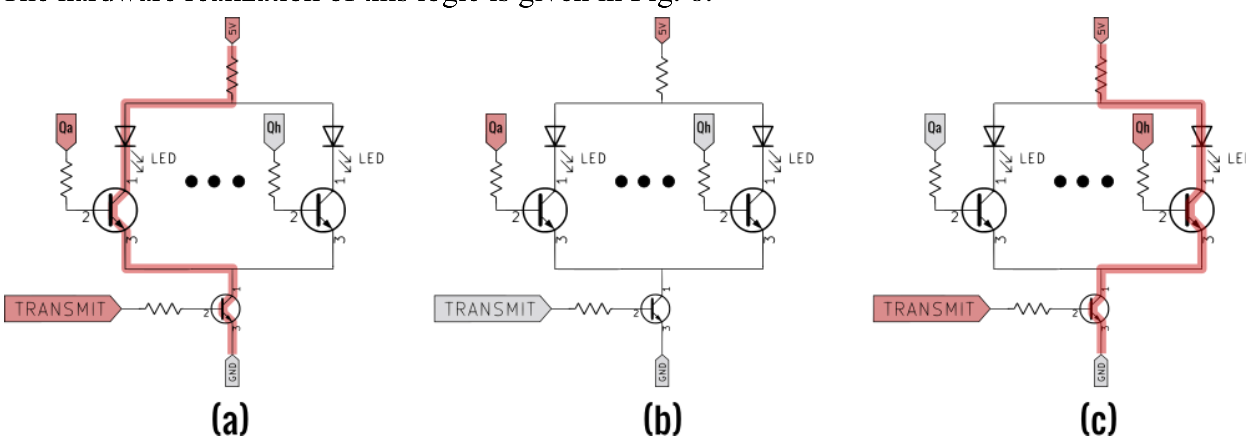



*Figure 8: States of the IR leds related to shift register outputs and the transmit signal where (a) led linked to Qa is transmitting (b) none is transmitting and (c) led linked to Qh is transmitting*

The transistor logic serves not only to perform a logical AND operation but also to amplify signal strength, thereby providing the capability to direct a greater current than the shift register IC can handle to the LED, if desired.

Similar to the transmitter side, the receiver side also leverages the outputs from the shift register by logically AND'ing them with the corresponding receiver output. To facilitate this AND operation, a logic IC known as the 74LS08, which comprises four 2-input AND gates, is utilized. The pinout and internal structure of this IC are detailed in Fig. 9.

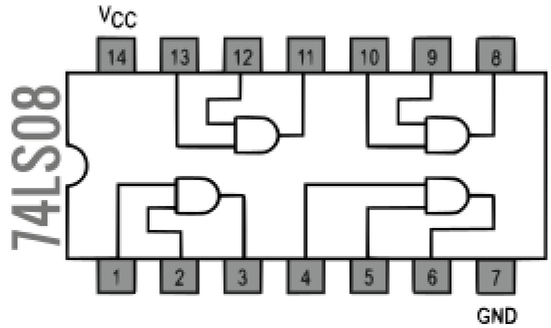



*Figure 9: Pinout and Internal Structure of 74LS08 IC*

The schematic diagram for the receiver side circuit is depicted in Fig. 10.

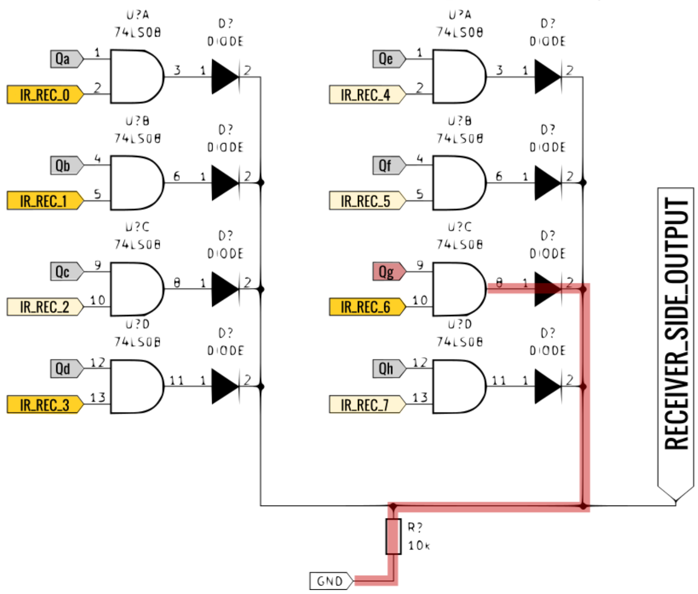



*Figure 10: Receiver side circuit schematic*

In this circuit, the 74LS08 IC is responsible for performing the AND operation. Diodes are incorporated to prevent short circuits during the transient operation of the shift register. Additionally, a pull-down resistor is used to ensure that the output does not float, providing a stable low state when no signals are present.

# Software

### Package Definition

In this project, a "package" is defined as 4 bytes of data transmitted between units. There are two types of packages: ping and acknowledgment. Ping and acknowledgment messages comprise 3 bytes of information and 1 byte of Cyclic Redundancy Check (CRC), totaling 4 bytes in length.

Initially, we considered sending a separate data package following the ping message. However, we realized that a 3-byte payload is sufficient to transmit all the necessary information. Consequently, we reduced the CRC length to 1 byte and incorporated the data into the ping and acknowledgment (ACK) messages.

The information bits consist of the next location (x and y coordinates), unit ID, intention and the target location (if known). The difference between the ping and acknowledgement messages occurs in the intention part. The details of these components will be discussed in the Data Sending Protocol section. Throughout this report, the terms "package" and "message" are used interchangeably. These packets are illustrated in Fig. 11.


*Figure 11: Data Packages*

### Cyclic Redundancy Check (CRC)

Cyclic Redundancy Check (CRC) is a widely used error detection technique in data communication. During transmission, the sending end calculates a check code for the data within a frame using a specific algorithm. This computed check code is appended to the data frame, which is then transmitted to the receiving end. At the receiving end, the accuracy and integrity of the received data are verified by recalculating the check code using the same algorithm. This process ensures the reliability of the transmitted data.  The CRC algorithm, being open-source, is directly implemented from its source code without delving into its mathematical background and tested throughout the entire testing process, ensuring its verification and reliability.

**Package Sending Algorithm**

The algorithm starts with setting the bytes in a byte array. Array being n bytes long, the first (n-1) number of bytes (i.e. payload) are set to any value desired. Then using a function, the CRC of the payload is calculated and set as the last byte of the array. Then the ***transmit_buffer()*** function is called. The communication starts by sending a start bit. Then, it goes through each byte of data in a byte array, and for each bit in a byte, it either sends a zero or a one using the functions ***transmit_zero()*** and ***transmit_one()*** according to the least bit of the byte. The program shifts the byte to the right (i.e. dividing by 2) after sending the bit. This process repeats for each byte, ensuring the entire data sequence is transmitted using IR communication. In essence, the code manages the systematic transmission of data in a simple and organized manner.

**Listen Package Algorithm**

The listening function is tracking low signals with a counter and decoding the received data along with the CRC validation. If a low signal is detected (i.e. IR receiver is triggered), after that instant, the function takes samples from the incoming signal by introducing a delay equal to the period of the 38kHz signal. If the signal is still low, the counter is incremented.And if the counter reaches a certain threshold (10 in this case), the listening function assumes that the start bit is received. Then the function decodes the data by continuously sampling the IR receiver pin at regular intervals and constructing a byte array with received bytes. This process continues until all bits are received. After the byte array is filled, the CRC check is applied. The function finally returns '1' if the package is valid, '2' if the CRC check fails (package corrupted), '0' if no signal is detected.

## Data Sending Protocol

We are using a custom-made data sending protocol that we explain here. Our protocol involves ping and acknowledgment (ack) messages, each with a 3-byte payload and a 1-byte CRC. The payload contains the next position, ID, intention, and target position. The inclusion of ID information enhances system reliability, as the receiving unit can identify the intended sender and ignore any conflicting messages from other units during transmission.

Each unit sends a ping from one of its transmitters, then rapidly switches its receivers to listen for incoming messages. If no message is received, the unit moves to the next transmitter and repeats the process. Upon receiving a message, the unit focuses on the transmitting source and listens to the entire message, which can be either a ping or an ack message. If an ack is received, the unit knows its ping message reached the intended recipient. Using this information, it determines its next action. If a ping message is received, the unit responds with an ack message and updates its status.

The ping and ack messages share similar payloads, differing only in the intention field. The intention field indicates the search state and whether the message is a ping or an ack. There are six search states: moving to area, currently searching, target not found, target found, moving to target, and target reached. These states, indicated by numbers 1-6, are used for collision avoidance. If the message is a ping, the intention number is used; if it is an ack, 9 is added to the intention number.

If the target position is unknown, an invalid position (20, 20, out of region bounds) is sent. Upon receiving a message, the unit can determine if the target position is valid. If invalid, it ignores the position; if valid, it updates its search status and moves directly to the target. Also, if the target is found, it updates this position and its search status to “target found”.

In the event of data collision, the receiving end can detect it by verifying the CRC information and subsequently disregard the incoming data. Given the rapid and continuous nature of communication, any disregarded data is swiftly replaced.

If a message originates from a distance greater than 3.6 tiles, it will be discarded. This ensures that the range requirement of the project is met.

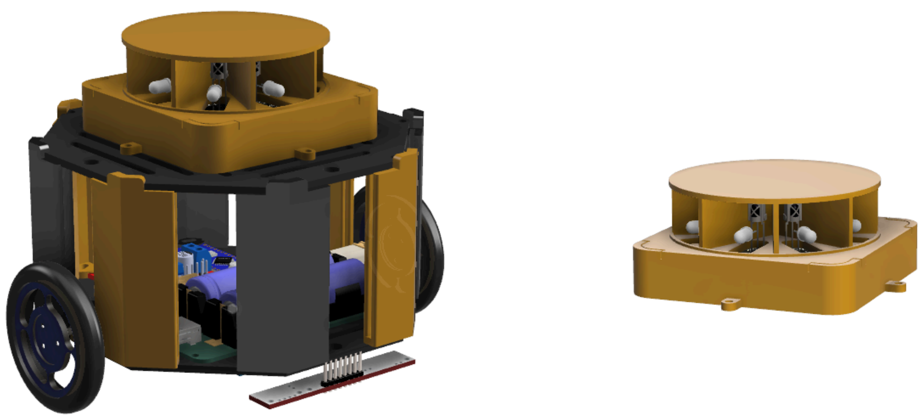
## Proposed Solution

Our Ad-Hoc Disaster Relief system faces the challenge of communicating in multiple directions with its limited angle range as the Mobile Units are moving. The most basic solution for this problem that came to mind was to place the IR transmitters and receivers in a casing, and rotate it. However, after considering the mechanical challenges involved and the limitation of the turning speed of the casing, it was decided to opt for an electrically implemented version of the same idea, mainly the **“Sensory Approach”.**

This strategy involves placing 8 transmitter and receiver pairs around the robot, each separated by 45° ensuring comprehensive signal coverage and the ability to transmit data in any direction. Simulating the rotation in an electrical manner involves turning on the transmitter or receivers one at a time consecutively. The switching between consecutive transmitter/receivers will be done by utilizing the “Controller Circuit” described in the “Hardware” section of the Communication Unit. This approach is advantageous due to the use of stationary sensors, faster rotation (switching) time and ensures reliability. A version of the Sensory Approach for 6 transmitter and receiver pairs is depicted in Figure 12.

Our communication unit also involves focusing on the direction of the incoming ping message to listen further to the intended message. Our “Sensory Approach” also enables this to be done momentarily, by directly selecting the receiver the message was received from.

Another important factor to consider for this method was to rotate (electrically switch) the receiver and transmitters at different speeds, so that there’s no interference between the incoming signal and the message transmitted.



(a) (b)

*Figure 12: Mobile unit (a) and  sensory sensory approach design (b).*

## Test Results

The communication testing was conducted to evaluate the performance and effectiveness of the communication unit in various real-world scenarios. This involved assessing the impact of different distances, angles, and data sizes on the success rate of data transmission between the transmitter and receiver. The primary parameters tested included distances of 0.5 meters and 1 meter, angles ranging from -45° to 45° in 15° increments with additional tests at ±22.5°, and data sizes of 4 bytes, 8 bytes, and 12 bytes.

The procedure for the tests was methodically structured. For the distance and angle tests, the transmitter was positioned at specified angles and distances from the receiver. A total of 256 data packages were transmitted for each configuration, and the number of successfully received packages was recorded. For the data size test, the transmitter was placed 1 meter from the receiver at a zero-degree angle, and packages of varying sizes were transmitted to record the success rates.

The results indicated a high success rate across the tested parameters. For the distance and angle tests, success rates were above 95% within the -22.5° to 22.5° angle range at 0.5 meters, supporting the effectiveness of the Sensory Approach. At 1 meter, success rates remained above 90% within the same angle range, validating the chosen parameters for practical use. Regarding data size, transmission success rates for 4-byte, 8-byte, and 12-byte packages were above 95%, even at the maximum distance of 1 meter.

These findings confirm that the communication unit performs reliably within the defined parameters. The high success rates across various distances, angles, and data sizes indicate that the unit can effectively handle real-world conditions. The constrained angle range of ±22.5° ensures optimal performance, minimizing the risk of data loss or corruption. These results provide a robust foundation for the application of the Sensory Approach in practical scenarios, ensuring reliable and accurate communication.

The results for the successful package percentage versus angle and successful package percentage versus package size are presented in Figure 13. The detailed test document can be found in Appendix 1.

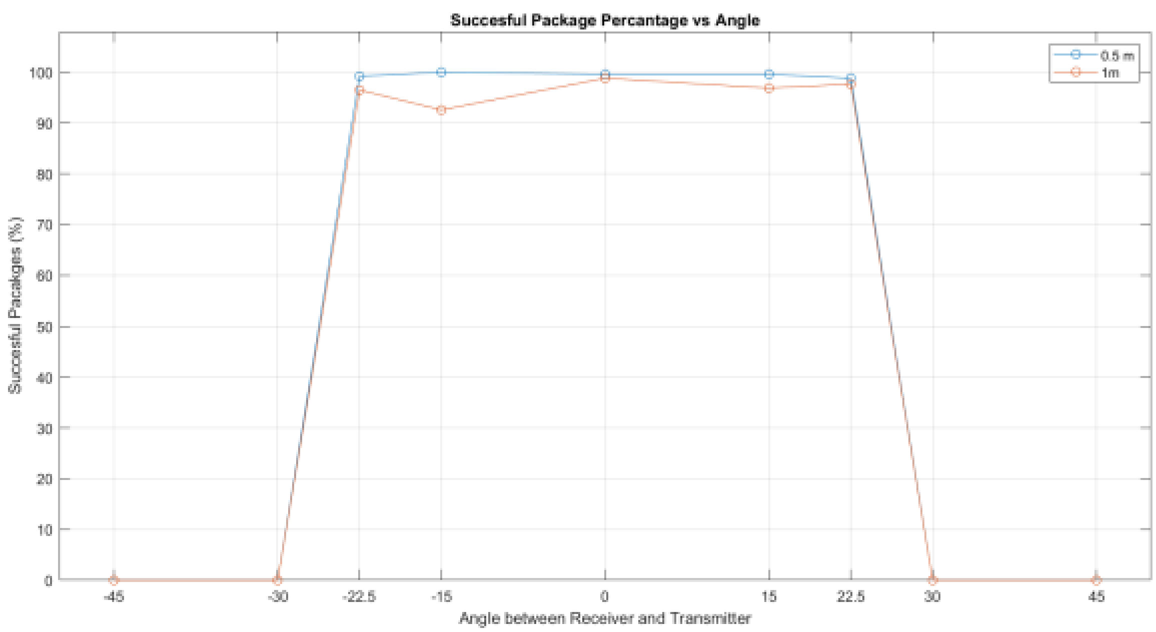



*Figure 13: Successful Package Percentage vs Positioning Angle*

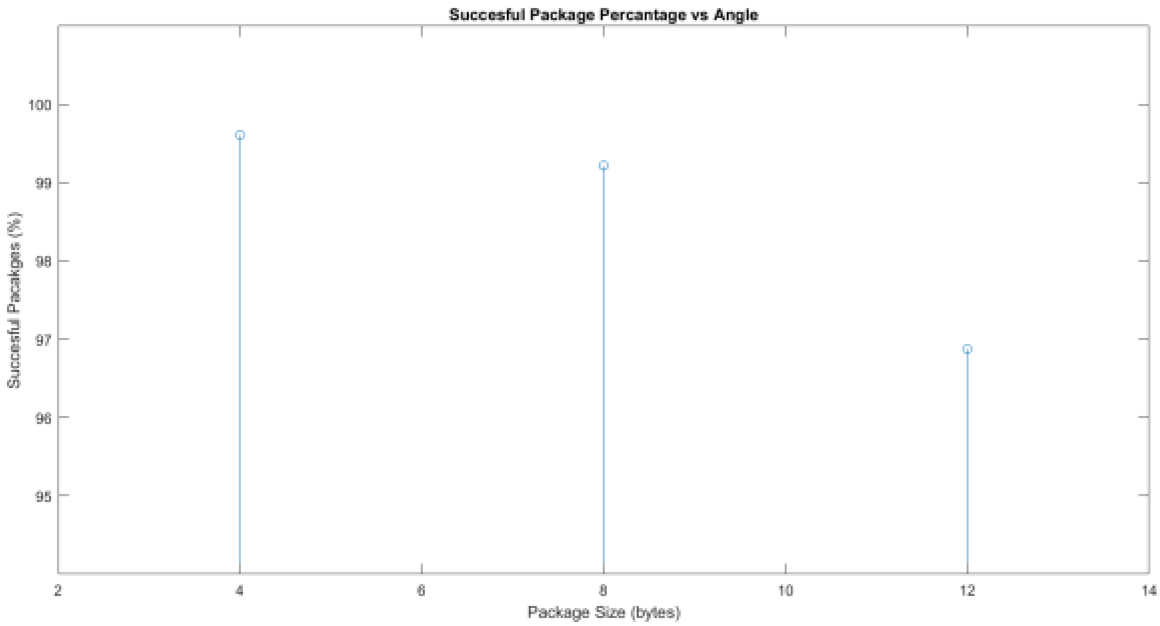



*Figure 14: Successful Package Percentage vs vs Package Size*

## Decision Unit

The decision unit is responsible for determining the next move of the MUs by employing the current information on the search status (data provided by the communication unit and the data gathered by itself) via a search algorithm. It also decides on which information to pass on to the communication, which will then pass it onto other MUs. Each of the MUs have their own decision unit. Based on the current information they have on the search (the unit's location, the positions of other units, and their scanned tiles, along with an awareness of surrounding obstacles), the decision unit decides on the next move of the MU. The next move is one of the following: forward, backward, right, left, and stay in place. This decided move is sent to the motion unit and is then executed. Based on the updated information, the next move will be decided. This process will repeat itself until the search is over. The BU also has a decision unit, but since it is stationary, its only job is to determine the data to pass on to the other units. The algorithm for the decision unit will run on Arduino UNO.

The decision unit requirements and their relation to overall system requirements are as follows:

| Decision Unit Requirement | Corresponding System Requirement | Solution |
|---|---|---|
| The search algorithm should certainly find the target. | Finding the Target | A search algorithm based on not going through the same tile twice was implemented. |
| There should be a search algorithm that decides on a route for each MU. | Route Planning | Algorithm will decide the next move of the MU using the information about the current situation of the tiles |
| The search algorithm should be capable of avoiding obstacles. | Recognizing & Avoiding Obstacles | A breadth first search algorithm is employed to find the route to the aimed position without encountering obstacles that are known. |
| Once the target is located, this information should be passed on to the communication subsystem to let other units know. | Reporting Target Location & Calling the MUs | A connection between decision and communication units will be made |
| Once the target information is received, the search algorithm should arrange itself to go to the target location. | To Gather Around the Target | MUs share their respective information about the search via the communication unit. Once the target location is known, the decision unit will find the shortest route to it. |
| The expected number of iterations to locate and gather around the target should be less than 60. | Finding and Gathering Around the Target in a Specified Amount of Time | Communication is used to speed up the process. |

There are two phases of the search. First, the units should scan the tiles and try to locate the target. In this phase, the information on the current status of the search should be communicated.

Second, once the target is located by an MU, that MU should carry this information to the BU and then return back. If another MU comes into the communication range, it should also share this information with the MU that came into its range. If an MU receives the information that the target is found, it should head towards the target. In this phase, the information that the target is found and its location should be communicated with the other units.

The search should be concluded as fast as possible. For this, in the first phase, each tile should ideally be scanned only once. However, due to the random initial positions of the MUs and the lack of communication outside a range, this is difficult to satisfy for all possible initial conditions.

Also, in the second phase, we want the MU that found the target to pass this information to the BU as fast as possible. Additionally, we want the MUs that received this information to go to the target as fast as possible. This phase is more straightforward since the fastest path to a known location is deterministic.

To have a successful search algorithm, the expected number of iterations for all of the MUs to gather around the target should be less than that of a dummy algorithm, i.e. without any communication and any intelligence in planning the search. The algorithm we have chosen for this purpose is the “Predetermined Area Assignment” algorithm.

This is one of the most critical subsystems of our system.

## Search Algorithm

The “Predetermined Area Assignment” search algorithm employs a systematic approach by dividing the 9x9 search area into three sections, each containing 27 tiles, and assigning them to individual Mobile Units (MUs). The area division is depicted in Fig.15. Each MU is initially designated an area based on its unique ID. When the search operation commences, MUs swiftly navigate to their designated areas using the shortest available route and start scanning the tiles. Upon detecting the target, an MU promptly heads towards the Base Unit’s (BU) coverage area, transmitting the information about the target's location. If an MU receives this update, it stops its search and directly moves towards the target's location. In the absence of such information until the completion of its area scan, the MU proceeds to the BU's coverage area to receive this information.

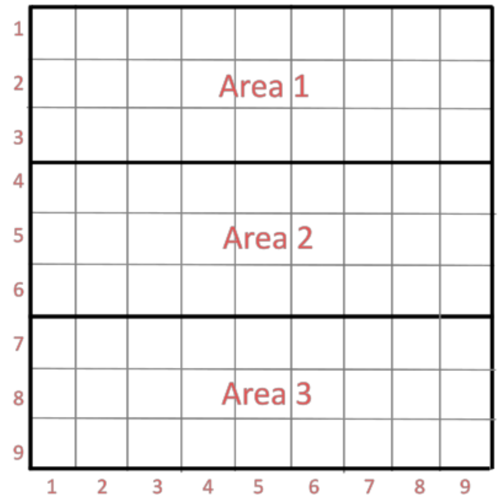


*Figure 15: Area Division for Plan B*

During the initial phase of the search, where the MUs move to their designated areas, communication between units is primarily employed to avoid supplying the information needed for the collision avoidance algorithm. The most important role of communication comes after the target has been found by one of the MUs.

A significant advantage of this algorithm lies in its ability to minimize the volume of transmitted data. Only information on the target is communicated, reducing unnecessary communication overhead. Additionally, the risk of collisions is notably low throughout the majority of the search duration as MUs operate within their designated areas.

Despite the minimal data transmission, this algorithm does not harm search efficiency. This is attributed to the fact that the maximum number of tiles required to reach the designated area is limited to five.

One alternative we considered instead of this algorithm was one where the total search area is dynamically shared. It was concluded that there is a risk of MUs initially not being within their coverage areas or taking an extended period to arrive. Such scenarios could result in MUs unawarely scanning the same area, significantly delaying the search progress.

The superiority of our chosen algorithm to the mentioned algorithm was proven by Monte Carlo simulations in the MATLAB environment. In the test, the average of iterations for 10.000 different initialization cases where calculated for the "Predetermined Area Assignment" algorithm, the "Dynamic Area Assignment" and a "Randomized Search" algorithm where the

MUs would start the search and start scanning empty tiles randomly until the target is found. The results were as in table 1 :

| Search Algorithm | Average Number of Iterations (10.000 cases) |
|---|---|
| Predetermined Area Assignment | 28 |
| Dynamic Area Assignment | 31 |
| Randomized Search | 40 |

***Table 1**: Performance of different Search Algorithms*

## Collision Avoidance System

As the Mobile Units (MUs) move around the search plane, there will be a risk of collision between them. Therefore there needed to be a measure taken against it. We chose to implement a collision avoidance algorithm that when employed lets the MU with the higher priority pass.

As an MU moves from one tile to the other, communication is kept with the other MUs and the BU if they are in the communication range. Once a new RFID has been scanned the info on the aimed positions and search states of the other MUs from the last communication instance is used to determine whether movement is allowed with respect to that particular MU or not. Depending on the respective states and positions, the decision unit decides whether the MU should continue with its move or stay and wait until the MU it is in risk of colliding with is out of collision range. An MU can only move if it is allowed to move with respect to both MUs. The states that are used to decide priority of a movement are the following

| | |
|---|---|
| **STATE 1** | MOVING TO SEARCH AREA |
| **STATE 2** | CURRENTLY SEARCHING |
| **STATE 3** | TARGET NOT FOUND |
| **STATE 4** | TARGET FOUND |
| **STATE 5** | MOVING TO THE TARGET |
| **STATE 6** | TARGET REACHED |

## Sensing Unit

The sensing unit of the project is designed to facilitate the tracking of the mobile units in order to determine their respective locations. During the exploration of the artificially created ground, where mobile units navigate tile by tile, the significant task is to convey their precise location to others to enable the implementation of an efficient search route. The determination of the location is a crucial aspect of the project. One important issue to consider is that the solution method is implemented for each tile. This can largely increase the cost of the sensing unit. Moreover, the speed of processing the location information must be compatible with the movement speed of the mobile units so that they can determine their location accurately.

The chosen technology for tracking the location of the mobile units is **RFID (Radio Frequency Identification)**. RFID subsystem encompasses RFID tags, RFID readers, and a backend system responsible for managing and processing the collected information. Each RFID tag incorporates an integrated circuit, storing data and a unique identification number (UID). This facilitates the ability to write the location and presence of the target information of each tile while a single RFID tag is placed in the center of each tile. Moreover, an RFID reader is placed under each mobile unit to analyze the information on the tags.

In the market, where diverse RFID technologies operate at varying frequencies, passive cards operating at 13.56 Mhz were subjected for this project. RFID exhibits optimal functionality within a 1.5-centimeter distance but experiences a decline in performance beyond 1.75 cm. Given that RFID readers are mounted beneath the mobile units, the height of the reader from the ground is meticulously adjusted.

A measure of success for the sensing unit is that a mobile unit should read the location information of the tile correctly as it passes over that tile. RFID reader swiftly captures tag information in milliseconds, aligning with the mobile units' movement speed since every tile is approximately 25 centimeters long, and mobile units move at 10 cm/sec speed. This process ensures the uninterrupted mobility of the units, obviating the need for stopping during the reading process.

The sensing unit requirements and their relation to overall system requirements are as follows:

| Sensing Unit Requirements | Corresponding System Requirements | Solution |
|---|---|---|
| RFID readers positioned under mobile units must read | Identifying location and Target Presence | Different IDs are used inside the RFID cards to |

| | | |
|---|---|---|
| the RFID tags, which store the location information of their corresponding tiles. | | differentiate between target and empty tile. |

Every RFID tag costs around $0.25. Since there are 81 tiles on the field, RFID tags cost nearly $20.25. Since an RFID reader is mounted under each mobile unit, three RFID readers will be purchased. This costs nearly $5 since every RFID reader costs around $1.6. The total cost of building the sensing unit is around $25.25.

RFID cards have 16 blocks of data, with the restriction that the data in every 4th block cannot be modified. The reader begins reading from the last block, which is why we store the location information in the 15th block. The location information is stored in two bytes: the first byte represents the x-coordinate, and the second byte represents the y-coordinate.

To designate a tile as a target, we add 9 to its coordinates. Since our field is a 9x9 grid, no RFID card originally has coordinates greater than 9. When a mobile unit reads a card with coordinates greater than 9, it recognizes that the tile is a target. By subtracting 9 from these coordinates, the mobile unit can determine the actual location.

When an RFID card is read (i.e., its UID is read), the decision unit sends a 500-millisecond signal to the motion unit. Upon receiving this signal, the motion unit stops, and the decision unit reads the data from the card. After processing the card data and making a decision, the decision unit transmits this information via TX/RX, and the motion unit executes the corresponding action.

## Motion Unit

The fundamental purpose of the motion unit is to manage motors, their control algorithms and hardware, and feedback mechanisms to achieve the desired movement. This unit is subdivided into three sub-subunits: **mechanical**, **driving**, and **feedback** units. Detailed explanations of the working principles and specific purposes of these units are provided in the upcoming sections.

| Motion Unit Requirements | Corresponding System Requirements | Solutions |
|---|---|---|
| Mobile units must be able to pass a tile in 2.5 seconds | Grid to be Passed in a Specified Time | 6 V DC tt motors are used for sufficient torque and speed |
| Mobile units must be able to follow a straight path | Route Planning | Using a line follower sensor |

# Motion Unit: Mechanical Subunit

**Introduction**

Choosing the appropriate motor and wheel combination is a pivotal decision in the project. Various factors must be considered when selecting a motor, such as torque, speed, voltage, size, component availability, reliability, and cost. Determining the optimal combination depends significantly on the specific requirements of the project and the desired performance outcomes.

For the motion unit, the final design has been settled on two wheels. With the integration of a line follower sensor, any deviation from the search path is corrected, making movement in any direction straightforward. Consequently, adding an extra wheel would serve solely as a source of friction and increase power consumption.

As for the wheel choice, the decision was made to use the one that came with the off-the-shelf robot chassis. Through inspection, it was determined to meet the robot's movement speed requirements and, importantly, fit perfectly with the purchased chassis. The assembled picture of the motor and wheel combination with some of the important measures can be found in Fig. 16.

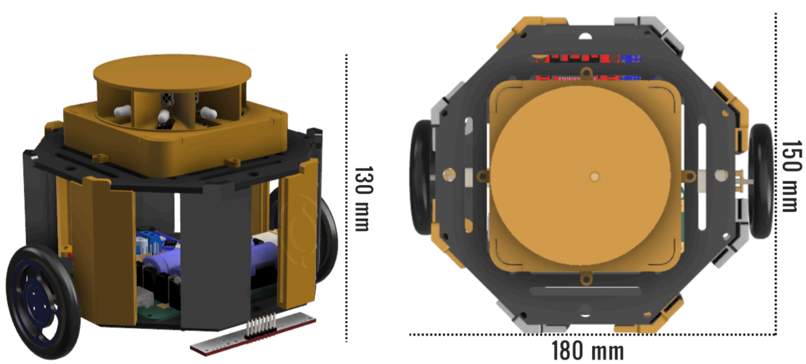



*Figure 16: Pictures of the robot chassis with important dimensions are shown for (a) side front, (b) top .*

Following thorough initial inspections, we have decided that chosen motors for the project are similar to those in the previous robot build, comprehensive assessments were performed to evaluate the suitability of these motors, covering crucial factors such as variations among motors of the same model, voltage-speed relationships, and maximum current draw. Given that the motors have already undergone rigorous testing in the previous setup, we are confident in their performance and compatibility for the current project.

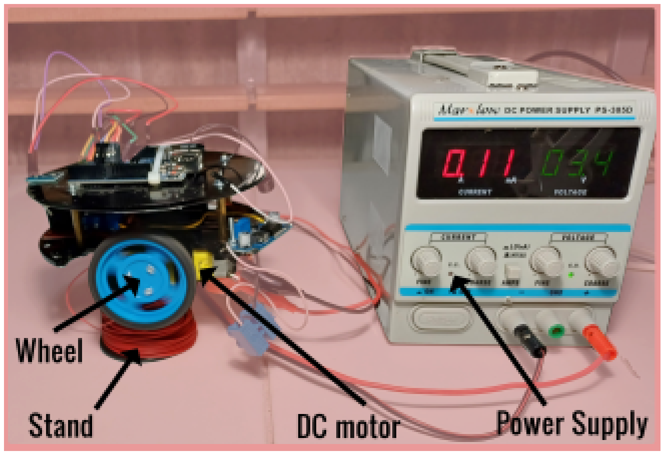



*Figure 17: Experimental setup of the previous mechanical subunit of the motion unit.*

**Motors' Armature Resistance Related Testing**

When a permanent magnet DC motor is at halt, there is no back EMF generated. Thus, the terminal voltage is equal to voltage drop on the armature resistance, $R_a$.

$$V_{terminal} = I_a \cdot R_a$$

To find this constant, the motor is allowed to run freely at various terminal voltages. It is then briefly stopped by hand, and the current drawn is noted. Based on the experiment, $R_a$ is determined to be approximately $4.2\Omega$. This value is crucial for estimating whether a motor can handle the drawn current (i.e. heat calculations) and the maximum current drawn possible. The graphical results can be seen in Fig. 18. Furthermore, this test reinforces our confidence in the motors' torque output. Measuring torque output accurately without specialized tools is challenging. Yet the manual halt during testing indicated that the torque output is more than sufficient to move the robot easily.

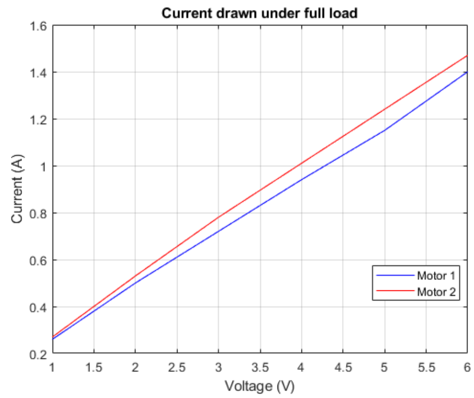



*Figure 18: Results of the Motors' armature resistance related testing*

**Motors' Back EMF Constant Related Testing**

In a permanent magnet DC motor, neglecting voltage drop on the windings, the back EMF constant $k_b$ is defined as the ratio of rotational speed to terminal voltage:

$$V_{terminal} = k_b \cdot RPM$$

To determine this constant, various terminal voltages were applied under no-load conditions (i.e., when the input current is minimal, making the voltage drop on the resistor negligible). RPM measurements were taken by placing a phone with a chronometer running next to the wheel and recording slow-motion videos of its rotation using another phone. The elapsed time for at least ten revolutions was calculated from the recordings. To easily count the revolutions, a tape is attached to the wheel. The results are mapped to RPM values. The resulting $k_b$ value, with units of voltage per RPM, was found to be around *0.017* for both motors. The results are shown in Fig. 19. In addition to that, knowing motor is rated for six volts and the diameter of the wheel is six cm, the upper limit of the robots movement speed $\upsilon_{max}$ (no load condition) can be estimated as;

$$\upsilon_{max} \approx \left(\frac{6}{0.017} \cdot \frac{1}{60}\right) \cdot (6\pi) = 110 cm/s$$

However, a more realistic approximation can be made. It is observed that the motors draws around $600mA$ of current when going at full speed at the ground. Knowing armature resistance of the motor is $4.2\Omega$ and applied terminal voltage of six volts, Achievable maximum speed can be estimated as;

$$\upsilon_{max,\, realistic} \approx \left(\frac{6-(4.2)0.6}{0.017} \cdot \frac{1}{60}\right) \cdot (6\pi) = 64 cm/s$$

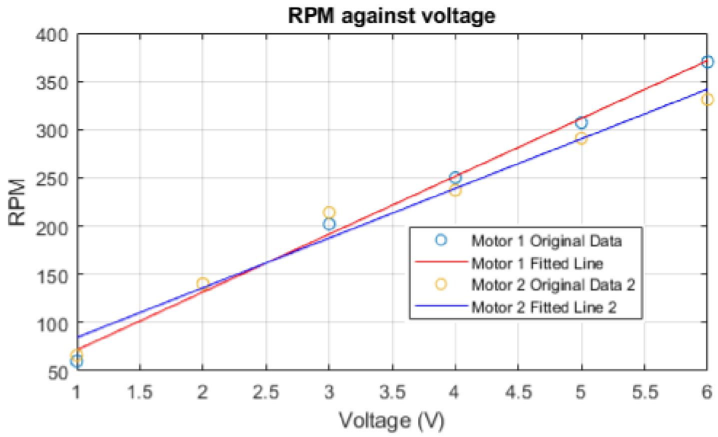
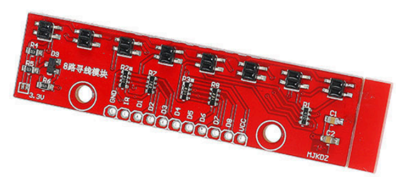



*Figure 19: Results of the Motors' back EMF constant related testing.*

**Cost analysis**

| Component List | | |
|---|---|---|
| Name | Price (1$=29.48TL) | Image |
| Line follower sensor | 75 TL |  |
| 60x11 mm Blue Color Snap-on Wheel Set | 40 TL |  |
| Robot Chassis | 667,65 TL |  |

| | | |
|---|---|---|
| L298N Motor Driver | 64,34 TL |  |

**Conclusion**
The tests reveal that this sub-subunit can attain satisfactory speeds of approximately 50 cm/s, well exceeding the project's requirements. The armature resistance imposes a limit on the maximum current drawn by this unit, capped at 1.45A per motor. This demand can be easily met with a moderately sized battery and power circuitry. Additionally, concerns regarding noticeable deviations between different motors have been freed, as they turned out to be negligible.

## Motion Unit: Driving Subunit

**Introduction**
In cases where the motor is inadequately driven, it can lead to abrupt surges in current and subsequent drops in bus voltage, adversely impacting both sensors and, more critically, the microcontroller. Our firsthand experiences during the prototyping phase revealed that the sudden initiation of the motor induces a noticeable voltage drop, prompting the controller to restart. The task of the drive subunit is entirely focused on this purpose. The scope of this unit includes providing "safe" functions that can be used by all the team members for properly accelerating and decelerating the motor, as well as circuits that convert logic signals into outputs to control the motor. By achieving that, the battery and power electronics devices with tightest ratings can be used.

**Motor Driver**
We are using the L293N 2A motor driver to drive the motors. Its pins and schematic can be seen in Fig. 20. OUT1 and OUT2 pins are connected to the right motor, OUT3 and OUT4 to the left, in the schematic shown in Figure 21. MD, H bridges that enable these outputs to be controlled by the settings of In and En pins can be observed. By setting these In values high or low we can go forwards or backwards, by using the En pin and changing its duty cycle we can adjust the motors speed.

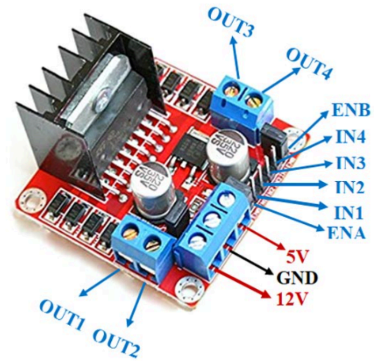



*Figure 20: L293N 2A motor driver.*

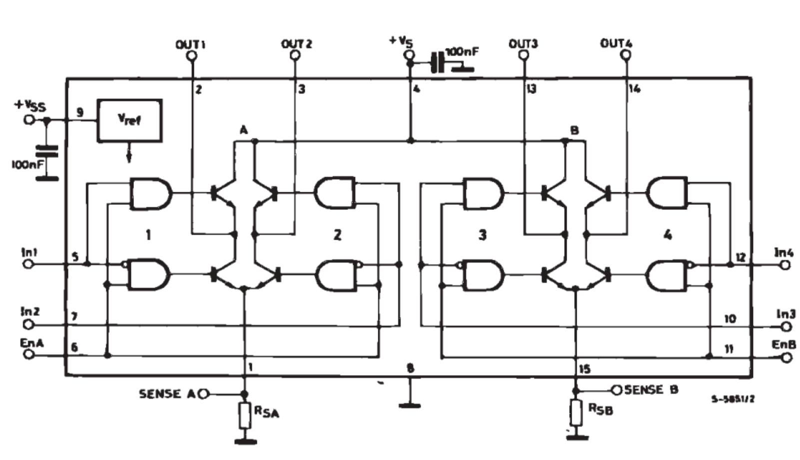



*Figure 21: Schematic of L293N 2A motor driver showing the H-bridge.*

**Pins**

In1 and In2: Pins controlling the right motor.
In3 and In4: Pins controlling the left motor.
EnA: Enable pin for In1 and In2.
EnB. Enable pin for In3 and In4.

**Driving the Motors**

To facilitate forward motion for the wheels**,** we set the **In1 pin** to high and the **In2 pin** to low for the right motor. This PWM value dictates the duty cycle of the EnA pin of the L293N 2A. By manipulating the duty cycles, we can regulate the effective voltage supplied to the motors, allowing us to control the motor's speed. For reverse motion, we invert the settings of In1 and In2. The same approach is employed for driving the left wheel. The duty cycles corresponding to the PWM values written in the scale 0 to 255 are illustrated in Fig. 22.

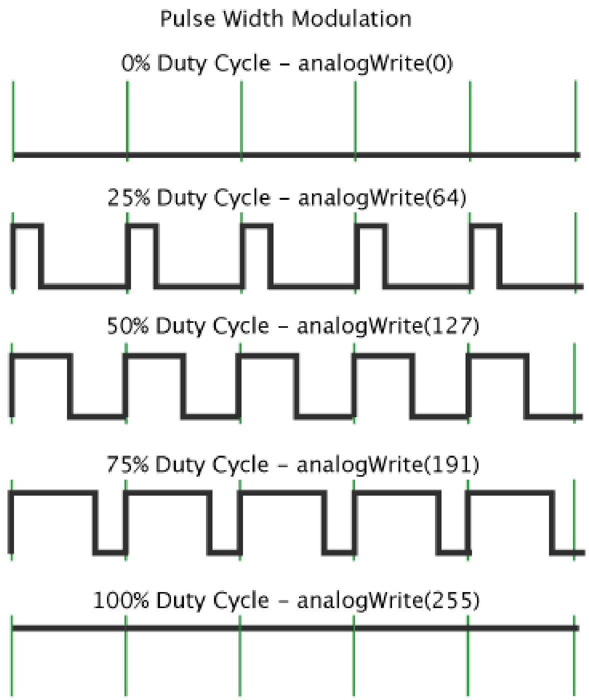



*Figure 22: Pulse width modulation with analogWrite() function*

To drive the motor, provide an **aimed PWM** value as input to the **drive_right_motor()** function. When a time equal to or greater than the update time has passed, the **RIGHT_MOTOR_CURRENT_PWM** of the motor is adjusted, either increased or decreased, based on the difference with the intended PWM. This gradual adjustment ensures that the desired PWM is reached incrementally. The primary purpose of employing this method, as opposed to immediately achieving the target PWM, is to prevent an overshoot of torque at the onset of movement and enhance the overall stability of the motion. Another major for this gradual increase is to prevent any sudden current change. Sudden current spikes may cause voltage drops and stress on power supply components and potentially harm the system. Gradual increment of PWM results in controlled acceleration, reducing the instantaneous torque demand on the motor and diminishing the risk of exceeding motor drivers current limit; therefore, improving the reliability of the system.

## Feedback Sub-subunit

The primary goal of this unit is to maintain the straight movement of our mobile units between tiles and to ensure that each RFID tag is scanned. The selected approach to address this control issue involves using a line follower on a search grid, featuring black lines on a white background, for the mobile unit to detect and follow. The necessity for the mobile units to stay on the search path without missing RFID tag readings demands a stable solution with minimal error. Therefore, using a line sensor is a logical choice.

**Line Follower Method**

The working principle of a line follower sensor depends on the detection of the reflected light. The sensor consists of an array of infrared LEDs and corresponding photodiodes or phototransistors. The IR LEDs emit infrared light downwards towards the ground, and the ground surface reflects the emitted infrared light back to the photodiodes. After the detection of the reflected light, the sensor outputs signals indicating the presence or absence of a black line beneath each IR LED. Based on these measurements, the orientation of the mobile unit relative to the line is obtained. The microcontroller then adjusts the speed of the motors to follow the line, making corrections to keep the line centered under the sensor array. To navigate straight paths and execute turns smoothly, the mobile unit employs a closed-loop system assisted by a line follower. When the unit needs to make a right or left turn, it initiates the turn until it no longer detects any lines, then adjusts its direction until it detects a line using a predetermined sensor, ensuring precise and seamless turns.

RFID tags are placed at the cross sections of the lines to identify targets and obtain the exact location of the mobile unit by scanning RFID tags placed on the tiles. As the mobile units traverse the grid, moving from one tile to another, they pause at each intersection of lines, a process regulated by the count of sensors detecting the lines at these junctions. Subsequently, the mobile units navigate in an open loop fashion until they encounter an RFID tag. Upon detection of an RFID tag, the Arduino's talk pin is activated, signaling the motion unit to halt. This systematic approach guarantees that each mobile unit halts precisely atop every RFID tag to access and read the data stored within it.Accessing the RFID tag holds crucial importance as the decision unit bases its motion decisions on the information retrieved, subsequently transmitting commands to the motion unit according to the current position. The motion unit executes its movements based on the directives received from the decision unit. Once the base unit determines its next course of action, it communicates its commands through the Arduino's Tx pin and the motion unit receives it from the Rx pin. Moreover, if a mobile unit fails to detect the presence of an RFID tag and continues without stopping, it initiates a sequence of backward and forward movements until it locates an RFID tag in a determined time period. If the mobile unit still cannot detect an RFID tag after executing the backward and forward movements, it continues its motion without interruption.

## Power Unit

The overall power delivery system of the robot is illustrated in Figure 23.

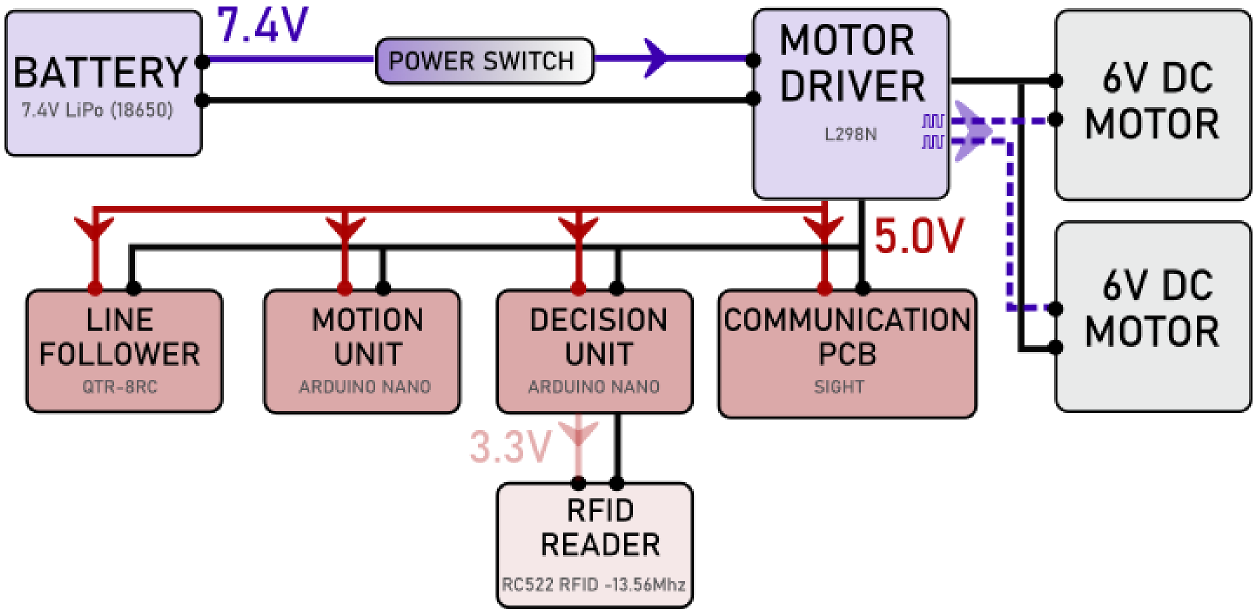



*Figure.23 Power delivery system of the robot*

### Detailed Analysis of the subunits in Terms of Power and Peak Demands

| Unit name | Expected peak current (mA) | Operating voltage (V) | Average current demand (mA) | Average used power (W) | Power usage (%) |
|---|---|---|---|---|---|
| Motors (2 motors) | 900 | 6 | 575 | 3.450 | 75.0 |
| QTR-8RC Line Follower | 100 | 5 | 100 | 0.500 | 10.9 |
| Decision Unit (Arduino Nano) | 250 | 5 | 50 | 0.250 | 5.4 |
| Motion Unit (Arduino Nano) | 250 | 5 | 50 | 0.250 | 5.4 |
| Communication PCB | 40 | 5 | 20 | 0.100 | 2.2 |
| RFID reader | 25 | 3.3 | 15 | 0.050 | 1.1 |
| | 1565 | NA | 810 | 4.600 | 100 |

**Power Unit Design Notes**

Li-ion type batteries are utilized. These batteries typically have nominal voltages in integer multiples of 3.7V. Given the requirement for most units to operate around 5 volts, a battery voltage of 7.4V is deemed necessary. Consequently, two 18650 Li-ion batteries are connected in series to meet this voltage requirement. These batteries are known for their ability to comfortably supply up to 3.5 Amps of peak current. Each battery has a capacity of 2200mAh. Based on an estimated worst-case average power consumption of 7.5W (at 7.4V), these batteries are capable of powering our robots longer than five hours. It's noteworthy to mention that the robots do not operate continuously at this maximum power level, resulting in a significantly high safety margin. Given that a small portion of the power is consumed by the 5V electronics, linear voltage regulators are employed to ensure stability and reliability in the voltage levels, Though with a slight decrease in efficiency. For recharging, the batteries are removed from their slots and charged using an external charger.

## Design Requirements

In this part, we discuss our design objectives and requirements for the project.

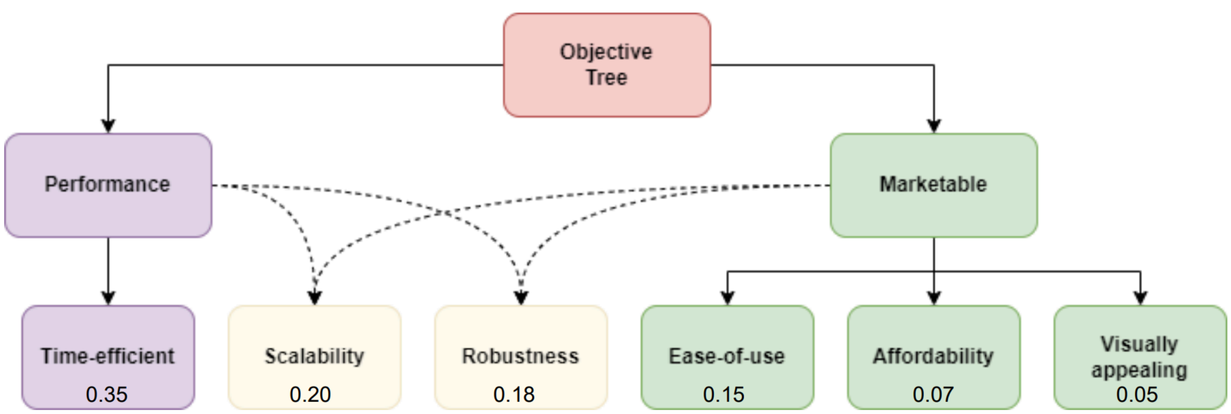



*Figure.24 Weighted Objective Tree*

**Time-Efficiency:** The robots are designed to be used in emergency scenarios where the target must be found as quickly as possible. There is no obvious solution for this. The success of the algorithms heavily depends on the initial state. The number of robots, grid size, or the presence of obstacles significantly affects the result. Therefore, instead of explicitly defining time efficiency, we prefer to define it as an abstract criterion that is used to evaluate designs or algorithms that allow us to find the desired target more quickly.

**Scalability:** In emergency scenarios, the scale and complexity of the problem can vary significantly, and having scalable solutions ensures that we can adapt to different challenges. Whether we need to search larger areas, handle a higher number of robots, or address more complex environments, scalability allows us to meet the demands of the emergency, regardless of the scale. Thus, when making decisions, we prioritize the scalability of the solutions.

**Ease of Use:** During emergency situations, even the most qualified operators may experience stress, potentially leading to errors in robot operation. To minimize human error and ensure a smooth response, our systems must be designed as foolproof as possible. This includes reducing the number of controls or buttons and incorporating intuitive interfaces. Therefore, this is one of our key metrics to evaluate our decision-making process.

**Affordability:** During an emergency situation, cost may not be the primary concern; however, when cost reduction doesn't lead to a loss in performance, it should be considered. This indirectly supports the rescue efforts. By reducing costs, the demand for rescue fleet robots can increase among customers. Additionally, more units can be donated to those who cannot afford them. As a result, both time efficiency and the number of people reached can be increased indirectly. In summary, as long as affordability does not compromise functionality, it remains a critical consideration in our decision-making process.

**Robust & Durable Design:** SIGHT company takes great pride in its products. It's clear that designing the most robust robot is not always the optimal solution, as enhanced robustness often results in increased weight, higher costs, and longer production times. However, we make certain that our robots possess more than enough robustness and durability for the specific environments and tasks they are intended for.

**Visually Appealing Solutions:** As SIGHT, we place a strong emphasis on the quality of our products. Our performance expectations are globally recognized and adhere to world standards. However, we don't only focus on performance quality but also on how well a product is presented. We believe that a well-presented product may perform poorly, but a poorly designed product most certainly will. Therefore, whenever the additional expense is acceptable, our decisions also prioritize design aesthetics.

## Requirement Analysis

The requirements of the system are as follows:

**Functional Requirements:**

- Finding the Target: The system should have the capability of moving around the field and locating the target.
- Identifying Location and Target Presence: The system must be capable of identifying its location and the presence of the target.
- Route Planning: The system must be able to plan and follow a route for finding the target.
- Recognizing & Avoiding Obstacles: The system should be capable of recognizing and avoiding obstacles and other Mobile Units (MUs).
- Communicating with Other MUs and BU: The system must have the functionality to communicate with other Mobile Units (MUs) and Base Unit (BU).
- Infrared Frequency: The system must operate using infrared frequencies for wireless communication.
- Reporting Target Location: The system should be able to report the location of the target to the Base Unit (BU).
- Calling the MUs: The Base Unit (BU) should call for the Mobile Units (MUs) once the target is located.
- To Gather Around the Target: Units should be able to gather around the target once it is located.

**Performance Requirements:**

- Finding and Gathering Around the Target in a Specified Amount of Time: The system should find the target within a reasonable time frame which has been decided as 3 minutes.
- Having a Range of Communication: The system's communication range should cover a specified distance, which is decided to be 90 cm.
- Reliable Communication: The system's communication should ensure reliable data transmission and reception among MUs and the BU. (%95 of the data reaches to the communicated unit, the analysis of whether the departing data is corrupt is being carried out with 100% success)
- Collision Avoidance: The system must implement collision avoidance mechanisms during communication, considering the possibility of multiple MUs transmitting simultaneously.
- Grid to be Passed in a Specified Time: The system should be able to pass through a grid in a defined time frame which has been decided as 2.5 sn
- Operate for a Specified Duration on a Single Charge: The system should operate continuously for a specific duration on a single charge which has been decided as 1 hour.

**Physical Requirements:**

- Platform Size and the Communication Range: The total rescue field should be 2.5Rx2.5R, R being the communication range. Since we have decided our communication range to be 90 cm, our field should be 225cmx225cm.
- Grid Structure: The robot platform should be composed of N x N square tiles where N is decided to be 9.
- Size of the Robot: The size of the robot should not exceed one tile.

**Constraints:**

- Budget Limitation: The allowable budget for the project is $300. This can lead to the usage of suboptimal components, harming the performance.

# Design Modifications

Since the CDRR (Conceptual Design Review Report), minor modifications have been made at both the system and subsystem levels of the design. Among these adjustments, a significant revision was executed within the motion unit. The “Line Follower Robot” method is employed for the motion unit instead of the previous method where the combination of several other components and sensors (gyroscopic sensor, compass etc.) was used for moving around the grid. The main reasons behind this decision were both the increased accuracy and control that came with the “Line Follower” method and that the method employed in the motion unit being irrelevant to the proof of concept of this project. As a consequence of the “Line Follower” method, a return to the initial choice of wheels was also made.

The choice of the search algorithm resulted in a minor change in the communication protocol. The package size has been set as 4 bytes which comprises 3-byte data information and 1-byte CRC byte. The protocol consists of sending a ping towards all 8 directions consecutively while listening for data in each direction between consecutive pings. An acknowledgment is sent towards the direction where a ping has been received. This methodology facilitates enhanced communication between mobile units and mitigates collision occurrences.

The decision unit had previously 2 alternative solutions other than the “Randomized Search” algorithm. After examining and testing each of these algorithms in MATLAB, the “Predetermined Search Area” method was employed. Moreover, the collision avoidance algorithm, that we had planned to employ using an Ultrasonic sensor due to communication rate concerns, has been employed without the additional need for an external sensor.

## Compatibility Analysis

The project's design showcases a seamless integration and compatibility between its subsystems—Communication, Decision, Motion, Sensing, and Power Units—in a well-coordinated way. This setup allows the mobile units (MUs) to work smoothly together, navigating and operating successfully in the search area. The visual depiction of the connections between the subsystems is seen in Fig. 1.

The process begins with the Sensing Unit, which plays a pivotal role in identifying the mobile unit's location within the search field. It reads RFID tags embedded in each tile to gather x and y coordinates and vital information on whether the target has been detected, adhering to RFID technology standards. This information is crucial for the Decision Unit, which synthesizes the data received from the Sensing Unit and any incoming data from the Communication Unit of other MUs or the base unit (BU). The interface between these units is on Arduino and in the form of variables which depicts the coordinates and the information on the target's existence.

Using the information from the Sensing Unit and the current search status, the Decision Unit prepares the data it needs to send to other mobile units by converting it into a binary format (1s and 0s) for transmission.This binary data is then relayed to the Communication Unit, where they are packaged with necessary headers and Cyclic Redundancy Check (CRC) data to ensure integrity and reliability during transmission. The interface between these units is on Arduino and is in the form of a binary data variable. The custom-made protocol used in this unit facilitates the exchange of information between the MUs and the BU, enhancing the system's overall efficiency and responsiveness. IR communication and this custom made protocol is used as standard in this step. Upon reception, the Communication Unit of the receiving MU processes the header and CRC, extracting the decision bits which are then forwarded to its Decision Unit.

Armed with up-to-date information from both the Sensing and Communication Units, the Decision Unit of each MU evaluates the current situation to determine the optimal next movement. This plan is relayed to the Motion Unit, as a variable on Arduino specifying the next move, directing it to execute the maneuver necessary for advancing the MU one tile in the desired direction. This cycle of sensing, deciding, communicating, and moving is repeated continuously, underpinned by the reliable and consistent power supplied by the Power Unit. The Power Unit ensures that all circuits across the subsystems are adequately powered, enabling sustained operations throughout the search process. The power unit supplies the current needed for the circuitry of all of the units.

There is no compatibility concern since, as explained, most of the interfaces between the units (all except the Power Unit) is on Arduino in the form of variables. Furthermore, the Power Unit is directly connected to the other subsystems, providing the necessary current for their operation. It incorporates a buffering mechanism that allows different units to connect without interfering with each other, ensuring stable and efficient power distribution without any compatibility concerns.

## Compliance with Requirements

Requirements and their respective solutions are discussed for each unit separately. Tables matching the requirements and solutions can be found in the unit sections. Here, the solutions and how they comply with the requirements will be briefly discussed.

**Communication Unit:** In the communication unit, sensory approach is used to implement communication.This approach entails positioning 8 sets of transmitter and receiver pairs evenly around the robot, with each pair spaced 45° apart, ensuring complete signal coverage and the capability to transmit data in any direction. Simulating rotational movement electrically involves activating the transmitters or receivers one by one in sequence. This solution complies with the requirements of infrared frequency and communication itself. By implementing a code that makes data received from a distance further than 90 cm invalid, the range requirement is satisfied. Cyclic Redundancy Check technique ensures that errors during data transmission and reception are mitigated which complies with the reliable communication requirement. Test results further demonstrated that these solutions are suitable for the requirements.Although using 8 sensors resulted in a narrower communication angle, the cost increased as more sensors were needed, however it increased efficiency.

**Sensing Unit:** RFID tags are used for identifications of the target and empty tiles. This way identifying location and target presence requirements is satisfied.

**Motion Unit:** To meet the time requirement, the 6 V DC motors are capable of generating adequate speed. Straight and stable movement of the robots are possible using different methods such as gyroscope, magnetometer and line follower. Tests conducted on gyroscope method showed that gyroscope alone is not enough to effectively counter the disturbances .Making an omnidirectional robot forced us to drive 4 motors instead of 2 and made feedback control harder; however, it resulted in a more linear movement for the MUs.

For the remaining requirements that are not discussed in any unit;

- Operate for a Specified Duration on a Single Charge: Satisfied by using two 3.7V LiPo batteries.
- Collision Avoidance: Satisfied by using ultrasonic sensors to find the distance between an obstacle and an MU. Using the distance, the robot will adjust its course in a way that will avoid collision.
- Physical Requirements: Our robots are 206mm in length and width. Tiles will be slightly larger than that and a 9x9 array will be made using those tiles.

## Deliverables

**Search Field:** A 9x9 square grid search field, with RFID tags on each tile that contains the information of the tile coordinate will be provided to the user to test the system.

**Mobile Units (MUs):** MUs are tasked with navigating through the search area, finding the target, and communicating its location to the BU. They will do these tasks while remaining in sync with other MUs and avoiding obstacles as needed in disaster scenarios. Each MU is composed of: a microcontroller, IR transmitter and receiver, possible sensors for obstacle detection, control and coordination software, communication software and a power supply.

**Base Unit (BU)**: The BU acts as the control hub of the whole system. It receives information from the MUs, coordinates rescue and manages communication.Its key components are: a microcontroller, IR transmitter and receiver, control and coordination software, communication software and a power supply.

## Resource Management

For details on the power distribution, please refer to the "Power Unit" section of the report.

### Cost Analysis

While the budget is currently set, there might be minor adjustments to it depending on the progress of the project, but not exceeding a total of 300$. The completion of the project and final tests is estimated to be no later than May 2024.

| | |
|---|---|
| Microcontrollers, Sensors, IR-Transmitters and Receivers | $130 |
| Small Scale Grid Model | $40 |
| Motion and Power Components (wheels, motors, batteries etc.) | $80 |
| **TOTAL** | **$250** |

Table 2:Estimated Budget for Ad-Hoc Network Communication System

### Schedule

In the remaining time of this project we will be focused on completing the individual subsystems and integrating them, so that in the end we have 3 Mobile Units (MUs), one Base Unit (BU) and a square search field ready for use. The 3 MUs will be the merge of all subsystems, while the Base unit will not need a motion unit, since it is designed to be stationary. For each unit (MUs and BU) subsystems will be integrated on Arduino, i.e., each unit will have its own Arduino that merges all subsystems of the project. Refer to the Gantt Chart in Appendix 3 for the overall schedule and an overview of the system design process.

To ensure the smooth operation of all subsystems together we must ensure that they meet our requirements fully by confirming them with corresponding tests before integrating them. So, the initial tasks in the next 3 weeks will be an intense period of working on each subsystem and testing them. The tests will be done systematically, where the success measures for each subsystem have already been explained in the System Design section of the report. However, a short overview of the plans for each individual subsystem will be explained in this section as well. The completion of all subsystems is scheduled to be at the end of April 2024.

For the sensing unit the solution approach with RFID-tags for each square on the grid and an RFID reader on the bottom of each MU will be implemented. Creating the search field is also a part of this subsystem. The whole unit is scheduled to be completed at the end of April.

For the motion unit, the plans and the base of it is complete. We have an operational moving unit, but it currently lacks coordination. For this problem integrating a compass, a gyroscope and turning the search grid into a line-following robot environment are our solutions. Implementation of these solutions has already begun and is scheduled to be finished at the end of april.

For the communication unit, the Sensory approach explained in the System Design section is currently in the process of being implemented. The test results that were done for the Communication Unit (see Appendix 2) also ensure that it will be enough to meet the desired data transmission rates and sizes specified in our communication protocol. This unit is also scheduled to be finalized in the next 2 weeks.

For the power unit, the analysis for the power requirements of each subsection have already been analyzed and listed in the previous sections and topology A is chosen. This subsystem requires the completion of all other subsystems before it is finalized. The tests done for this subunit during integration will be more crucial, since this unit is essential for the functioning of all other subunits. It is planned to be finalized at the end of April.

For the decision unit, though the first solution plan with the random next move where the mobile units communicate with each other works quite well already, the other solution ideas should also be investigated before finalizing the choice for the search algorithm. The simulations done on MATLAB play a crucial role in determining the most fitting search algorithm. So, the first focus will be to complete these in the next 2 weeks.  The next important task will be to implement this search algorithm in Arduino, which is planned to be completed before the end of April.

The integration of all subunits is scheduled to start at the second week of April, even if not all units are complete by that time. All subsystems for each MU and the BU will be integrated in their individual Arduinos. The power, sensing and motion units are the first to be merged, we can think of this as main-unit A. After the completion of the communication and decision units their merging will be completed as well, which we will call main-unit B. Once these main units operate successfully, they will be merged as well. The last part will be ensuring that this merged system operates as desired on the search field. The flow of one Mobile Unit (MU) also shown in the block diagram in Figure 2 is as follows: The position of the MU will be determined by reading the RFID tag on the current square it is on using the sensing unit. The location data will be sent to the decision unit. The communication unit if in range of any other unit (MU or BU) will also be receiving extra information about scanned or un-scanned tile positions, which it delivers to the decision unit as well. Based on this information the decision unit decides on the next move and the motion unit acts accordingly. All of the units are powered by the power unit. The communication unit also is tasked with transmitting information such as scanned position, target position etc.

After merging all subsystems the overall system will be tested, ensuring that its performance is consistent with the expected individual subunit performances. The most important criteria in the overall testing will be whether the search is completed in the required time mentioned in the decision unit design.

Each member is responsible for ensuring the successful completion of all tasks in the scheduled times. All members will have tasks in each subsystem, but their individual focuses on each subsystem will differ depending on their expertise. The tasks assigned to each team member is indicated in the Gantt Chart in Appendix 1. The tasks are distributed by considering the amount of time each member has spent on a particular subunit until now and what strengths they have in terms of technical skills.

# Conclusion

SIGHT is dedicated to developing a specialized Ad-Hoc communication system tailored specifically for disaster relief operations. This comprehensive system includes a base unit, three mobile units, and a meticulously designed test environment. Our project's subsystems encompass decision-making, communication, motion control, power management, and sensing capabilities.

In this FinalReport, detailed solution processes and tests that have been carried out for each subsystem have been discussed.

The proposed strategy for the communication unit employs the 'Sensory Approach,' which entails positioning infrared transceivers at 45° intervals and activating them simultaneously to facilitate information exchange from all directions. Furthermore, the selected solution for the search algorithm dictates that each mobile unit should move towards an unscanned tile using the shortest path determined by its information matrix. Each mobile unit searches through a predetermined area based on their ID. Upon establishing communication between mobile units, the information matrices of both are updated, leading to new decisions based on the revised matrix data. Additionally, our system's mobile units are intricately designed to accurately locate targets and relay precise location information to the base unit by reading RFID tags on the tiles.The motion unit incorporates a line follower sensor for navigation. A grid with black lines against a white background is devised to facilitate seamless movement during the search process.

We recognize the unique challenges embedded in our mission, particularly focusing on guaranteeing the accuracy of communication between mobile units and the base unit via infrared waves. Moreover, we employ advanced algorithms to enhance the mobile units' capacity to rapidly pinpoint targets, thus reducing search duration. In conclusion, SIGHT is committed to leading the way in innovative solutions for disaster relief situations. With our unwavering determination, focus, and adaptability, we are poised to effect positive change in the midst of adversity.