Enhancing Parking Spot Identification Accuracy Using Ultra-Wide Band Technology

Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

in

B.Tech Computer Science & Engineering

By

VAISHNAV SANTHOSH
19BCE2450

Under the guidance of

Prof. Jasmin T Jose

SCOPE VIT, Vellore.

MAY, 2023

DECLARATION

I hereby declare that the thesis entitled "Enhancing Parking Spot Identification Accuracy Using Ultra-Wide Band Technology" submitted by me, for the award of the degree of *Bachelor of Technology in Computer Science & Engineering* to VIT is a record of bonafide work carried out by me under the supervision of Prof. Jasmin T Jose.

I further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

Place : Vellore

Date : 19-05-2023

Vaishnav Santhosh

Signature of the Candidate

CERTIFICATE

This is to certify that the thesis entitled "Enhancing Parking Spot Identification Accuracy Using Ultra-Wide Band Technology" submitted by **Vaishnav Santhosh 19BCE2450, SCOPE**, VIT, for the award of the degree of *Bachelor of Technology in Computer Science and Engineering*, is a record of bonafide work carried out by him / her under my supervision during the period, 01. 07. 2022 to 30.04.2023, as per the VIT code of academic and research ethics.

The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university. The thesis fulfills the requirements and regulations of the University and in my opinion meets the necessary standards for submission.

Place : Vellore

Date : **Signature of the Guide**

Internal Examiner **External Examiner**

Dr. VAIRAMUTHU S

HOD, Computer Science & Engineering

ACKNOWLEDGEMENTS

In performing our assignment, we had to take the help and guidelines of some respected persons, who deserve our greatest gratitude. The completion of this project gives us much pleasure. We would like to show our gratitude to **PROF. JASMIN T JOSE** for guiding us through numerous consultations. We would also like to extend our sincere gratitude to all those who have directly and indirectly helped us in writing this assignment. We also thank VIT VELLORE and the Dean of SCOPE office for the opportunity. Many people, especially our classmates and team members themselves, have made valuable comment suggestions on this proposal which gave us inspiration to improve our project and working model. We thank all the people for their help directly and indirectly to complete our assignment.

Vaishnav Santhosh

Student Name

Abstract

With the increasing number of vehicles on the road, efficient parking management has become a necessity. In this project, we propose a parking system management using Ultra Wide Band technology to address the common problem of forgetting where a car has been parked in large, multi-level parking facilities. The system involves placing tags on vehicles and anchors in the parking area, which communicate with a base station to triangulate the location of the parked vehicle. By using a smart device to ping the location in a parking app, the system can provide the location of the vehicle to the user upon request, allowing for efficient retrieval of the car. This system not only benefits the parking facility providers, but also the consumers by simplifying the process of locating a parked vehicle. Our proposed system has the potential to be highly maintainable and effective in both indoor and outdoor parking environments.

CONTENTS

List of Figures

List of Abbreviations

UWB	Ultra-Wide Band
RFID	Radio-Frequency Identification
BLE	Bluetooth Low Energy
NFC	Near Field Communications
SPS	Smart Parking System
AI	Artificial Intelligence

Symbols and Notations

m	Meters
cm	Centimeters

1. INTRODUCTION

1.1 THEORETICAL BACKGROUND

The use of technology has revolutionized many aspects of daily life, including the way we park our cars. In recent years, the development of Ultra-wide Band (UWB) technology has provided a new approach to enhance parking spot identification accuracy. UWB is a wireless communication technology that uses radio waves to transmit data over short distances. The UWB technology has several advantages, such as its ability to provide accurate location information in both indoor and outdoor environments. Traditional parking systems rely on visual cues or sensors to locate and identify empty parking spots. However, these systems are often inaccurate and can lead to frustration for drivers searching for available spots. By contrast, UWB technology uses sensors that are placed around the parking area to identify and locate empty parking spots accurately. These sensors can communicate with a central system that displays the location of available parking spots in real-time.

1.2 MOTIVATION

The motivation behind the project is to learn about UWB technology and its applications, to improve the parking experience for drivers and to contribute to the growing demand for sustainable and efficient parking solutions in urban areas.

1.3 AIM OF THE PROPOSED WORK

The aim is to determine the extent to which UWB can be used to detect parking spots accurately and reliably in urban environments, provide real time information to the parker and foster sustainability.

1.4 OBJECTIVES OF THE PROPOSED WORK

1. To compare the performance of UWB with other technologies used for detection such as Wi-Fi, Bluetooth, and RFID.
2. To identify the factors that influence the effectiveness of UWB for parking spot detection, including the characteristics of the urban environment and the design of the UWB system.
3. To identify potential challenges and limitations of UWB-based parking spot detection and propose strategies to address them.
4. To explore the potential applications of UWB for parking spot detection, beyond the traditional use of sensors and cameras.
5. To examine the economic and social impacts of using UWB for parking spot detection,

including the potential benefits and costs for different stakeholders.

2. LITERATURE SURVEY

2.1 LITERATURE SURVEY

Comparing ubisense, bespoon, and decawave uwb location systems: Indoor performance analysis [1] does a performance comparison between ubisense, Bespoon and decawave's implementation of UWB systems which is placed under the same experimental conditions including characterization of the quality of the estimated tag-to-sensor distances, areas under Line-of-Sight and diverse Non-Line-of-Sight conditions. The conclusion of the paper was that Decawave is slightly better than BeSpoon and significantly more reliable, in terms of accuracy, than BeSpoon.

IEEE 802.15. 4 historical evolution and trends [2] talks about the evolution and usage trends of the IEEE 802.15.4 standard which UWB uses. It presents the chronological development of the standard by highlighting each feature which has been introduced over the years and gives us an insight into the standard's future directions.

An overview of the IEEE 802.15. 4z standard its comparison and to the existing UWB standards [3] talks about the new IEEE standard 802.15.4z whose main objective is to enhance the already existing Impulse Radio Ultra - Wideband technology. The paper compares the current state of this standard with pre-existing standards and proposes some changes to be made.

An overview of UWB standards and organizations (IEEE 802.15. 4, fira, apple): Interoperability aspects and future research directions [4] talks about the differences of UWB compatibility and interoperability between different industry standards and configurations present currently in the market. The paper talks about in detail about the compatibility issues and interoperability aspects related to physical,

medium-access-control and upper layers.

Positioning and parking analysis for an indoor positioning system: A comparative study between Bluetooth Low Energy and Ultra-Wideband technology [5] evaluates how different radio technologies combined with different positioning techniques perform with accuracy and precision as metrics by positioning tests to determine performance characteristics and ups and downs of the technology.

Smart Parking Management System [6] helps in bringing out one of those efficient ways of car park management by making use of an android mobile application whereby users can pre-book a car park space and thus this helps in saving a lot of time and energy. The user is also

given the option to cancel a booking in a certain allotted time thus a simple yet quite an efficient system.

Smart parking systems: comprehensive review based on various aspects [7] identifies the different types of sensors that can be used in car parks and their advantages over each other. It also shows an in-depth survey conducted by considering all the various research papers and data relating to smart parking systems ever used.

Evaluating the Effect of Smart Parking Technology on Campus Parking System Efficiency using Discrete Event Simulation [8] investigates the search time taken to find parking spaces. For the data they have gone with a 234-car park space in a university and DES (Discrete Event Simulation) is the tool used to study the patterns/ events in these parking spaces.

Smart Car Parking System Solution for the Internet of Things in Smart Cities [9] has considered the energy consumed and spaces required in transferring real time data over the network when a consumer requires parking status. The paper proposes an alternative approach thus helping people get real-time information on car parking and the congestion status in those areas as the data is stored locally and only processed data is sent over the network thus helping in saving both time and energy.

IoT Based Smart Parking System [10] investigates smart parking systems with two main objectives. The first is to help people book parking spaces where ultrasonic sensors are used with AI to check if a space is available or not. The second objective is to help people complete payments online using PayPal.

2.2 SUMMARY/GAPS IDENTIFIED IN THE SURVEY

Surveys [1], [2], [3], [4] and [5] talk about the UWB platform and its technological specifications and performance based on different factors such as line of sight, indoor/outdoor placement, distance between sensors, etc. and the interoperability between the standards set by different organizations. [6], [7], [8] and [9] talk about the current implementations of smart parking in the real world which use sensors to detect if a car is present at a parking spot or book a slot based on availability. Our project tends to make it easier for both the parker, who just needs a tag in their car and can get the details easily from their phone, and the owner of the lot, who just needs to set up a couple of anchors around the parking spot compared to buying one sensor to detect a car per parking spot.

3. OVERVIEW OF THE PROPOSED SYSTEM

3.1 INTRODUCTION AND RELATED CONCEPTS

The proposed system uses UWB sensors to detect the presence of vehicles in parking spots. The system aims to provide real-time feedback to drivers and parking lot operators, improve parking efficiency, and address the challenges of parking management.

Before choosing UWB, we compared existing technologies in order to figure which one was suitable for the project. Each technology has its advantages and limitations, so here's a comparison of the four technologies for parking spot detection:

RFID (Radio Frequency Identification):

Details:

- Accuracy of less than 10cm.
- Range can go up to 1m.
- It’s in a passive state so no battery is required.

Advantages:

- Low-cost tags can be easily attached to vehicles.
- Low power consumption.
- Can be used for access control and security applications.

Limitations:

- Limited range.
- Line-of-sight required.
- Data transfer rate is low.

Wi-Fi:

Details:

- Accuracy of less than 15m.
- Range can go up to 150m.
- Battery lifetime is medium.

Advantages:

- High data transfer rate.
- Large range.
- Can be integrated with other applications.

Limitations:

- High power consumption.
- Limited accuracy for parking spot detection.
- Can be affected by interference and noise.

Bluetooth:

Details:

- Accuracy of less than 8m.
- Range can go up to 75m.
- Battery lifetime is high.

Advantages:

- Low power consumption.
- Can be used for short-range communication.
- Large installed base.

Limitations:

- Limited range.
- Data transfer rate is low.
- Can be affected by interference and noise.

UWB (Ultra-Wideband):

Details:

- Accuracy of less than 30cm.
- Range can go up to 150m.
- Battery lifetime is low to medium.

Advantages:

- High accuracy for parking spot detection
- Low power consumption
- Can operate in non-line-of-sight conditions.
- High data transfer rate

Limitations:

- Higher cost compared to other technologies.
- Limited range compared to Wi-Fi.

- Requires specialized hardware and software.

Overall, UWB technology offers the highest accuracy for parking spot detection and can operate in non-line-of-sight conditions. However, it may be more expensive but considering that smartphones have started to add UWB antennas to phones, the cost could be reduced in the future. RFID, Wi-Fi, and Bluetooth are more widely used and have lower cost and power consumption but may have limitations in accuracy and range. The choice of technology will depend on the specific requirements of the parking spot detection system and the available budget.

3.2 FRAMEWORK, ARCHITECTURE OR MODULE FOR THE PROPOSED SYSTEM

The raspberry pi shall communicate with the front-end application made available to the user for determining the live location of the parked vehicle. The anchors are set up in different areas of the parking lot and there exists a listener that acts passively and watches over the network as a whole and sends information back to the raspberry pi when required. The USB to UART bridging helps by turning into a translator allowing devices to send/receive data from one interface to another. The listener is connected using this means.

The app on the user side communicates with the raspberry pi and relays the recent last known location of the vehicle to the user. The raspberry pi talks with the listener, anchors and the tag and figures out the exact location of the tag with respect to each other and the same is demonstrated on the user's app in a map form. This map shall guide the user to the vehicle parked in the assigned spot. The listener, tag and anchors for practicality are connected to power by using power banks. There is a purposeful delay of a few seconds every time the live location of the vehicle is brought into picture to save battery resources. The raspberry pi through serial connection gets data from the listener and stores the same in Redis database for application-level use. Hence the listener needs to be in range of the anchors.

3.3 PROPOSED SYSTEM MODEL

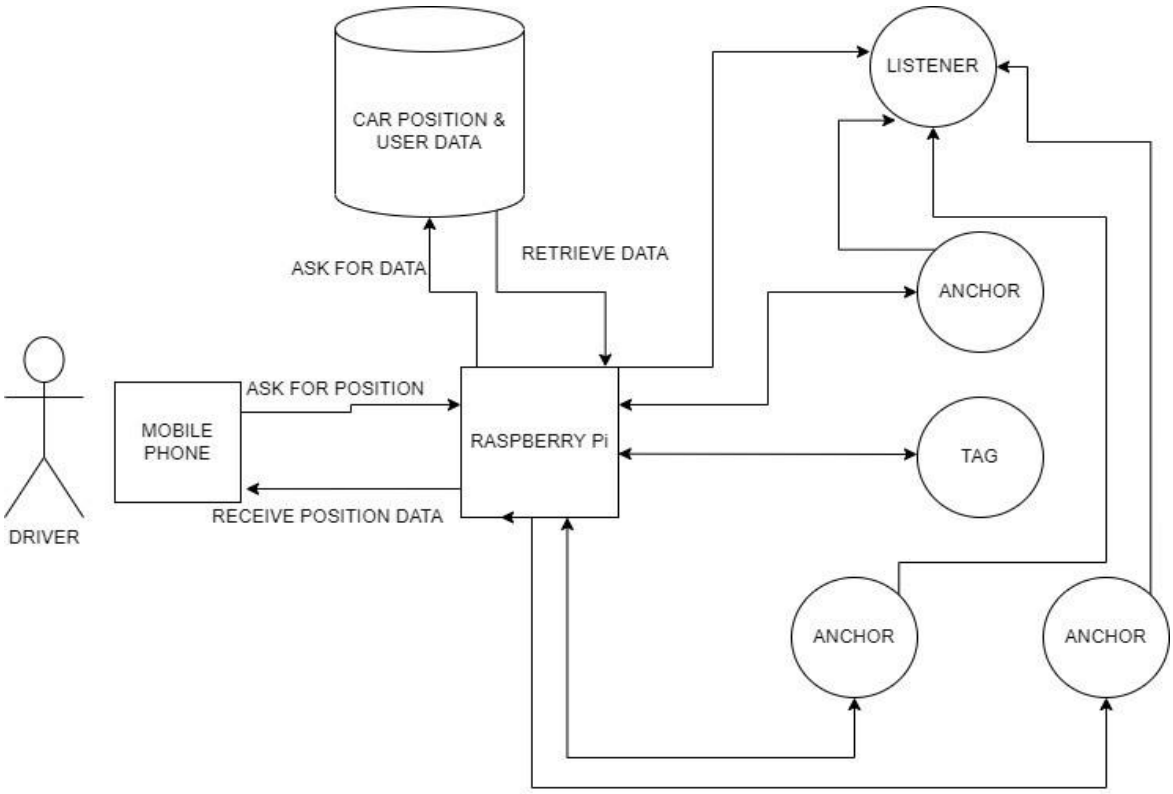

Fig 1 System Architecture

The system uses a raspberry pi, listener, multiple anchors, and a tag. The tag also known as the vehicle locator shows the user the vehicle location in real time when necessary. The listener just sits and looks over the network setup. The raspberry pi communicates with the tags, anchors, and listener. The anchors are like the boundaries of the network/ the area covered by the network for reading any tag that comes into contact. Using DWM1001's allows us to directly assign them as listeners, anchors, or tags and get to developing the application soon.

4. PROPOSED SYSTEM ANALYSIS AND DESIGN

4.1 INTRODUCTION

The proposed system aims to develop an efficient and accurate parking spot detection system using UWB technology. The proposed system will use UWB technology to detect the presence or absence of vehicles in parking spots and provide real-time feedback to drivers and parking lot operators.

The analysis will involve identifying the key requirements for the system, including hardware, software, and operational requirements. The hardware requirements will include UWB transceivers, antennas, and other related equipment, while the software requirements will include software to interface with the UWB hardware, process the data, and perform the parking spot detection.

The analysis will also consider the operational requirements of the system, including accuracy, real-time performance, scalability, reliability, compatibility, user-friendliness, and maintenance. The system will be designed to perform accurately, reliably, and consistently under different weather and lighting conditions.

4.2 REQUIREMENT ANALYSIS

These are the functional, non-functional and system requirements for our project.

4.2.1 FUNCTIONAL REQUIREMENTS

Functional requirements talk about the requirements of the project to work as intended.

4.2.1.1 PRODUCT PERSPECTIVE

The product will use UWB which lets parkers remember their parking spot easily due to the reliability of UWB and streamline the expense and management duties of stakeholders of the parking lot. It aims to enhance the parking experience for both parkers and stakeholders by providing accurate and real-time parking information while reducing the overall costs and management burden of parking lot operations. The software will provide an intuitive and user-friendly interface to enable easy adoption and use by parkers and stakeholders alike.

4.2.1.2 PRODUCT FEATURES

The system utilizes UWB which provides a parker with accurate location information of where they have parked a car which is achieved by placing UWB tags inside the parked vehicle and installing UWB anchors throughout the parking area. The UWB tags have a unique identifier that is picked up by the UWB anchors and transmitted to a centralized system. The parker can then access the system through their smartphone and input the unique identifier to retrieve the exact location of their parked car. This feature enhances the accuracy of the parking spot identification, making it more reliable and user-friendly. By utilizing UWB technology, the system can overcome the limitations of traditional parking systems that rely on visual cues or sensors. The system eliminates the need for the parker to remember their parking spot, reducing frustration and saving time.

4.2.1.3 USER CHARACTERISTICS

The target user of the application will be a person owning a vehicle looking to park their vehicle in the parking lot consisting of the system. These users are often in a hurry and looking for a quick and easy way to locate their parked vehicle. They may have experienced frustration or stress in the past due to difficulty in finding their parked car. The system is designed to cater to these users' needs by providing a simple and efficient solution for locating their parked car, reducing stress, and improving their overall parking experience.

4.2.1.4 ASSUMPTION & DEPENDENCIES

The project assumes that the parking lot is generally rectangular in shape and has adequate space to accommodate the required sensors and equipment. The system relies on a good line of sight between the four vertices of the parking lot, allowing for accurate triangulation of the parked vehicle's location. Any obstructions or interference that may affect the line of sight could impact the system's accuracy and performance. Therefore, it is crucial to conduct a thorough assessment of the parking lot's characteristics and limitations before implementing the system.

4.2.1.5 DOMAIN REQUIREMENTS

The sensor used in the system must comply with IEEE 802.15.4-2011 standard for wireless communication. The system should be able to handle multiple active tags and anchors and the owner of the parking lot must have access to a dashboard to view the status of the system in real-time.

4.2.1.6 USER REQUIREMENTS

The user requires an android device to install the app and the app must have a user-friendly interface for easy navigation. The communication between the app and the Raspberry Pi base station should be seamless and reliable, with minimal delay or interruption. The app should also provide clear instructions on how to use the system, including how to input the tag ID and retrieve the location of the parked vehicle.

4.2.2 NON-FUNCTIONAL REQUIREMENTS

Non-functional requirements talk about the requirements needed by different stakeholders to work efficiently.

4.2.2.1 PRODUCT REQUIREMENTS

Product requirements talk about how the product should perform in terms of efficiency, reliability, and usability.

4.2.2.1.1 EFFICIENCY

The system should be able to accurately detect parking spots in real-time and provide updates to the user interface quickly. The system should be accurate in detecting parking spots and minimizing false positives or negatives to provide an optimal user experience.

4.2.2.1.2 RELIABILITY

The system should be able to handle increasing amounts of data and traffic as more users begin to use the system. It should be always reliable and available to ensure that parking spots are always detected and available to users.

4.2.2.1.4 USABILITY

The system should be easy to use for both admins and users. This helps to build a strong foundation for the efficient working of the project as proper movements and responses are recorded and later used for learning for upgrading the project.

4.2.2.2 ORGANIZATIONAL REQUIREMENTS

Organizational requirements talk about the requirements from the perspective of an organization willing to implement the project.

4.2.2.2.1 IMPLEMENTATION REQUIREMENTS

Data collection: There is a need to collect UWB data from different locations in the parking area to get the most accurate readings from each anchor.

Database setup: There is a need for a database where the transfer of data needs to be fast to keep up with the changing data from the different UWB tags and easy to scale with an increasing number of tags.

Testing and Evaluation: To test the system in a real-world parking environment to evaluate its accuracy and effectiveness. We may need to refine the system based on the results of the testing and evaluation.

4.2.2.2.2 ENGINEERING STANDARD REQUIREMENTS

The project should comply with the relevant UWB technology standards such as IEEE 802.15.4z, which is used for high-precision ranging and positioning. The parking spot detection system should have a high level of accuracy, which means that it should be able to detect the presence or absence of a vehicle with a high degree of certainty. The system should be designed to work at a reasonable range that is appropriate for the intended application. The system should be designed to have low power consumption, especially if it is intended to be used in a battery-operated device. The system should be able to operate in the presence of interference from other UWB devices or other sources of electromagnetic interference. The system should be designed to operate reliably in various environmental conditions, such as changes in temperature, humidity, and lighting. The system should have appropriate measures in place to protect the privacy and security of the data it collects, such as encryption and access controls. The system should have a user-friendly interface that allows users to easily interact with it and understand the information it provides. The system should comply with all relevant laws and regulations, such as those related to privacy, data protection, and safety.

4.2.2.3 OPERATIONAL REQUIREMENTS

Real-time performance: The system should perform in real-time to provide timely feedback to drivers and parking lot operators. Real-time performance will require the system to process data quickly and efficiently.

Scalability: The system should be scalable to accommodate a large number of parking spots. The number of parking spots will depend on the size of the parking lot, but the system should be designed to accommodate an increasing number of parking spots as required.

Compatibility: The system should be compatible with different types of vehicles, such as cars, trucks, and motorcycles. It should also be designed to work with different parking lot layouts and configurations.

User-friendly: The system should be user-friendly and easy to use for drivers and parking lot operators. The user interface should be intuitive, and the system should provide clear and concise feedback to users.

4.2.3 SYSTEM REQUIREMENTS

The hardware and software required for the project to run.

4.2.3.1 HARDWARE REQUIREMENTS

Raspberry Pi, DWM1001-DEV (6 units)
Out of the 6 DWM1001's used there are 3 anchors, 2 tags and 1 listener.

4.2.3.2 SOFTWARE REQUIREMENTS

Java for Android app, Python for interaction with sensors and data, Redis for database

5. RESULTS AND DISCUSSION

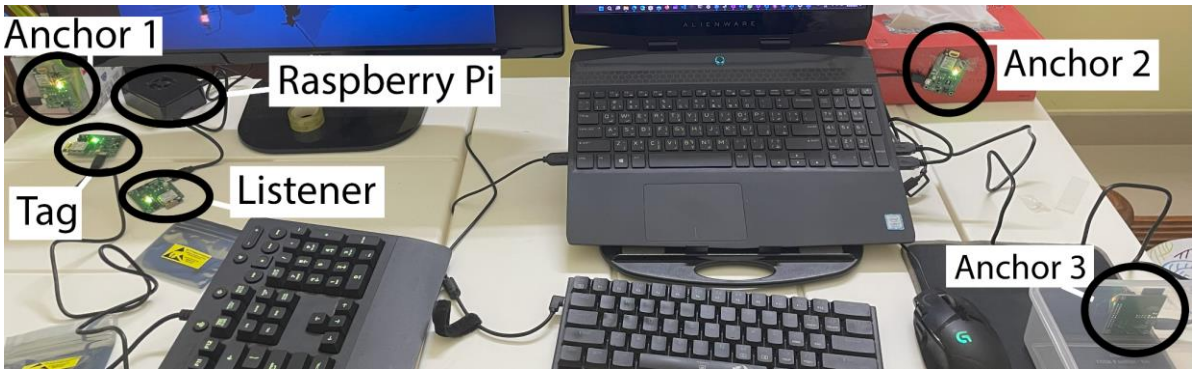

Fig 2 Setup

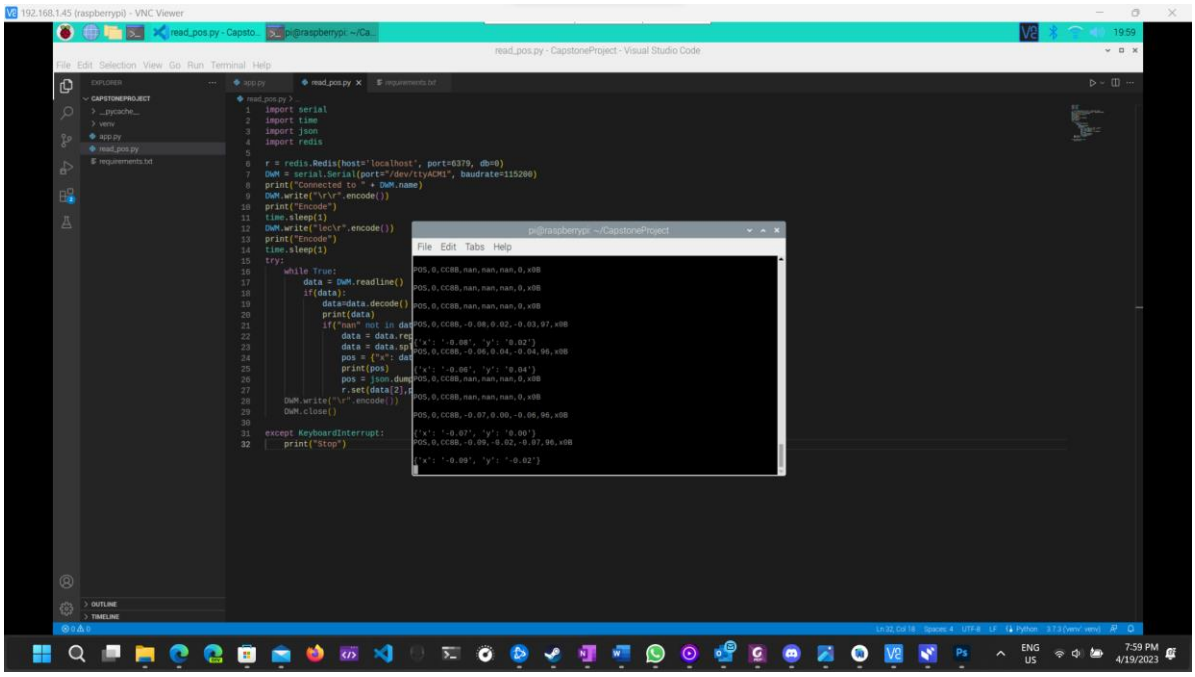

Fig 3 Raspberry Pi Receiving Tag Location

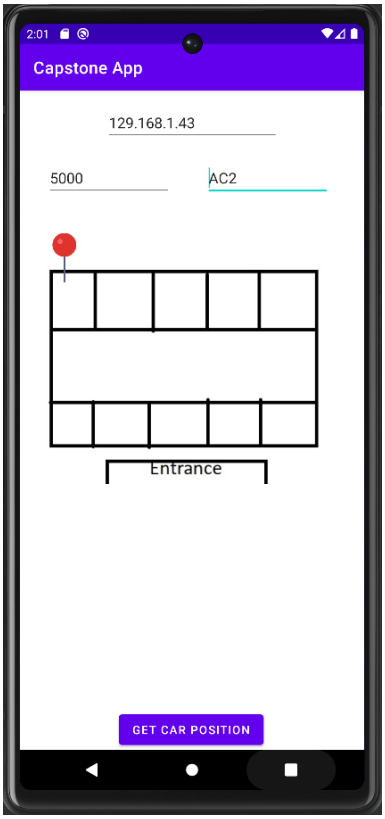

Fig 4 Android App

We conducted a successful experiment to test our system consisting of three anchors and a listener connected to a Raspberry Pi. The tag was placed next to Anchor 1 to simulate a parked vehicle. The Raspberry Pi constantly received data from the listener and stored it in the Redis database. We developed a Flask application to handle requests from the Android app, which asked the user for their tag ID and displayed the location of their parked vehicle.

Our system demonstrated modularity and scalability, as it can accommodate many tags and is easy to update with new anchors when the parking lot expands. The use of unique IDs for tags ensures user privacy, as the tags only work within the network and cannot identify the type of vehicle.

When compared with existing technologies [7], UWB comes with its own features. RFIDs are not preferred nowadays as criminals could easily tap onto the signal and manipulate the parking system; this could lead to a loss of net profit for parking spaces. Moreover, criminals could use this opportunity to gain access to other vehicles stored in these spaces.

BLE could be manipulated by signal jamming or be subjected to main in the middle attacks. A true key could get spoofed, and the resulting fake key created could easily help a hacker gain access to private parking spaces free of cost. Coming to UWB, which is based on time and not signal strength, can't be subjected to such attacks mentioned above as UWB performs calculations on distance close to centimeter level of precision as it consumes signals coming

from multiple antennas.

Nowadays many handheld devices come with UWB support thus helping cost controlling in our project. This comes very handy to use as the project uses UWB as the main proposed solution. UWB provides extremely accurate and precise location information, making it ideal for parking spot identification. It offers centimeter-level accuracy, which is superior to other technologies like IR, ultrasonic, and Wi-Fi, which typically have lower positioning accuracy. UWB has a relatively longer range compared to technologies like BLE and RFID. It can cover larger parking areas and multi-level structures effectively. This makes it suitable for various parking environments, both indoor and outdoor. UWB operates using a wide range of frequencies and has high immunity to interference from other wireless signals. It can coexist with Wi-Fi, BLE, and other wireless technologies without significant performance degradation. In contrast, technologies like IR, ultrasonic, and RFID may be more susceptible to interference, leading to reduced accuracy and reliability. While the choice of technology ultimately depends on specific requirements and constraints, UWB's accuracy, range, resistance to interference, versatility, privacy, scalability, and power efficiency make it a compelling option for enhancing parking spot identification and management compared to IR, ultrasonic, Wi-Fi, BLE, and RFID technologies.

For comparison against a modern system, let's take an SPS based on AI and image processing were designed where the system deploys ultrasonic sensors for parking lot occupancy detection and uses cameras for number plate recognition which is used for billing and vehicle security. UWB technology offers advantages in terms of accuracy, simplicity, privacy, scalability, and suitability for various parking environments compared to this as UWB technology provides highly accurate and reliable location information. It uses radio waves to transmit data, allowing for precise positioning of vehicles within the parking lot. In contrast, an SPS relying on AI and image processing may encounter challenges with accuracy, especially in complex parking environments or adverse weather conditions that can affect camera performance. UWB requires minimal infrastructure setup. The system typically consists of UWB tags and anchors, making it easier to install and maintain compared to the deployment of multiple ultrasonic sensors and cameras. This simplicity can reduce costs and installation complexity for parking lot owners. UWB offers inherent privacy benefits as it relies on unique identifiers (tags) that are only recognized within the UWB network. This ensures that personal information, such as vehicle number plates, is not exposed to external systems or potential security breaches. In contrast, an SPS using cameras for number plate

recognition may raise privacy concerns, as the system captures and processes sensitive information. UWB can be easily scaled to accommodate varying parking lot sizes and configurations. Additional tags and anchors can be added without significant adjustments to the system infrastructure. In contrast, expanding an SPS based on AI and image processing may require additional cameras and sensors, leading to increased complexity and cost. UWB performs well in both indoor and outdoor parking environments, providing accurate location information regardless of the parking lot's physical characteristics. This versatility makes it suitable for various parking scenarios, including multi-level garages, underground parking lots, and open-air parking spaces. An SPS relying on cameras may face limitations in certain lighting conditions or enclosed spaces.

Many commercial and residential spaces make use of external third-party services offered by companies that use high end systems that have a subscription-based plan that provides parking solutions to their customers based on their immediate preferences like data handling or least time-based parking spot identification.

Overall, our experiment validated the functionality and efficiency of our system, providing a promising solution for enhancing parking spot identification accuracy using UWB technology. Future work could focus on improving the reliability of the system and exploring additional features, such as real-time parking availability and reservation systems.

6. REFERENCES

[1] Ruiz, Antonio Ramón Jiménez, and Fernando Seco Granja. "Comparing ubisense, bespoon, and decawave uwb location systems: Indoor performance analysis." *IEEE Transactions on instrumentation and Measurement* 66.8 (2017): 2106-2117.

[2] Ramonet, Alberto Gallegos, and Taku Noguchi. "IEEE 802.15. 4 historical evolution and trends." *2019 21st International Conference on Advanced Communication Technology (ICACT)*. IEEE, 2019.

[3] Sedlacek, Petr, Martin Slanina, and Pavel Masek. "An overview of the IEEE 802.15. 4z standard its comparison and to the existing UWB standards." *2019 29th International Conference Radioelektronika (RADIOELEKTRONIKA)*. IEEE, 2019.

[4] Coppens, Dieter, et al. "An overview of uwb standards and organizations (ieee 802.15. 4, fira, apple): Interoperability aspects and future research directions." *IEEE Access* (2022).

[5] Brodin Kont, August. "Positioning and parking analysis for an indoor positioning system: A comparative study between Bluetooth Low Energy and Ultra Wideband technology." (2019).

[6] Amol Pomaji, Suraj Boinwad, Shrikant Wankhede, Pushpendra Singh, Bhagyashree Dhakulkar, “Smart Parking Management System”, International Journal of Computer Sciences and Engineering, May 2019, Vol.-7, Issue-5

[7] Abrar Fahim, Mehedi Hasan, Muhtasim Alam Chowdhury, “Smart parking systems: comprehensive review based on various aspects”, Department of Electrical and Computer Engineering, North South University, Dhaka, Department of Electrical and Electronic Engineering, University of Science and Technology Chittagong, 2021

[8] Glenn Phillip Surpris, Embry-Riddle Aeronautical University - Daytona Beach, “Evaluating the Effect of Smart Parking Technology on Campus Parking System Efficiency using Discrete Event Simulation”, 2012

[9] Wael Alsafery, Badraddin Alturki, Stephan Reiff-Marganiec, Kamal Jambi, “Smart Car Parking System Solution for the Internet of Things in Smart Cities”, United Kingdom, ICCAIS, 2018

[10] Mohd Mustari Syafiq Ismail, Muzammil Jusoh, Thennarasan Sabapathy, Mohamed Nasrun Osman, Hasliza Abdul Rahim, Mohd Najib Mohd Yasin, Ainur Fasihah Mohd Fazilah, “IoT Based Smart Parking System”, 2nd International Conference on Advance & Scientific Innovation, 2019

[11] DWM1001-DEV – Qorvo. https://www.qorvo.com/products/p/DWM1001-DEV

[12] Flask Documentation https://flask.palletsprojects.com/en/2.2.x/quickstart/

[13] redis-py dev Documentation https://redis.readthedocs.io/en/stable/genindex.html

[14] pySerial's Documentation https://pythonhosted.org/pyserial/