AN-NAJAH NATIONAL UNIVERSITY

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

Computer Engineering Department

Indoor Localization

Presented by:

Rahaf Omar Nasrallah

Masa Hassan Masri

Supervised by:

Dr. Suleiman Abu Kharmeh

A report submitted in partial fulfillment of the requirements for Bachelor degree in Computer Engineering - Hardware Project

Nablus, Palestine 2024

DISCLAIMER STATEMENT

This report was written by students Masa Masri and Rahaf Nasrallah at the Computer Engineering Department, Faculty of Engineering, An-Najah National University. It has not been altered or corrected, other than editorial corrections, as a result of assessment and it may contain language as well as content errors. The views expressed in it together with any outcomes and recommendations are solely those of the students. An-Najah National University accepts no responsibility or liability for the consequences of this report being used for a purpose other than the purpose for which it was commissioned.

DEDICATION

To all the martyrs of Gaza and the West Bank. And to every Palestinian suffering this pain as a price for their steadfastness in this holy land.

ACKNOWLEDGMENT

We would like to thank our supervisor Dr. Suleiman Abu Kharmeh for his unwavering support throughout our project process. We appreciate his valuable guidance, inspiration and insightful ideas that have significantly contributed to the accomplishment of this work.

We also would like to express our sincere gratitude to all the doctors who have been a source of knowledge throughout our educational journey. You played a crucial role in our learning and your influence will continue to inspire us in our future endeavors.

Furthermore, we are grateful to our families and friends who stood by us during the demanding phases of this project. We are truly grateful for their continued presence in both the challenging and rewarding moments of this journey.

List of contents

Abstract

Indoor localization also known as indoor positioning is crucial because it has many applications in environments like supermarkets, hospitals, libraries, train stations and airports especially for blind people or people suffering from mental diseases like Alzheimer. There are multiple topologies for indoor localization, for our project we've implemented a navigation robot based on Wi-Fi received signal strength indication (RSSI) which is applied at a supermarket that helps customers to find the location of needed sections. The robot also assists in monitoring supermarket conditions like smoke or detecting spilled water by scanning the floor, and provides streaming of the robot route to afford a real time tracking of the robot.

Chapter 1: Introduction

Over the past few years, the widespread use of smartphones and other wireless devices in addition to the IoT integration and wearable devices led to the development of various services, including indoor localization. Indoor localization refers to the procedure of determining the location of a device or user within an indoor environment. For the outdoor scenario GPS is applied but it's inefficient indoors due to building external walls, because it requires line-of-sight (LOS) between the handset and the satellites.

There are multiple topologies for indoor localization including angle of arrival (AOA), time of arrival (TOA) and received signal strength (RSS) which is based on technologies such as WiFi, radio frequency identification device (RFID), ultra wideband (UWB), Bluetooth and Zigbee.[1]

Localization techniques in WSNs can be summarized in two categories: the range-based and range-free method [2] Received signal strength indicator (RSSI) is an example of range-based positioning methods. The range-based localization method requires distance (or angle) between nodes for estimating the positions. Range based techniques compute the precise distance between transmitting and receiving nodes on the basis of distance estimation and position calculation.

We have chosen to implement localization based on Wi-Fi Received Signal Strength Indication (RSSI) due to its simplicity and widespread availability. Wi-Fi is extensively deployed, with private access points and hotspots found in locations such as airports, hospitals, shopping malls, and various other places. Additionally, it offers high throughput and integrates both communication and positioning functionalities.

Chapter 2: Constraints

The environment of our work, located within the university campus, presents significant challenges due to the high interference caused by the multitude of routers and access points distributed across the building, in addition to a large number of mobile hotspots activated by students and staff mobile devices.

Multipath Effects and Noise are fundamental challenges of indoor localization. Due to the inherent nature of the signals, they can be reflected, refracted and diffracted on the walls, metals, and in some cases even human beings. This affects the behavior of the signals. RSSI approaches rely on these signals from the AP to estimate the user location. This has significant consequences on the accuracy of indoor localization.

Chapter 3: Related Work

There are various methods and researches for indoor localization, a paper by Abu Kharmeh et al. (2023) proposes a method of indoor positioning utilizing a construction of an extensive dataset using a robot equipped with multiple WiFi-transceiver nodes. These nodes collect received-signal-strength indicators (RSSIs) at various elevation points then stream those values to an online database for further analysis in the localization process.Furthermore, the paper highlights the importance of exploring the impact of factors such as antenna height on received WiFi signal strength. These considerations contribute to the development of a robust and efficient indoor localization system [3]. In [4] WiFi RSS is also utilized within wireless sensor networks (WSNs). Specifically, the paper explores indoor localization based on multilateration and averaged RSSI values. The proposed approach addresses challenges associated with the accuracy of distances derived from RSSI readings.The study delves into the complexities of RSSI-based localization, highlighting the sensitivity of RSSI values to environmental dynamics and the challenges associated with establishing precise relationships between RSSI and distance. The paper categorizes RSSI-based methods into channel model and fingerprint methods, noting the advantages and limitations of each approach. The researchers in [5] utilized the angle of arrival (AoA) based wireless indoor localization for patients to find their way in a hospital environment. The method utilizes Wi-Fi access points (APs) positioned in a linear arrangement on the ceiling. By employing geometric calculations with known AP coordinates and incident radio angles, a mobile device like a smartphone can determine the target position. Unlike traditional range-based methods relying on parameters like RSSI, AoA leverages directional radio signal angles for precise localization. The method, while potentially complex and costly due to the need for directional antennas or antenna arrays, presents a viable approach to enhancing location-based services in indoor settings. Referring to [6] TOF-based localization in indoor environments measures the time it takes for wireless LAN frames to travel from a source station to a receiver station, similar to GPS. This method requires precise measurement of the time of arrival (TOA) of IEEE 802.11 frames. Several existing technologies that have been used to provide indoor localization services are presented in survey [1]. It discusses Radio communication technologies, such as IEEE 802.11, Bluetooth, Zigbee, RFID and UltraWideband (UWB), followed by visible light and acoustic based technologies.

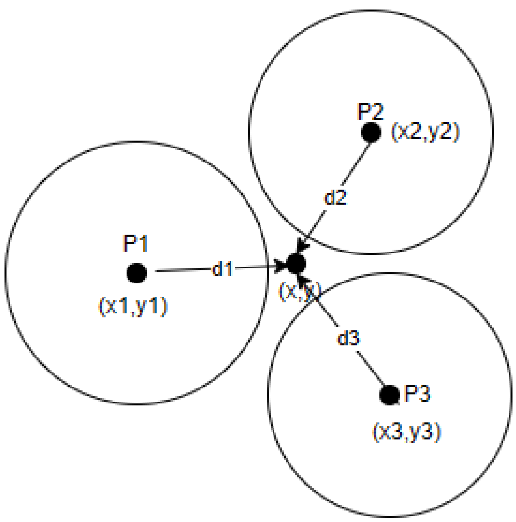
Zigbee is favorable for localization of sensors in WSN, it is not readily available on most of the user devices, therefore it is not favorable for indoor localization of users. We chose to use IEEE 802.11 among them primarily because of its widespread availability; nearly every building is equipped with WiFi access points, and transceivers are commonly found in handheld mobile devices.

Chapter 4: Theoretical Background

4.1 Localization

4.1.1 Trilateration and Multilateration

Trilateration is a method to determine the position of an object based on simultaneous measurement of distances from three stations located at known sites. This is a common operation in robot localization [7].



It is expressed as the problem of finding the intersection of three circles, that is, finding the solutions to the following system of quadratic equation:

$$(x - x1)^2 + (y - y1)^2 = d1^2$$

$$(x - x2)^2 + (y - y2)^2 = d2^2$$

$$(x - x3)^2 + (y - y3)^2 = d3^2$$

Figure 1. The trilateration to find the location of an object at (x,y) from its distance to three points (p1 ,p2 and p3).

Multilateration is also a technique in wireless sensor networks, and is instrumental in determining the coordinates of objects.But this method relies on measurements from multiple reference points (more than three points), often anchor nodes with known coordinates.[8]

4.1.2 GNSS-like and fingerprinting

GNSS stands for Global Navigation Satellite System. It is a term used to describe a constellation of satellites that provides signals for positioning, navigation, and timing services to users worldwide. GNSS enables users to determine their precise location. It is widely used for applications such as navigation in vehicles.

"GNSS-like" typically refers to systems or technologies that share similarities with the Global Navigation Satellite System (GNSS). The most well-known GNSS-like is the Global Positioning System (GPS).

Fingerprinting refers to a technique used for real-time indoor positioning in Wi-Fi networks. It involves creating a database of received signal strength (RSS) from multiple access points at known reference points during an offline or training phase. The collected data forms a radio map. During the online phase, a device measures its current RSS from access points and sends this sample to a central server. The server compares the measured fingerprint to stored fingerprints in the reference points, determining the location of the device and reporting the estimated result back to it. Fingerprinting is considered a low-cost and high-accuracy method for indoor localization in the presence of obstacles and challenges like non-line-of-sight transmission and multipath effects [9].

4.1.3 Newton Raphson

Newton Raphson Method is a powerful technique for solving equations numerically. It is used for approximation of the roots of the real-valued functions. [10]

Newton Raphson Method involves iteratively refining an initial guess to converge it toward the desired root. However, the method is efficient in case of small-degree equations, this method yields very quick results.

4.1.4 Logarithmic Regression

Regression is a statistical method that attempts to determine the character of the relationship between one dependent variable (usually denoted by Y) and a series of other variables (known as independent variables) [11].
Logarithmic regression is a type of regression used to model situations where growth or decay accelerates rapidly at first and then slows over time.
The equation of a logarithmic regression model takes the following form:

$$Y = a + b * lnx$$

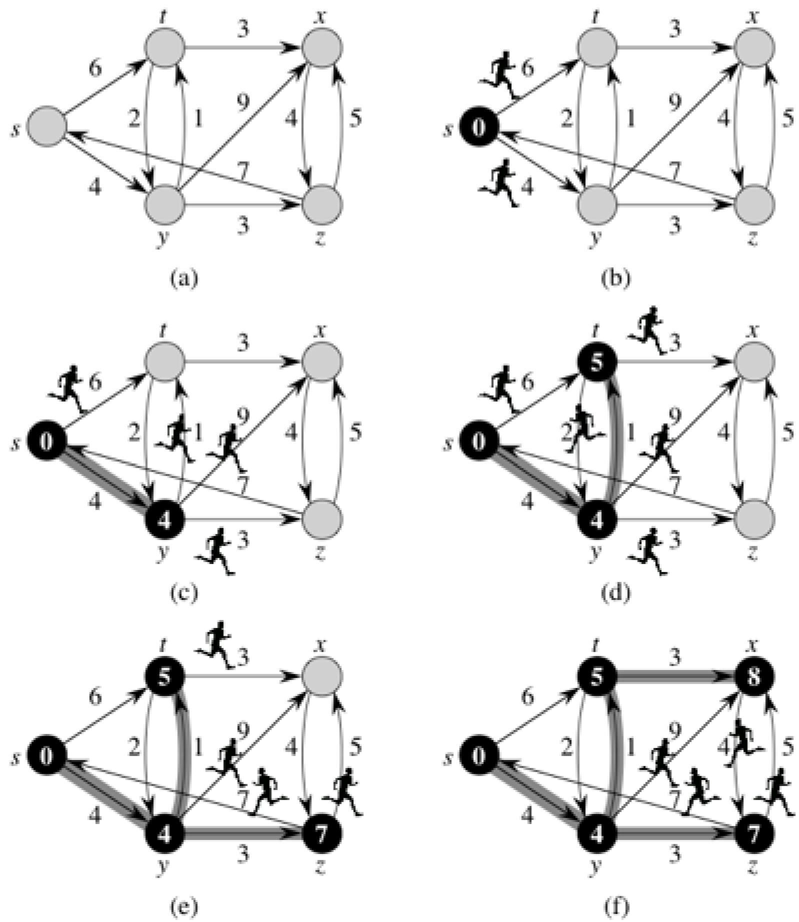
4.2 Navigation

We explored the possibilities of using multiple Algorithms to find the shortest path that will help navigate to the targeted cell such as A*,BFS,DFS,Dijkstra, but after examining the qualities of each and their time and space complexities we decided to stick with Dijkstra as the building block for our navigation system.

4.2.1 Dijkstra algorithm

Dijkstra's Algorithm is employed to determine the most efficient route between nodes within a graph. Specifically, it identifies the shortest path originating from a designated node, often referred to as the "source node," to all other nodes in the graph, resulting in the creation of a shortest-path tree.
In practical terms, this algorithm finds extensive application in navigation systems, such as GPS devices, where it calculates the shortest route from the current location to the desired destination. Its utility extends to various industries, like the networks industry for example.

The algorithm initializes with assigning tentative distance values to nodes, marking one node as the source with a distance of 0, and all others as unreachable with infinite distances. It then iteratively selects and visits nodes with the smallest tentative distances, updating the distances of their unvisited neighbors. This process continues until all nodes are visited, resulting in a shortest-path tree from the source to every other node.



Chapter 5: Tools and technologies

- Software technologies and frameworks:

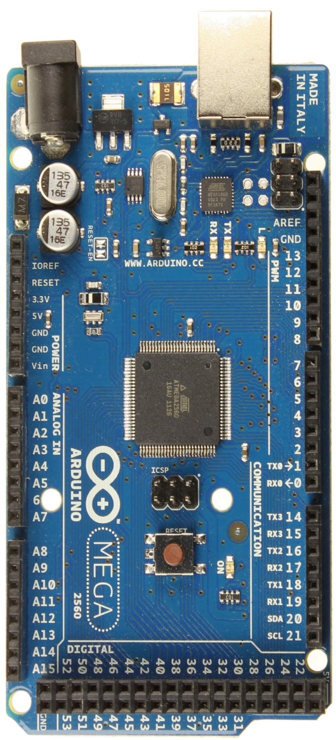
- **draw.io** : Online diagram software, we used it to design the demonstrating figures.

- **stats.blue** : online statistical software was used for regression equations calculation.

- **Flutter** : We used flutter to build a mobile application that accommodates the project and can be used to view the varying values of sensors and to instruct the robot to navigate from one cell to another.

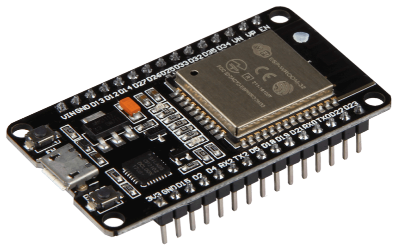
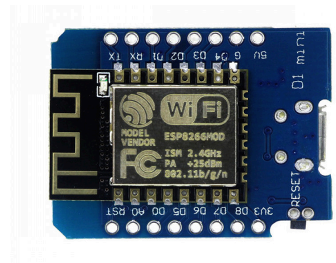
- Hardware components:

  - Arduino mega 2560 board :



The Arduino Mega 2560 is a microcontroller development board based on the ATmega2560 chip. It features a large number of digital and analog input/output pins, making it suitable for our project.

- **Esp32 & ESP8266 :**

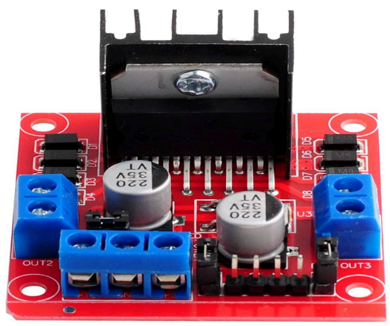
The ESP32 is a versatile and cost-effective system-on-a-chip (SoC) microcontroller. With built-in Wi-Fi and Bluetooth capabilities, the ESP32 is ideal for our project, where wireless communication is essential. Its low-power design makes it suitable for battery-operated devices and applications requiring connectivity, we used our esps in two different way first as access points and we used one of them to scan the RSSI values and communicate with the mobile app using wireless network and with the arduino board serially.

- **LCD 16x2 :**

The LCD 16x2 is a standard alphanumeric liquid crystal display widely used in embedded systems. Its 16x2 format means it can display 16 characters per line and has two lines. This type of display is employed for presenting information in a readable format, making it valuable for our projects which depend on displaying a lot of information.

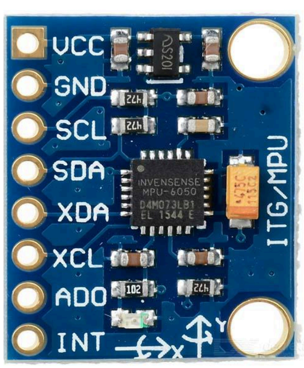
- **DC Motors** :

DC motors are electrical motors that operate on direct current. They are fundamental components in robotics, automation, and other projects where mechanical movement is required. Their simplicity and ease of control make them suitable for our project.



- **H-Bridge (L298n)** :

The H-Bridge, exemplified by the L298N module, is an electronic circuit crucial for controlling the speed and direction of DC motors. It facilitates bidirectional control, enabling motors to move forward or backward. Widely used in motor driver modules, the H-Bridge is an integral component in projects like ours.



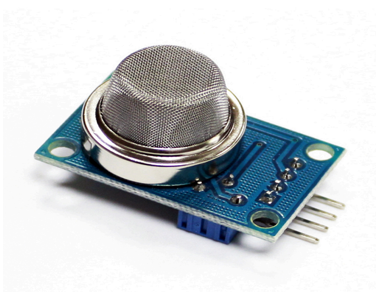
- **MPU6050**:

The MPU6050 is an Inertial Measurement Unit (IMU) sensor, combining a gyroscope and accelerometer. It accurately measures acceleration, rotation, and tilt, making it invaluable for projects requiring motion sensing. Its compact size and reliability make it work for what we're aiming for, we used it to calculate the angle of the robot.

- **Water Sensor** :

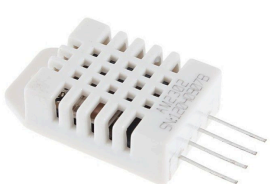
Water sensors are designed to detect the presence or absence of water. They find applications in water leak detection systems and water level monitoring. These sensors are vital in preventing water damage by providing early indications of leaks or high water levels.

- **Smoke Sensor**:



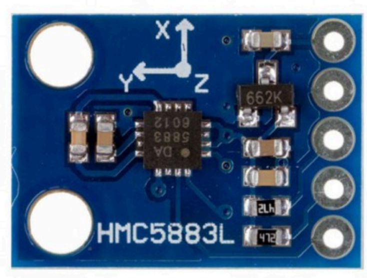
Smoke sensors, or smoke detectors, are essential components in fire detection.
They are designed to identify the presence of smoke or airborne pollutants. These sensors play a crucial role in ensuring safety of the device and the place as well.

- **DHT22 Sensor** :



The DHT22 sensor is a digital temperature and humidity sensor known for its accuracy and reliability. It provides calibrated readings for temperature and humidity, making it suitable for our need to provide information on surrounding conditions.

- **Compass Module (HMC5883L)**:



The HMC5883L is a compass module that measures magnetic fields, providing accurate heading information. This module is employed to determine orientation or direction. Its compact size and precision make it an essential component in navigation systems.

- **ESP32 CAM**

The ESP32-CAM is a versatile development board that combines the ESP32 microcontroller with a camera module, enabling IoT (Internet of Things). We used it for streaming the route of the robot.

- **Keypad**

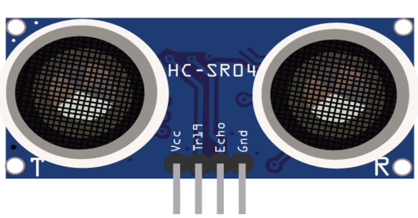
The keypad is an input device that allows users to enter data or commands into electronic systems by pressing buttons arranged in a grid or a linear fashion. We used it for entering commands to the robot to navigate, localize etc..

- **Power Banks :**

Power banks are portable energy storage devices equipped with rechargeable batteries. They serve as convenient sources of power for charging electronic devices on the go, such as smartphones, tablets, and other USB-powered gadgets. Power banks are widely used to ensure continuous device operation when away from traditional power sources, we used them to power our esps.

- **Rechargeable Lithium Batteries :**

Rechargeable lithium batteries utilize lithium-ion technology, offering high energy density and the ability to be recharged multiple times. These batteries are commonly employed in various electronic devices, providing a reliable and rechargeable power source. Their versatility makes them suitable for applications ranging from consumer electronics to electric vehicles.



- **Ultrasonic Sensor:**

Ultrasonic sensors gauge distances by emitting sound waves and measuring their return time. This ingenious technology serves the purpose in our application of helping with avoiding obstacles. By interpreting the echoes, the sensors provide real-time feedback to help achieve that.

Chapter 6: Methodology

6.1 Localization

6.1.1 Network Infrastructure

In this project, the network infrastructure is designed to implement an indoor positioning system using ESP8266 modules. The network consists of three ESP8266 modules configured in access point mode and another ESP32 module dedicated to RSSI (Received Signal Strength Indication) scanning. The setup forms a 3x3 grid layout, with each ESP8266 positioned at a corner of the grid.

1. Access Point ESPs (ESP1, ESP2, ESP3):

These three ESP8266 modules are configured as access points, They serve as the fixed reference points in the indoor environment. They are Positioned at the corners of a 3x3 grid, they create a trilateration system as demonstrated in Figure 5.
Each ESP broadcasts its unique SSID, allowing the scanning ESP32 to identify and measure the signal strength from each access point.

2. Scanning ESP32:

This ESP32 module is dedicated to scanning the RSSI from the three access point ESPs, and it's located on the robot. It moves across the 3x3 grid, collecting signal strength information at different locations.
It Utilizes the Wi-Fi functionality to measure the RSSI values from each of the three access points. The collected data is used to estimate the position of the scanning ESP so as the robot within the grid based on the trilateration principle.

3. Grid Layout:

The 3x3 grid layout provides a spatial reference for the indoor positioning system. The positioning accuracy is enhanced by strategically placing the access point ESPs at the corners of the grid.

The scanning ESP gathers RSSI measurements and determines its location in which cell of the grid.

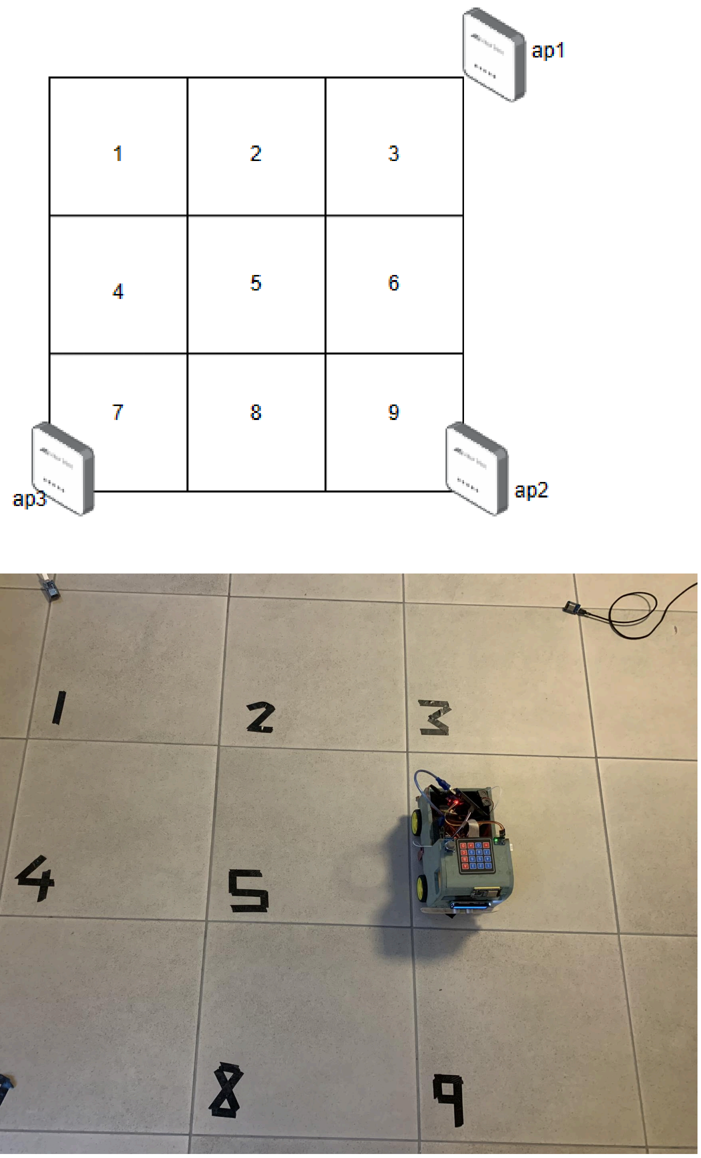


Figure 2: Grid defining the anchor nodes positions.

This network infrastructure enables the trilateration-based indoor positioning system, allowing the scanning ESP to estimate its position within the defined grid by analyzing the signal strengths received from the three access point ESPs.

6.1.2 Wi-Fi Scan

We've conducted a Wi-Fi scan using the ESP32 module to measure the Received Signal Strength Indication (RSSI) from three access points at various distances. The results have been documented in an Excel sheet, as depicted in Table 1.

distance (cm)	RSSI * -1 ap1	RSSI * -1 ap2	RSSI * -1 ap3
0	23	13	30
10	36	32	41
20	45	42	45
30	46	49	51
45	49	53	52
60	52	55	53
75	54	54	56
90	57	57	55
105	65	60	58
120	68	60	63
135	61	68	63
150	62	64	60

distance	RSSI * -1	RSSI * -1	RSSI * -1
165	63	72	68
180	68	75	67

Table 1: Sample RSSI values from access points at different distances.

6.1.3 distance estimation

In order for the robot to know the distance of it from the access points, we scan the RSSI value. Then we estimate the RSSI value in the regression equation. So after this process we gain the approximated distance from the three access points.

Regression for the first access point:

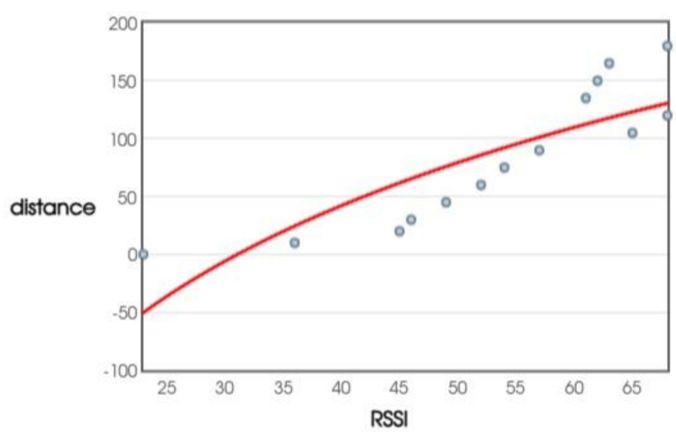


Figure 3. Logarithmic Regression Curve for AP1.

Regression Equation: $\mathrm{DISTANCE} = -573.4752 + 166.8416 \cdot \ln(\text{-RSSI})$

Correlation: $r = 0.8272$

R-squared: $r^2 = 0.6843$

Regression for the second access point:

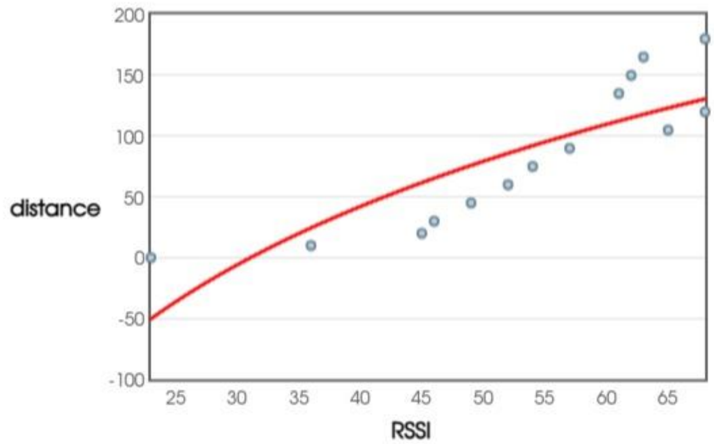


Figure 4. Logarithmic Regression Curve for AP2.

Regression Equation: $\mathrm{DISTANCE} = -314.2834 + 101.8577 \cdot \ln(\text{-RSSI})$

Correlation: $r = 0.7638$

R-squared: $r^2 = 0.5834$

Regression for the third access point:

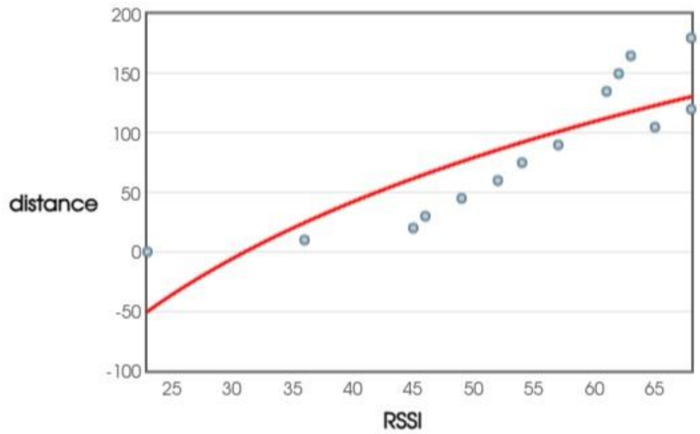


Figure 5. Logarithmic Regression Curve for AP3.

Regression Equation: $\text{DISTANCE} = -857.9809 + 237.0412 \cdot \ln(\text{-RSSI})$

Correlation: $r = 0.8699$

R-squared: $r^2 = 0.7568$

6.1.4 Position calculation

After obtaining the distances from three distances, we apply the trilateration to determine the robot's approximate position in the defined grid coordinates. This method allows for localization and positioning of the robot within the environment based on wireless signal strength.

6.1.5 Error minimization

In order to reduce errors arising from the inaccuracy of RSSI readings due to interference and obstacles, several measures were implemented. Firstly, the system calculates the average of three RSSI readings before determining the position. This approach helps to smooth out fluctuations in signal strength caused by environmental factors, thereby improving the accuracy of the positioning system.

Additionally, we put the AP's and the Scanning Esp (transceiver) on the same height, according to a study by Abu Kharmeh et al. (2023) a very important observation that should be taken into consideration in any indoor-positioning system that the value of the RSSI varies significantly from a fixed reference when the transceiver (Scanning Esp) height is changed. [3]

Furthermore, to address the issue of signal degradation with increasing distance, the grid area
was minimized. By reducing the area over which the system operates, the signal propagation distance is effectively shortened, leading to more reliable RSSI readings and enhanced positioning accuracy.

Additionally, the choice of ESPs as access points was strategic. Utilizing ESPs allows us to control channel allocation, with non-overlapping channels 1, 6, and 11 selected for operation. This selection is based on the principle of channel separation by 5, wherein adjacent channels are sufficiently spaced to prevent interference between access points as shown in Figure 6. This ensures that the signals transmitted by neighboring access points do not overlap, thereby minimizing interference and optimizing the performance of the positioning system.[12]

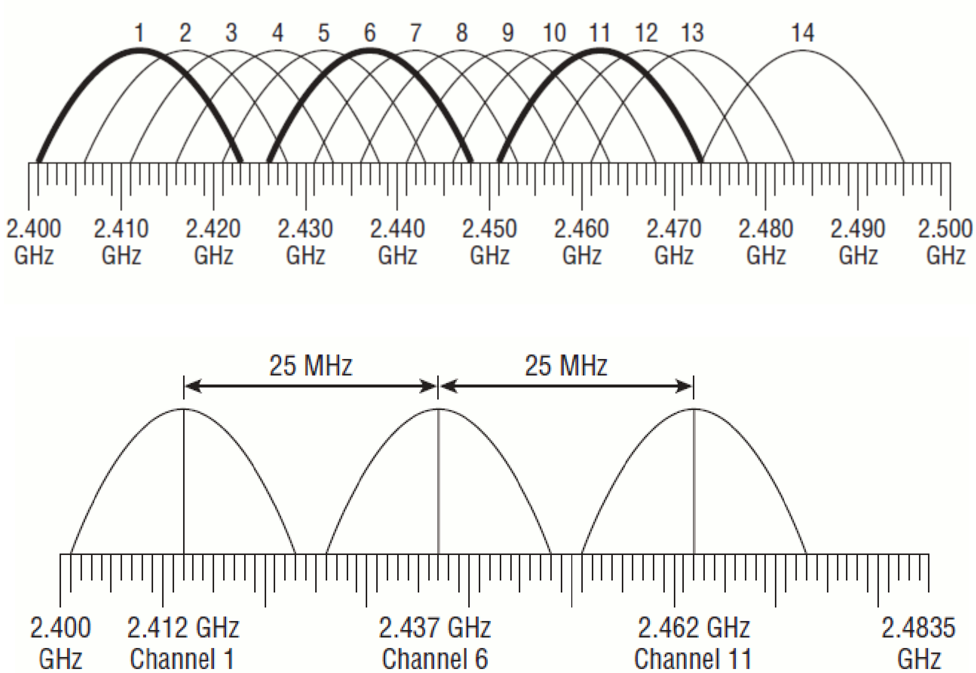


Figure 6. Non overlapping channels

6.2 Navigation

6.2.1 Shortest path

We used the dijkstra algorithm to determine the shortest path that the robot will follow, after that we developed a code that maps this path to the movements the robot makes which are (move forward, turn right, turn left), this depends on the direction that the robot would be currently in as will as the direction the robot will be following to move to the next cell.

6.2.2 Robot Movements

The functionality of moving the robot forward is very standard and is implemented by powering all the motors to move forward for a certain period so that it can cross the distance we wanted, which is 45cm.
For the left and right turning we used the mpu6050 to calculate the angle the robot is in, and keep reading it and moving the motors of the robot, each side opposite from each other until the angle becomes 90 degrees less than what it started as if we're moving to the right and 90 degrees more if the desire was to turn left, this approach provided an acceptable level of accuracy.

6.2.3 Obstacle avoidance

We used the ultrasonic sensor to help with avoiding the obstacle that would get in the way of the robot, we implemented the functionality of stopping the robot when an obstacle was found and alerting the user.

6.3 Robot structure

6.3.1 motors

We used four DC motors for the car to allow it to move in a smoother way and be able to maneuver well.

6.3.2 power

We used lithium batteries to power the motors through the H-Bridge, we used three of them and they are able to generate 3.7 voltage each meaning the collective voltage is 11.2 volt, we also used a 9 volt battery to power the arduino board, and we depended on power banks to power the esps that were used both as an access point and for the one responsible for scanning.

6.4 Surrounding conditions

We utilized the water, smoke and DHT sensor to provide readings of the current surrounding conditions that could impact our system, the user can access them either by the mobile application or display them on the lcd, an update will happen if a value such as the smoke or water levels crossed a chosen threshold.

6.5 LCD and keypad

We implemented the LCD and keypad in this project to send some control commands to the system. If ‘1’ is pressed for example it locates the cell the robot is in, ‘2’ activates the navigating functionality and ‘3’ displays the current surrounding conditions on the lcd.

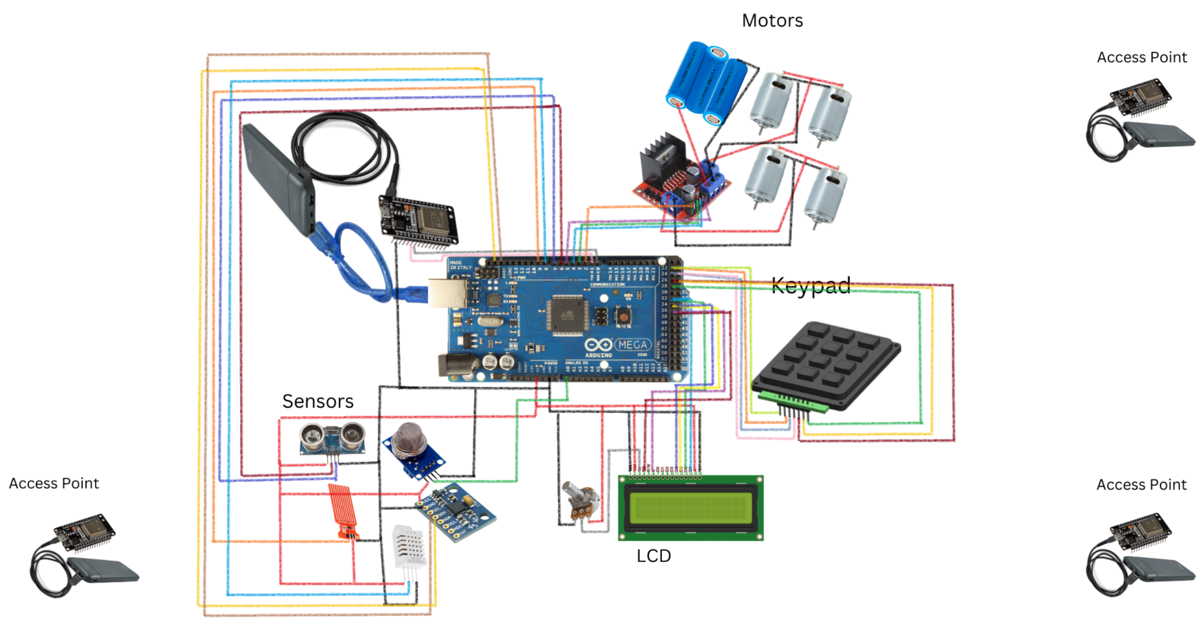
6.6 Route Streaming

We employed the ESP32-CAM to stream the robot's route to the mobile application. This streaming functionality enables users to visualize the path from one position to another. It can serve various purposes including security monitoring, image processing, and more.

6.7 Mobile Application

We've developed a mobile application that provides an interface for both users and administrators. The application serves multiple purposes. Firstly, it allows users to monitor surrounding conditions, including detecting emergencies such as fires or spilled water, along with other indicators. Secondly, it enables camera streaming functionality. Thirdly, users can track the location of the robot through the application. Lastly, it allows navigating the robot to a specific position chosen from the app.

6.8 Circuit Connections



Chapter 7 :Results and Analysis

For an efficient RSS-based IPS, there are various factors that should be considered, such as human-body effects, building material, device diversity, antenna polarization, and sensor placement height, and a good understanding of RSSI behavior with these factors will lead to achieve that. After reading and researching about these things we were able to produce a project that can estimate its location based on the RSSI values it scans from the surrounding ESPs configured as access points around it. The accuracy of the estimate can vary sometimes because of the non linear relation between the RSSI and distance and mainly because of the interference, but with our efforts to try and minimize that we could get an estimate that if not 100% accurate would be close to the intended result in terms of distance.

As for the navigation of the robot we were able to build one that is autonomous and would only need to know the desired place it should go to, choosing the right algorithm and mapping that to the movements the robot makes proved to be successful, we faced some problems regarding the accuracy of the turns when we used the approach of time delays due to the unique characteristics of each motor and also relating to the surface area the robot will move on, but we were able to solve using the gyroscope of the MPU6050, that calculated the degree of the turn in acceptable accuracy.
We were also successful in integrating a mobile app to our project that would serve as another vehicle to control the system.
In conclusion, despite encountering certain challenges and errors, we were able to overcome these obstacles.

Chapter 8 : Conclusion And Future Work

In this project, we propose a simple and low-cost wireless indoor localization system utilizing WiFi metric. The specific WiFi-associated signal strength collected as part of this work will be a valuable asset for future use for the indoor-localization process. This project is a way to make use of the correlation between the distance from the access point and the corresponding RSSI value.

In future work, we plan to conduct additional analysis to assess the accuracy of the obtained RSSI values. We aim to expand the area in a manner that reflects a more realistic indoor environment, incorporating features such as walls to simulate real-world conditions accurately and explore the integration of advanced algorithms to account for factors such as walls and interference.

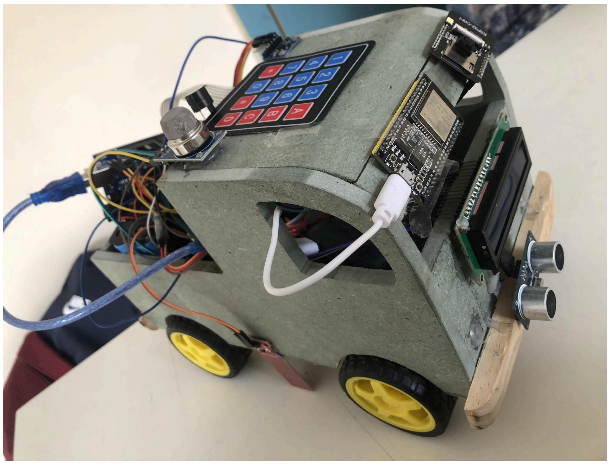
Abbreviations

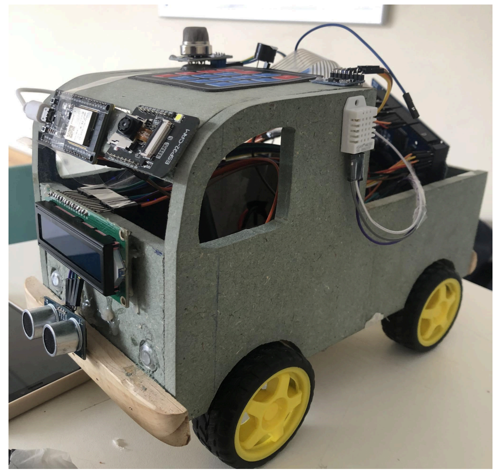
The following abbreviations are used in this report::

WSNs	wireless sensor networks
TOA	time of arrival
RSS	received signal strength
RSSI	received signal strength indicator
AOA	angles of arrival
AP	access point
IPS	Indoor positioning system

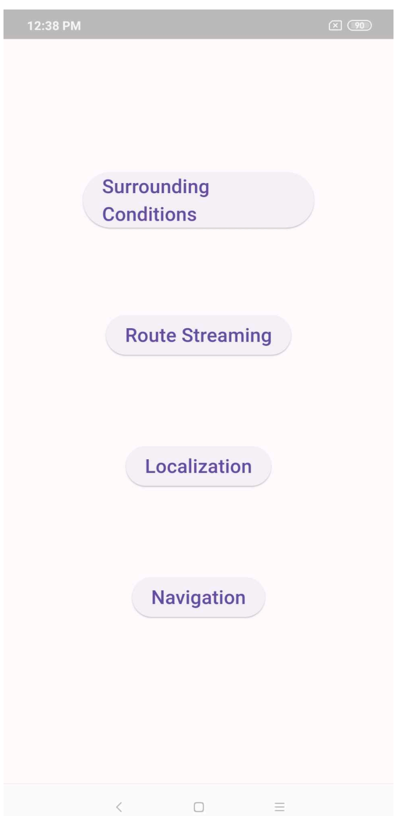
Appendices

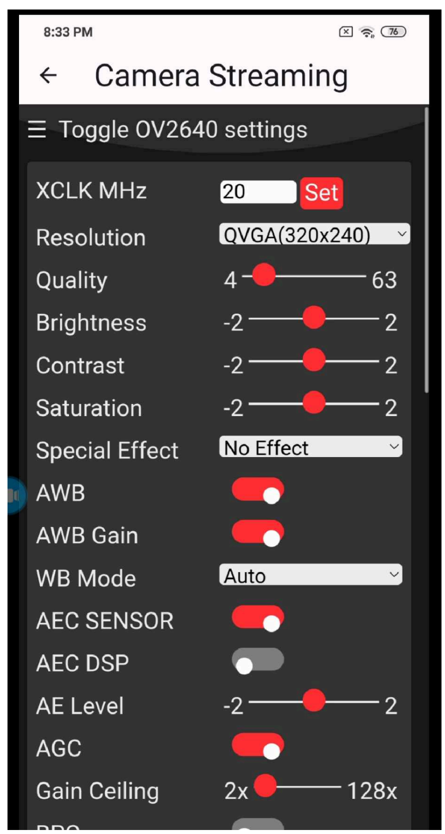
Appendix I : Robot Images

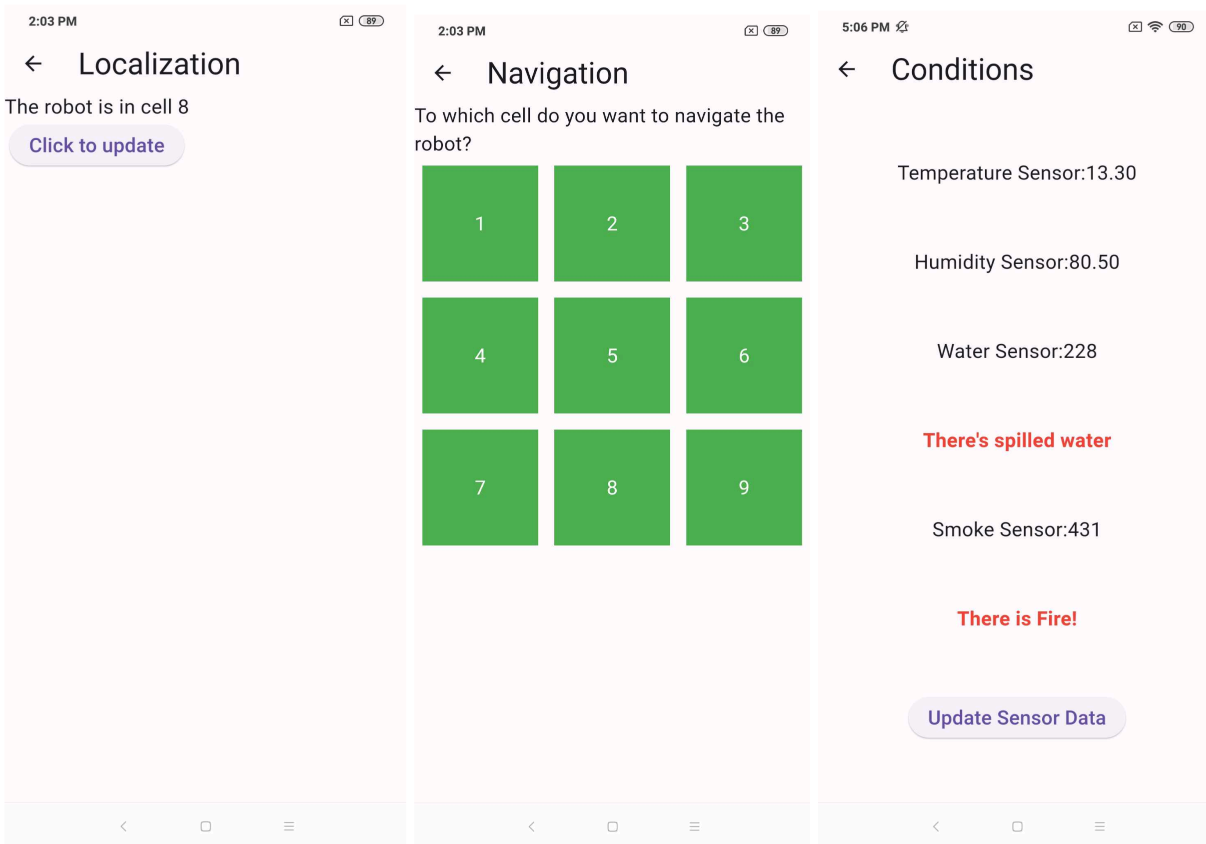




Appendix II : Screenshots from the mobile app







References

[1] F. Zafari, A. Gkelias and K. K. Leung, "A Survey of Indoor Localization Systems and Technologies," in *IEEE Communications Surveys & Tutorials*, vol. 21, no. 3, pp. 2568-2599, third quarter 2019, doi: 10.1109/COMST.2019.2911558.

[2] S.P. Singh, S.C. Sharma, Range free localization techniques in wireless sensor networks: A review, Procedia Comput. Sci. 57 (2015) 7-16.

[3] Abu Kharmeh S, Natsheh E, Sulaiman B, Abuabiah M, Tarapiah S. Indoor WiFi-Beacon Dataset Construction Using Autonomous Low-Cost Robot for 3D Location Estimation. *Applied Sciences*. 2023; 13(11):6768. https://doi.org/10.3390/app13116768

[4] Du J, Yuan C, Yue M, Ma T. A Novel Localization Algorithm Based on RSSI and Multilateration for Indoor Environments. *Electronics*. 2022; 11(2):289. https://doi.org/10.3390/electronics11020289

[5] Hou Y, Yang X, Abbasi QH. Efficient AoA-Based Wireless Indoor Localization for Hospital Outpatients Using Mobile Devices. *Sensors*. 2018; 18(11):3698. https://doi.org/10.3390/s18113698

[6] S. Koenig, M. T. Schmidt and C. Hoene, "Multipath mitigation for indoor localization based on IEEE 802.11 time-of-flight measurements," 2011 IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks, Lucca, Italy, 2011, pp. 1-8, doi: 10.1109/WoWMoM.2011.5986392. keywords: {Calibration;Linear regression;Time measurement;Wireless LAN;Correlation;Estimation;Position measurement},

[7] M. N. Rahman, M. T. I. A. T. Hanuranto and S. T. M. T. R. Mayasari, "Trilateration and iterative multilateration algorithm for localization schemes on Wireless Sensor Network," *2017 International Conference on Control, Electronics, Renewable Energy and Communications (ICCRC)*, Yogyakarta, Indonesia, 2017, pp. 88-92, doi: 10.1109/ICCEREC.2017.8226710.

[8] Y. Zhou, Jun Li and L. Lamont, "Multilateration localization in the presence of anchor location uncertainties," *2012 IEEE Global Communications Conference (GLOBECOM)*, Anaheim, CA, 2012, pp. 309-314, doi: 10.1109/GLOCOM.2012.6503131.

[9] W. Meng, W. Xiao, W. Ni and L. Xie, "Secure and robust Wi-Fi fingerprinting indoor localization," *2011 International Conference on Indoor Positioning and Indoor Navigation*, Guimaraes, Portugal, 2011, pp. 1-7, doi: 10.1109/IPIN.2011.6071908.

[10] GeeksforGeeks. (2023, July 4). Newton-Raphson Method. Retrieved from https://www.geeksforgeeks.org/newton-raphson-method/

[11] Investopedia. (n.d.). Regression. Retrieved from https://www.investopedia.com/terms/r/regression.asp

[12] Data Alliance. (2023, Nov 22). WiFi Channels Guide. Retrieved from https://www.data-alliance.net/wifi-channels-guide#:~:text=At%202.4%20GHz%20non-overlapping%20channels%201%2C%206%2C%20and,the%20best%20to%20avoid%20interference%20with%20your%20signal.