Real Time Location System (RTLS) using UWB

A Project Report Submitted

in Partial Fulfilment of the Requirements

for the Degree of

Bachelor of Technology

in

Computer Science and Engineering

by

Beerelly Srinitha

(Roll No. CS20B1004)

ಭಾರತೀಯ ಮಾಹಿತಿ ತಂತ್ರಜ್ಞಾನ ಸಂಸ್ಥೆ ರಾಯಚೂರು

भारतीय सूचना प्रौद्योगिकी संस्थान रायचूर

Indian Institute of Information Technology Raichur

to

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

INDIAN INSTITUTE OF INFORMATION TECHNOLOGY RAICHUR-584135, INDIA

May 2024

DECLARATION

I, **Beerelly Srinitha** (**Roll No: CS20B1004**), hereby declare that, this report entitled **Real Time Location System (RTLS) using UWB** submitted to Indian Institute of Information Technology Raichur towards partial requirement of **Bachelor of Technology(Hon)** in **Computer Science and Engineering** is an original work carried out by me under the supervision of **Dr. Suresh Chavhan** and has not formed the basis for the award of any degree or diploma, in this or any other institution or university. I have sincerely tried to uphold the academic ethics and honesty. Whenever an external information or statement or result is used then, that have been duly acknowledged and cited.

Raichur-584135 **Beerelly Srinitha**

May 2024

CERTIFICATE

This is to certify that the work contained in this project report entitled **"Real Time Location System (RTLS) using UWB"** submitted by **Beerelly Srinitha** (**Roll No: CS20B1004**) to the Indian Institute of Information Technology Raichur towards partial requirement of **Bachelor of Technology(Hon)** in **IIIT Raichur** has been carried out by her under my supervision and that it has not been submitted elsewhere for the award of any degree.

Raichur-584135 **Dr. Suresh Chavhan**

May 2024 Project Supervisor

ABSTRACT

The project aims to develop a Real-Time Locating System (RTLS) using Ultra-Wideband (UWB) technology to address the increasing demand for accurate, efficient and precise real-time tracking systems in various industries. High location precision is the goal of the RTLS, with a target range of 30 centimetres. This is crucial for applications such as parking management, staff monitoring, and asset tracking. The sophisticated features of UWB technology provide enhanced spatial resolution and decreased signal interference, guaranteeing accuracy and dependability when tracking objects and people in small areas. This precision is essential for cutting operational costs in a variety of industries, streamlining workflow procedures, and improving inventory management. Asset management will be completely transformed by integrating this cutting-edge tracking technology into current infrastructures and delivering actionable insights via real-time data analytics. This all-inclusive solution would be beneficial.

Contents

List of Figures viii

List of Tables x

1 Introduction 1

2 Related Works 5

3 Ultra-wideband 8

4 Techniques and Algorithms 10

4.1 Localization Techniques 10

4.1.1 TOF - Using Two-way time-of-arrival (TW-TOA) . . . 10

4.1.2 Time-difference-of-arrival (TDOA) 11

4.2 Position Calculation Algorithms 13

4.2.1 Trilateration 13

4.2.2 Triangulation 15

5 Origin Of the Problem 17

5.1 Motivation Behind 17

5.2 Problem Statement 17
5.3 Use cases for this Solution 18

6 Research Plan **19**
6.1 Plan 19
6.1.1 Localization Simulation 20
6.1.2 LOS and NLOS Scenarios 20
6.1.3 Importance of Number of Anchors 20
6.1.4 Anchor Position Recommendation System 20
6.1.5 LSTM Prediction 21
6.2 Target Outcomes 21
6.2.1 High Position Accuracy 21
6.2.2 Improved Operational Efficiency 21
6.2.3 Real-Time Tracking 21

7 Proposed Architecture **22**

8 Proposed Solution **24**
8.1 Proposed Methodology 24
8.1.1 Detecting 24
8.1.2 Locating 24
8.1.3 Tracking 25
8.1.4 Data Analysis and Predicting 25
8.2 Proposed Algorithm 27

9 Simulations and Results **29**
9.1 Localization Simulation 29

9.1.1 Static Case 32
9.1.2 Dynamic Case 34
9.2 LOS and NLOS Scenarios 36
9.3 Importance of Number of Anchors 38
9.4 Anchor Position Recommendation System 41
9.5 LSTM Simulations 44

10 Case Study of the proposed methodology 46

10.1 Detecting 46
10.2 Locating 47
10.3 Tracking and Predicting 48

11 Conclusion 50

Bibliography 51

List of Figures

4.1 ToF For Localization 11
4.2 TDOA For Localization 12
4.3 Intersection Of Circles 13
4.4 Trilateration 14
4.5 Triangulation 15

7.1 Proposed Architecture 23

8.1 Proposed Methodology 26

9.1 Simulation Scenario 31
9.2 Localization of the tag in static case using UWB 32
9.3 Zoomed in Version of Fig 10.2 33
9.4 Dynamic case at the Start 34
9.5 Dynamic case at the end 35
9.6 Line Of Sight Scenario 36
9.7 Non Line Of Sight Scenario 37
9.8 Results for LOS Scenario 37
9.9 Results for NLOS Scenario 38

9.10 LOS Scenario with one anchor 39
9.11 LOS Scenario with two anchors 40
9.12 Results for LOS scenario with one anchor 40
9.13 Results for LOS scenario with two anchors 41
9.14 Tag Positions which are randomly generated 42
9.15 Floor Map with Tags and Anchors Positioned 43
9.16 Predicted Anchor Positions 43
9.17 Trajectory Prediction Using LSTM Model 44
9.18 Accuracy vs Number of Steps 45

10.1 Detecting 47
10.2 Locating 48
10.3 Tracking and Predicting 49

List of Tables

2.1 Summary of Existing Works 6
2.2 Works focused in this paper 7

3.1 Features of UWB 9

9.1 Simulation Parameters 30

Chapter 1

Introduction

In response to the growing demand for precise and efficient tracking of both things and people in restricted spaces, the Real-Time Location System (RTLS) emerges as a formidable solution, using the capabilities of Ultra-Wideband (UWB) technology. Unlike traditional tracking systems[1], which frequently fall short in precision, UWB technology provides a cutting-edge method. It operates within a certain frequency range, typically from 3.1 to 10.6 GHz, and uses a wide bandwidth to achieve outstanding positional accuracy[4].

The capacity of UWB to transfer data across a broad spectrum gives it a distinct edge[3] and allows the system to record fine-grained spatial information. Because of this feature, the RTLS can achieve impressive precision within a 30-centimeter range while maintaining great position accuracy[2]. Furthermore, UWB's capacity to withstand interference[6] makes it even more suitable for important uses like asset tracking, employee monitoring, and parking solutions. The technical capabilities of UWB go beyond its bandwidth and frequency range and include its ability to withstand interference from signals. UWB systems reduce the possibility of interference with nearby other wireless technologies by using low-power density and short-duration pulses. Because of this, UWB is especially skilled at providing accurate and dependable location data in difficult settings, guaranteeing a solid solution for a range of sectors.

With more industries realizing the importance of sophisticated tracking capabilities, the UWB-powered RTLS stands out as a complete solution offering unmatched precision for a wide range of applications. This project intends to transform asset tracking and management in dynamic and limited contexts by streamlining office operations, hotels, retail, and parking management, optimizing manufacturing processes, and improving healthcare logistics. Because of its special properties, ultra-wideband (UWB) technology is generally resistant to jamming. Ultra-short pulses are transmitted over a broad frequency range by UWB to function. The low power density and wide frequency range of UWB signals make it difficult for conventional narrowband jamming techniques to effectively interfere with UWB communication.

Localization simulation serves as a crucial tool in understanding and optimizing the performance of localization systems in various scenarios. By mimicking real-world conditions, these simulations provide invaluable insights into the accuracy, reliability, and robustness of localization algorithms. In this research, we delve into the intricacies of localization simulation, exploring both static and dynamic cases to assess system performance across different environmental conditions and user movements. Indoor localization has emerged as a pivotal technology with diverse applications ranging from asset tracking in industrial settings to enhancing user experience in smart buildings. With the advent of ultra-wideband (UWB) technology and advanced algorithms, real-time locating systems (RTLS) have become increasingly sophisticated, enabling accurate positioning even in complex indoor environments.

This paper delves into a comprehensive exploration of various facets of indoor localization, employing state-of-the-art methodologies and simulations. Among the key focal points are the significance of anchor density, the distinction between line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios, and the development of an anchor position recommendation system to optimize localization accuracy. Anchors serve as pivotal reference points in RTLS, influencing the precision and reliability of localization algorithms. Through meticulous analysis, this paper elucidates the nuanced relationship between the number of anchors deployed and the efficacy of indoor positioning systems. Moreover, the distinction between LOS and NLOS environments poses distinct challenges to indoor localization algorithms. By scrutinizing both scenarios, this paper offers insights into the robustness and adaptability of UWB-based localization methods in real-world conditions.

Furthermore, the paper explores the utilization of long short-term memory (LSTM) networks for path trajectory predictions, leveraging historical data to anticipate future movement patterns accurately. Such predictive capabilities hold immense potential in various applications, including indoor navigation and crowd management. Additionally, virtual simulations are pivotal in evaluating and refining indoor localization algorithms. By replicating diverse environmental conditions and user behaviours, these simulations enable researchers to validate the efficacy of proposed methodologies in a controlled yet realistic setting. In summary, this paper presents a holistic examination of indoor localization, encompassing theoretical analyses, simulation-based validations, and practical recommendations. By elucidating the importance of anchor density, navigating LOS and NLOS scenarios, and harnessing advanced techniques like LSTM for trajectory prediction, it contributes to the ongoing evolution of indoor positioning systems, fostering enhanced accuracy, reliability, and usability in diverse real-world applications.

Chapter 2

Related Works

Enough attention has been paid to outdoor/indoor localization using UWB technology in recent years. In wireless networks, there are numerous techniques for localization [1]. Increased interest has been shown in the TDoA-based positioning technique.

The focus of [2] is on TDoA-based WCS methods applied in RTLS, which rely on packet pairs and a recorded timestamp. In the meantime, the authors in [3] suggest a synchronization technique for the unilateral TDoA that works well for ultra-wideband (UWB) localization systems. The authors used DWM1000[4] to execute a UWB-based project. To lower the deployment cost, the authors of [5] outline the architecture of a multi-level Internet of Things positioning system. The authors of [6] examine various clock-drift correction techniques for ToA and TDoA, with special attention to the DW1000 transceiver.

The authors of [7] proposed a TDOA-based method for geolocating and tracking an unknown number of multiple emitters in the presence of clutter returns and missed detections. The authors in [8] introduced a hybrid location technique that incorporates ToA and received signal strength (RSSI) measurements. The authors of [9] introduce a best linear unbiased estimator (BLUE) technique based on ultrasonic TDoA data and examine geometrical dilution of precision (GDOP). The authors of [10] create an algorithm framework that incorporates EKF, UKF, and PF.

The above-mentioned positioning methods are algorithmic and do not take into account the interactions between hardware, software, localization system, and anchor deployment. The RTLS provided in this paper focuses on various factors like the importance of the number of anchors, the LOS and NLOS environments, anchor position recommendations, virtual simulations for UWB-based indoor localization methods, path trajectory predictions and many other outcomes.

Table 2.1: Summary of Existing Works

Reference	**Focus**	**Methodology/Technique**
[1]	Outdoor/indoor localization using UWB	Various localization techniques in wireless networks
[2]	TDoA-based WCS methods in RTLS	Packet pairs and timestamp-based TDoA
[3]	Synchronization technique for TDoA	Unilateral TDoA synchronization for UWB systems
[4]	UWB-based project using DWM1000	Implementation of UWB technology for localization
[5]	Multi-level IoT positioning system architecture	Lowering deployment cost of IoT positioning systems
[6]	Clock-drift correction techniques for ToA and TDoA	Correction methods for DW1000 transceiver
[7]	TDoA-based method for geolocation and tracking	Multi-emitter tracking in cluttered environments
[8]	Hybrid location technique	Integration of ToA and RSSI measurements for localization
[9]	BLUE technique based on ultrasonic TDoA data	Estimation technique considering GDOP
[10]	Algorithm framework incorporating EKF, UKF, and PF	Fusion of different estimation algorithms

Table 2.2: Works focused in this paper

Focused Works	
Aspect	Description
Comprehensive Approach	Considers hardware, software, and anchor deployment interactions
Virtual Simulations for UWB-based Localization	Utilizes simulations to evaluate and refine localization algorithms
Anchor Density Importance	Investigates the impact of the number of anchors on localization accuracy
LOS and NLOS Environments	Addresses challenges and strategies for LOS and NLOS scenarios
Anchor Position Recommendations	Recommends optimal placement of anchors for improved localization
Path Trajectory Predictions using LSTM	Predicts movement patterns for enhanced navigation and crowd management

Chapter 3

Ultra-wideband

Ultra-wideband is a short-range wireless communication protocol. It uses radio waves to enable devices to talk to each other. As the name suggests, it also uses a wider frequency. The frequency range of the UWB is between 3.1 and 10.6 GHz. There is one drawback which is its short range, but that doesn't matter much when you have more devices that are in a room together.

UWB technology represents a cutting-edge solution with a broad spectrum of features tailored for diverse applications. The features of UWB are shown in the table 9.1. Operating within an impressive bandwidth of 500 MHz, UWB ensures robust data transmission capabilities. Its data rates ranging from 7 to 27 megabits per second empower efficient communication across various platforms. Spanning the frequency range of 3.1 to 10.6 GHz, UWB offers reliable connectivity in different environments, making it a versatile choice for modern wireless communication needs. Moreover, its low power consumption ensures extended battery life, making it particularly suitable for battery-operated devices.

Table 3.1: Features of UWB

Features	
Bandwidth	500 MHz
Data rate	7 to 27 megabits per second
Frequency range	3.1 and 10.6 GHz
Battery	Low consumption
Range	up to 200 meters (656 feet) based on the IEEE 802.15.4a standard (200 for ESP32 UWB PRO)
Accuracy	10 centimeters (3.9 inches)
Cost	2000 to 5000 INR
Best For	Proximity Marketing, Customer Analytics, Indoor Navigation, Smart Homes, Factory Automation, Asset-Tracking, Logistics

In addition to its technical prowess, UWB boasts an impressive range of up to 200 meters, as per the IEEE 802.15.4a standard, or 200 meters for ESP32 UWB PRO, facilitating connectivity over substantial distances. With a remarkable accuracy of 10 centimetres, UWB enables precise location tracking and positioning, crucial for various applications requiring spatial awareness. Furthermore, UWB presents a cost-effective solution, with prices ranging from 2000 to 5000 INR, making it accessible to a wide range of users. Its adaptability shines through in its suitability for proximity marketing, customer analytics, indoor navigation, smart homes, factory automation, asset tracking, and logistics, solidifying its position as a key player in the realm of wireless technologies.

Chapter 4

Techniques and Algorithms

4.1 Localization Techniques

4.1.1 TOF - Using Two-way time-of-arrival (TW-TOA)

TOF is a positioning method based on two-way ranging. That means the tag needs to send and receive signals from the anchor several times and then the flight time of the signal between the anchor and the tag can be measured, as radio waves travel at the speed of light, we can calculate the distance between the tag and each anchor. With the TOF method, the UWB tag should complete the ranging with each anchor.

For example, as shown in Fig.4.1 where there is one tag and three anchors, AP1, AP2 and AP3 refer to three anchors respectively. When the ranging between Tag and three anchors is finished, there will be three corresponding distance values d1 d3. With each anchor as the centre of the circle, the intersection of three circles at one point is the location of the Tag. In the

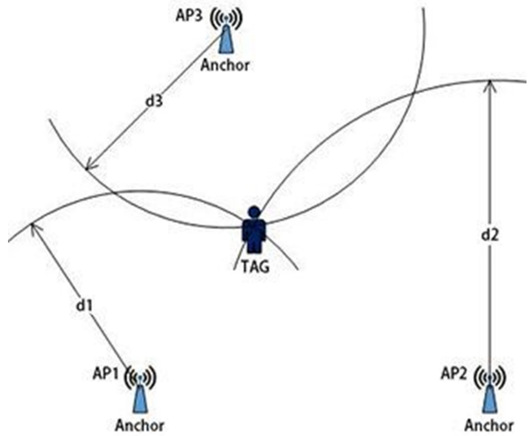


Figure 4.1: ToF For Localization

one-dimensional mode, if we have two anchors to range and then we can get the tag's location. For the two-dimensional mode, three anchors can be needed and if you want to get the X, Y and Z coordinates of the tag, four anchors are required.

4.1.2 Time-difference-of-arrival (TDOA)

TDOA is localization based on comparing the time difference between signals and each anchor and this technique requires an accurate time synchronization function. When using the TDOA method, the UWB tag will send out a poll message and all the nearby UWB anchors will receive it and record the arrival time. Because the location of anchors is different, so anchors won't receive the message at the same time. We can use these time differences to determine the tag's location.

The key point of this method is to keep all anchors in sync. There are two kinds of time synchronization including wired and wireless methods. The

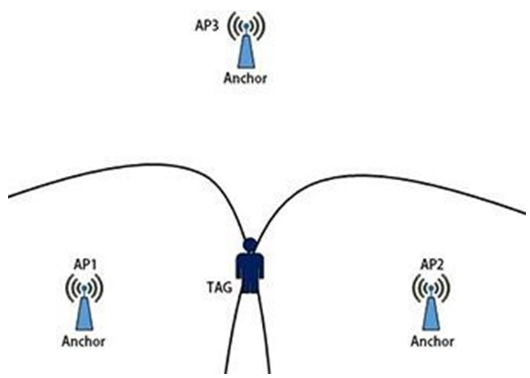


Figure 4.2: TDOA For Localization

former synchronization accuracy is higher, but the network maintenance is complex because of the wired connection. Another is wireless synchronization, the accuracy is a little less than the wired time synchronization, but the system is simple because the data can be transmitted by WiFi and will greatly reduce total costs. When finishing the time synchronization, The tag sends a broadcast message, and all the anchors will send the timestamp of receiving this message to the server, and the server will calculate the location of the tag.

As shown in the Fig.4.2 let us take that there are three anchors and one tag, AP1, AP2 and AP3 refer to three anchors. When the tag completes communication with three anchors, there will be three corresponding different arrival times (T1, T2 and T3) and then we calculate the distance difference between the signal source and each anchor. Since the distance difference between the tag and AP1, AP2 is a constant, we can draw a hyperbola. In any two groups of anchors, the intersection of two hyperbola points is the location of Tag.

4.2 Position Calculation Algorithms

4.2.1 Trilateration

Trilateration is a technique used to determine the position of an object by measuring the distances to three known points. Trilateration is a popular algorithm for positioning systems. For instance, GPS systems today use trilateration to convert distance measurements of satellite positions to coordinates of the object. Assuming two anchor points, A1 and A2, and the distances, d1 and d2, between the anchors and the position of the object A position, P, can be determined using 2D-trilateration. For an easier solution, a 2D plane is defined with the line between two anchor points on the x-axis. The anchor points are defined to be separated by x on the axis. One solution to find the position, P, is to use Pythagoras' theorem. As shown in Fig.4.3 there exist two solutions for the Py coordinate. Where one will be the true solution and the other an ambiguous solution.

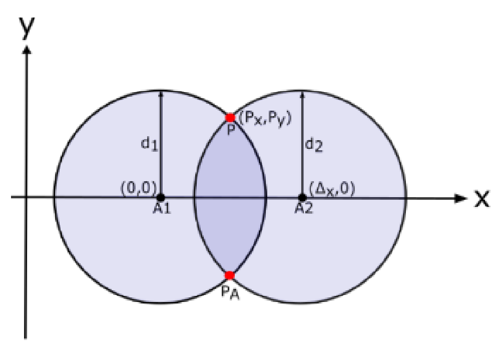


Figure 4.3: Intersection Of Circles

Both the true solution and the ambiguous solution can be seen by the intersections of the circles. The true solution is denoted by P and the ambiguous solution by PA. The anchor points are denoted by A1 and A2. The solutions in 3D space are found using Pythagoras' theorem similar to the solution in 2D space. The equations to find the position, P, are shown in the following equations. Here d1,d2, and d3 denote the distance between the anchors and the position of the object. The true solution is denoted by P as shown in Fig.4.4 and anchor points for the trilateration are denoted by A1, A2 and A3

$$P_x = \frac{d_1^2 - d_2^2 + \Delta_{2,x}^2}{2\Delta_{2,x}} \tag{4.1}$$

$$P_y = \frac{d_1^2 - d_3^2 + \Delta_{3,x}^2 + \Delta_{3,y}^2 - 2\Delta_{3,x}P_x}{2\Delta_{3,y}} \tag{4.2}$$

$$P_z = \pm\sqrt{d_1^2 - P_x^2 - P_y^2} \tag{4.3}$$

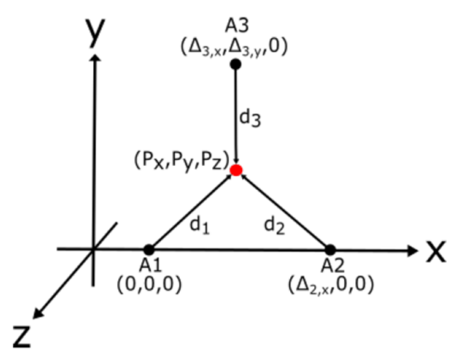


Figure 4.4: Trilateration

4.2.2 Triangulation

Triangulation is a method used to determine the position of an object by measuring angles from two known points. Instead of utilizing distances, as trilateration does, triangulation uses angles to position an object within an area. One of the advantages of using triangulation is that the orientation of the object can be determined in a client-based positioning system. While getting an orientation is an improvement, the geometry of triangulation is a complicated matter and can cause inconsistencies if not handled correctly. To reliably find the position of an object with triangulation, three anchor points are needed. The algorithm is based on that the location of the anchor points is known and the fixed angles between them can be determined. Let the cartesian coordinates be defined as (A1,x;A1,y;A2,x;A2,y;A3,x;A3,y) for anchor-points 1-3 respectively. The angles $\theta 31$ and $\theta 12$ are directly connected to the angles between the anchor points and the object. These are computed as shown in the following equations.

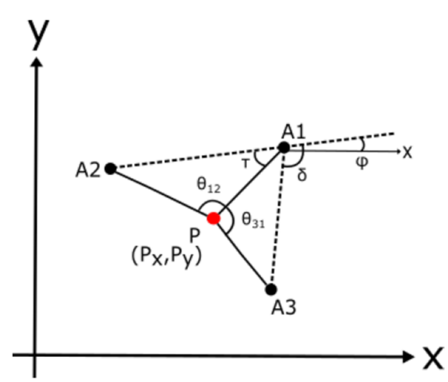


Figure 4.5: Triangulation

$$\theta_{31} = 360^\circ + \lambda_{A1} - \lambda_{A3} \tag{4.4}$$

$$\theta_{12} = \lambda_{A2} - \lambda_{A1} \tag{4.5}$$

$$\sigma = \delta - \theta_{31} \tag{4.6}$$

Let a and b are the Euclidean distances from anchor-point 2 to 1 and 3 to 1 respectively. Then τ is derived as shown. From these two equations, the Euclidean distance from the object to A1 can be computed and defined as d. With the definitions and derivations the position and orientation of the object can be found and derived where Px and Py denote the coordinates and the orientation of the object is labelled as Pθ. This method can compute the position and orientation reliably when the object is within the triangle formed by the three anchor points. When the object is on or outside of this triangle, the method can still give good results but does not work consistently.

$$p = \frac{a \sin(\theta_{12})}{b \cos(\theta_{31})} \tag{4.7}$$

$$\tau = \tan^{-1}\left(\frac{\sin(\theta_{12}) - p\sin(\sigma)}{p\sin(\sigma) - \sin(\theta_{12})}\right) \tag{4.8}$$

$$d = \frac{b \sin(\tau + \theta_{12})}{\sin(\theta_{12})} \tag{4.9}$$

$$P_x = A_{1,x} + d\cos(\phi + \tau) \tag{4.10}$$

$$P_y = A_{1,y} + d\sin(\phi + \tau) \tag{4.11}$$

$$P_\theta = \phi + \tau - \lambda_{A1} \tag{4.12}$$

Chapter 5

Origin Of the Problem

5.1 Motivation Behind

The need for a Real-Time Location System (RTLS) using Ultra-Wideband (UWB) technology arises from the growing demand for efficient and accurate tracking of objects and people within confined spaces. Traditional tracking systems may lack the precision required for applications such as asset tracking, employee monitoring, and parking solutions. The goal is to provide a solution that ensures high position accuracy (within a range of 30 centimeters) for various use cases, including warehouse management, manufacturing, healthcare, offices, hotels, retail, and parking management.

5.2 Problem Statement

To develop a Real-time locating system (RTLS), that can be used to automatically identify and track the location of objects or people in real-time, usually within a building or other contained area. Wireless RTLS tags can be attached to objects or worn by people, and in most RTLS, fixed reference points receive wireless signals from tags to determine their location using TDoA (Time Difference of Arrival) or Two Way Ranging. With key aspects such as positional Accuracy (range 30cms).

5.3 Use cases for this Solution

Asset tracking, Employee tracking in warehouses, Manufacturing, IT, Hospitals, Offices, Hotels, Retail Industries Parking solution to identify where the vehicle is parked or guide to available parking spots and so on...

Chapter 6

Research Plan

This research plan outlines the compo and target outcomes for the development of a UWB-based tracking system. By implementing advanced UWB transceivers, a robust data processing unit, and efficient power management, we aim to achieve high positioning accuracy, real-time tracking, improved operational efficiency, and reduced costs.

6.1 Plan

The primary objective is to explore various localization techniques through simulation and assess the effectiveness of an Anchor Position Recommendation System. The project also aims to investigate the performance of Long Short-Term Memory (LSTM) models in path trajectory prediction and also analyze the Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) scenarios and evaluate the impact of factors like the number of anchors on localization accuracy.

6.1.1 Localization Simulation

Reviewing various cases of localization simulations. Discussing the background of the simulation in evaluating localization techniques. Providing a framework for conducting simulation experiments. Analyzing the position accuracy and the error rates.

6.1.2 LOS and NLOS Scenarios

Defining Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) scenarios in localization. Designing experiments to simulate LOS and NLOS conditions. Comparing the performance of localization techniques in LOS vs. NLOS scenarios and discussing the implications of LOS and NLOS on localization accuracy.

6.1.3 Importance of Number of Anchors

Investigate the influence of the number of anchors on localization accuracy. Designing experiments varying the number of anchors in simulation scenarios. Analyze the results to determine the optimal number of anchors for different environments and to discuss practical implications and recommendations based on the findings.

6.1.4 Anchor Position Recommendation System

Introducing the concept of an Anchor Position Recommendation System for different floor types and various scenarios. Proposing algorithms or methods for determining optimal anchor positions. Conducting simulations to evaluate the effectiveness of the recommendation system.

6.1.5 LSTM Prediction

Evaluating the concept of LSTM models in path trajectory prediction of tags. Defining the parameters and architecture for LSTM simulations. Describing the methodology for training and testing LSTM models. Analyze the performance of LSTM model with the results obtained in the scenarios.

6.2 Target Outcomes

6.2.1 High Position Accuracy

Achieve positioning accuracy within a range of 30 centimetres to meet the specific requirements of the use cases.

6.2.2 Improved Operational Efficiency

Enhance asset tracking, employee monitoring, and parking management processes, improving operational efficiency.

6.2.3 Real-Time Tracking

Provide instantaneous location updates to support real-time decision-making in diverse industries.

Chapter 7

Proposed Architecture

The Fig.7.1 shows a UWB-based indoor positioning system. There are four anchors and two tags. The anchors are fixed to known locations, while the tags are attached to the objects or people to be tracked. The anchors measure the time of flight of the signals sent by the tags, and this information is used to calculate the location of the tags. Also, the collected information will be sent to a cloud-based LSTM network with the help of Wi-Fi Technology. The LSTM helps to predict the path trajectory. Now the whole data from the cloud can be accessed using user dashboards or mobile apps.

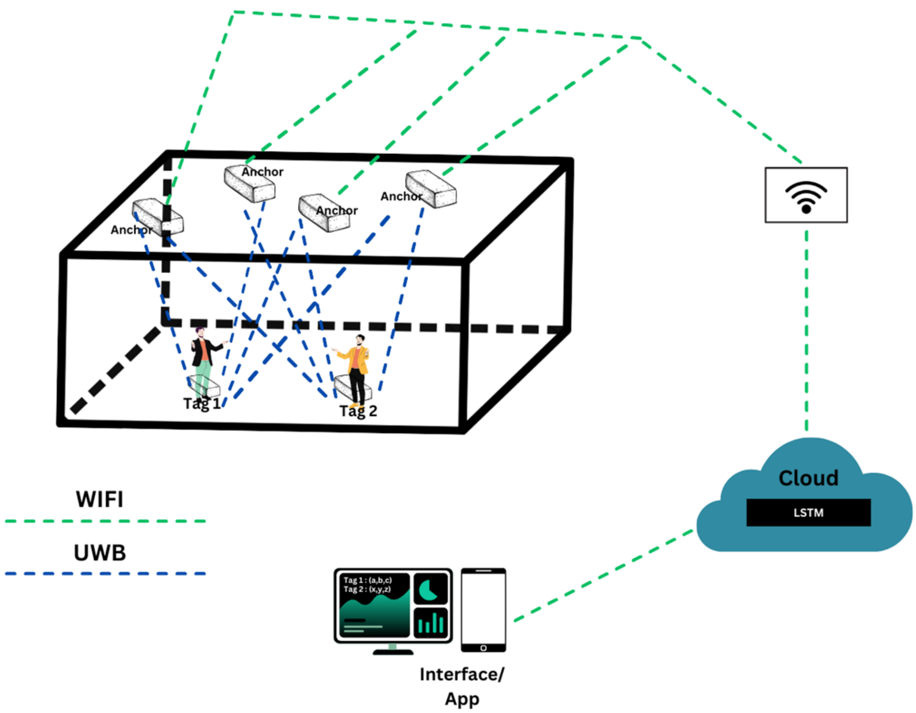


Figure 7.1: Proposed Architecture

Chapter 8

Proposed Solution

8.1 Proposed Methodology

8.1.1 Detecting

Using cellular communication or IEEE 802.11 p communication protocol for identifying the UWB devices attached in the communication range of 250 to 500 meters. It identifies the presence of an object within a given range.

8.1.2 Locating

Virtually deploying fixed anchors within the specified area to serve as reference points. UWB Technology implementation with static and dynamic tags and tracking them. It determines the exact position or location of the identified pedestrian/vehicle in a specific coordinate system. It involves specifying the spatial or geographical details.

- Time Difference of Arrival (TDoA): Implement TDoA methodology for calculating position accuracy by measuring the time delay of UWB signals between tags and anchors.

- Two-Way Ranging: Employ Two-Way Ranging techniques like ToF to enhance accuracy by measuring the round-trip time of UWB signals.

8.1.3 Tracking

Monitoring the movement or changes in the position of the detected and located pedestrian/vehicle over time. It focuses on maintaining continuous awareness of their trajectory using UWB.

8.1.4 Data Analysis and Predicting

Combine data from multiple anchors and sensors to improve accuracy and reliability, use that data for path predictions using models like LSTM ML model and then aggregate an optimal anchor recommendation system and also mitigate errors caused by signal reflections or interference. Forecasting the future state or behaviour of the pedestrian/vehicle based on its historical data and current trajectory This can be crucial for making informed decisions or taking pre-emptive actions.

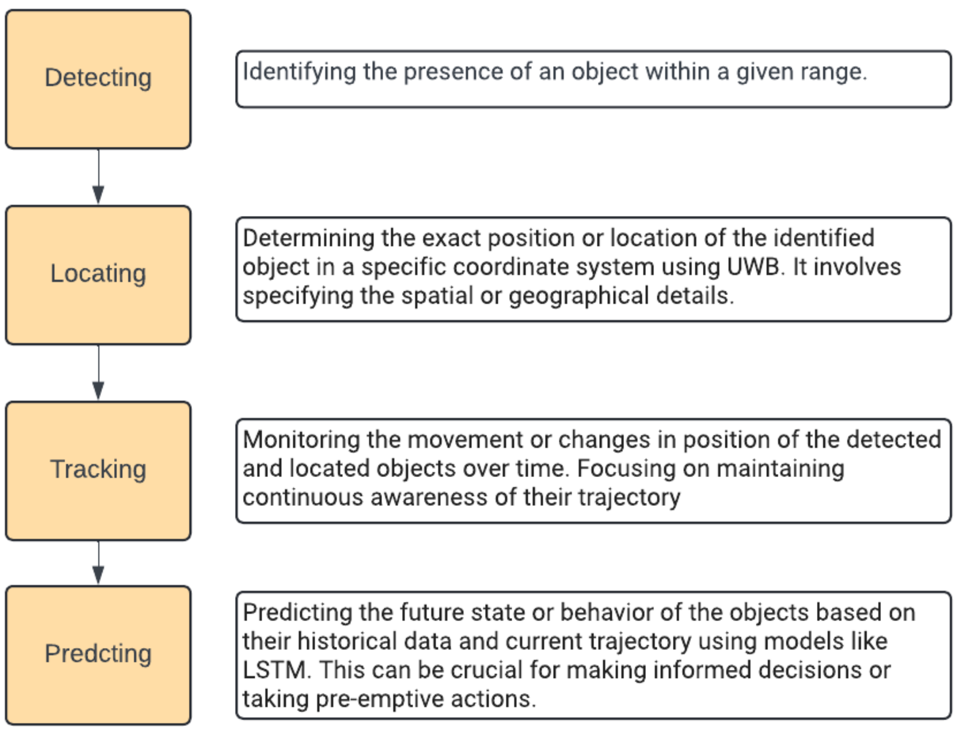


Figure 8.1: Proposed Methodology

8.2 Proposed Algorithm

The proposed algorithm presented here outlines a comprehensive approach for locating, tracking, and predicting the trajectory of objects within a specified environment. It is designed based on the structured architecture discussed above to address the challenges associated with real-time monitoring and prediction tasks. The Locating phase focuses on determining the initial position of the object. It continuously checks the distance between the tag (the object being tracked) and the anchor (reference point), triggering measurements when the distance falls below a predefined threshold. Ultra-wideband (UWB) signals are utilized for precise distance and time-of-flight (ToF) measurements. The algorithm then records the object's position based on these measurements. Once the object is located, the tracking phase stays in real-time.

Similar to the locating phase, it continuously checks the distance between the tag and the anchor. If within range, it updates the object's position using the latest measurements and continues tracking. If the object moves out of range, tracking is paused until it re-enters the designated area. Now in the predicting phase historical data collected from previous trajectories to train a Long Short-Term Memory (LSTM) model, a type of recurrent neural network (RNN), capable of learning temporal dependencies. The trained model is then used to predict the future trajectory of the object based on its current path. These predictions are utilized to make informed decisions, such as anticipating potential collisions or deviations from expected paths.

The proposed algorithm integrates the capabilities of UWB signal processing for accurate localization, real-time tracking mechanisms, and machine learning techniques for predictive analysis. By combining these components, the algorithm offers a holistic solution for dynamic object monitoring and prediction within constrained environments, such as warehouses, manufacturing facilities, or even outdoor spaces requiring precise tracking and forecasting capabilities.

Algorithm 1 Proposed Algorithm

```
procedure LOCATING
    while true do
        if distance(tag, anchor) < 200 meters then
            signal_strength, ToF ← measure_UWB_signals(tag, anchor)
            object_position ← locate_object(signal_strength, ToF)
            record_position(object_position)
        end if
    end while
end procedure
procedure TRACKING
    while true do
        if distance(tag, anchor) < 200 meters then
            object_position ← update_position(tag, anchor)
            track_object(object_position)
        else
            pause_tracking()
        end if
    end while
end procedure
procedure PREDICTING
    historical_data ← collect_historical_data()
    LSTM_model ← train_LSTM_model(historical_data)
    while true do
        cur_traj ← gather_current_trajectory()
        pred_traj ← predict_future_trajectory(LSTM_model, cur_traj)
        make_decision_based_on_prediction(pred_traj)
    end while
end procedure
```

Chapter 9

Simulations and Results

9.1 Localization Simulation

The virtual simulation of Ultra-Wideband (UWB) localization was conducted using MATLAB. The Time Difference of Arrival (TDOA) and Time of Flight (ToF) methods were employed for localization, leveraging the precise timing differences of signals received by multiple sensors.

Various scenarios were considered to evaluate the performance of the localization system under different conditions. These scenarios included varying distances between the transmitters and receivers, different signal-to-noise ratios (SNR), and diverse environmental factors such as mobility and interference. The MATLAB simulation involved generating synthetic UWB signals, simulating their propagation in the environment, and processing the received signals to estimate arrival time differences. These time differences were then used to compute the positions of the transmitters concerning the receivers using the algorithms. Through extensive simulation runs and analysis, the accuracy and robustness of the UWB localization system were evaluated, providing insights into its performance in real-world applications.

Table 9.1: Simulation Parameters

Parameters	**Value**
Tag Initial Location	[50 50]
Anchor 1 Location	[40 41]
Anchor 2 Location	[62 83]
Anchor 3 Location	[87 24]
Tag Velocity	[0.5, 0.2]
Simulation Area	100 x 100

Here in Fig.9.1, the Device is the Tag and the Synchronized nodes are the anchors.

This simulation scenario is only used to evaluate different cases of localization. We will now discuss two cases where in one the tag is fixed and in the other the tag is dynamic.

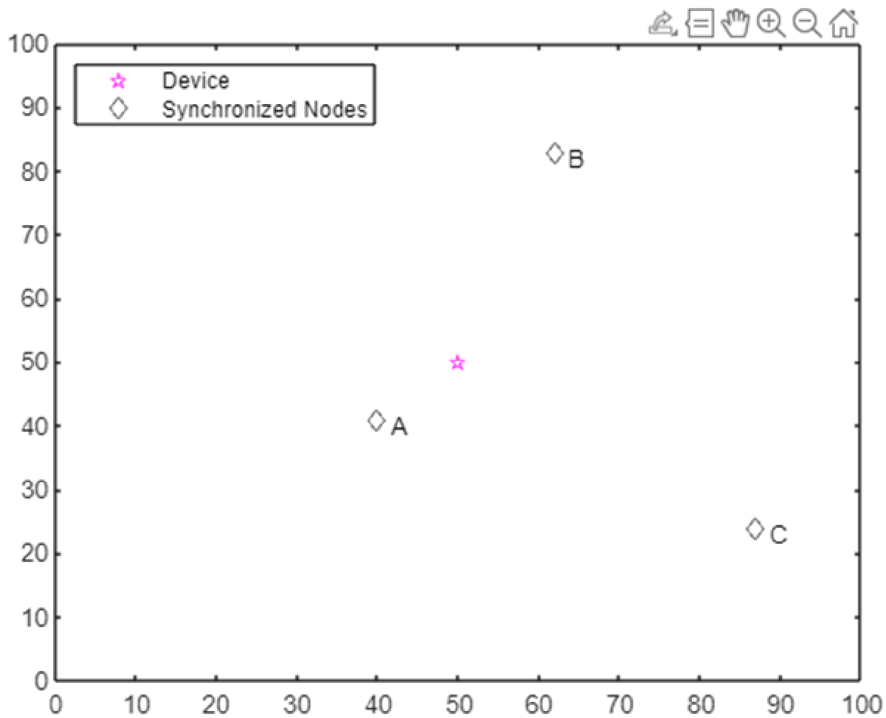


Figure 9.1: Simulation Scenario

9.1.1 Static Case

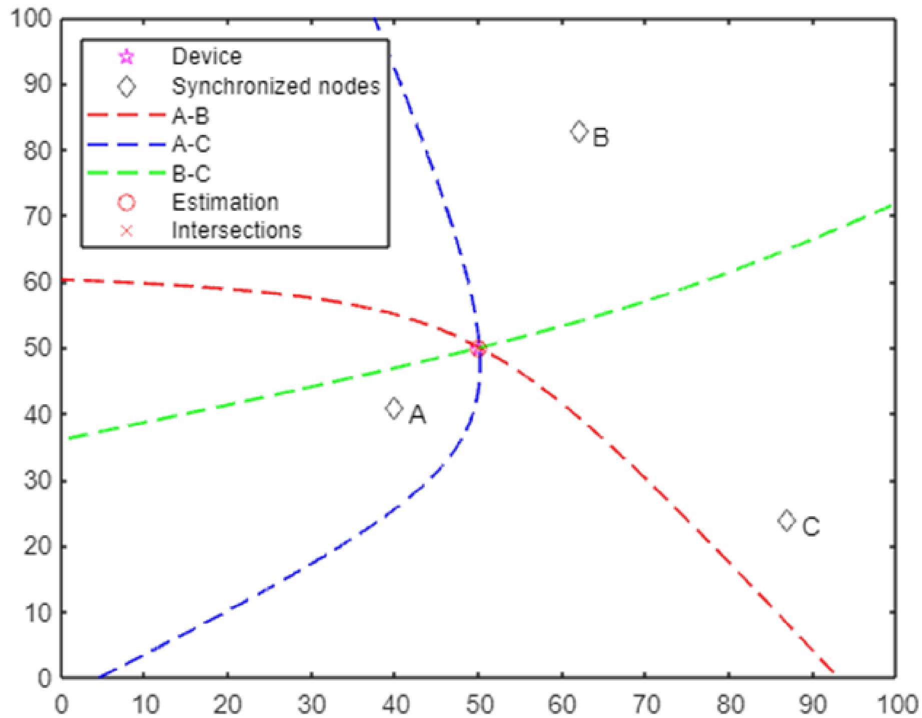


Figure 9.2: Localization of the tag in static case using UWB

In this case, both the anchors and tag are not moving and are fixed. Fig.9.2 shows the tag position as it is localized at the intersection of hyperbolas drawn using the anchors.

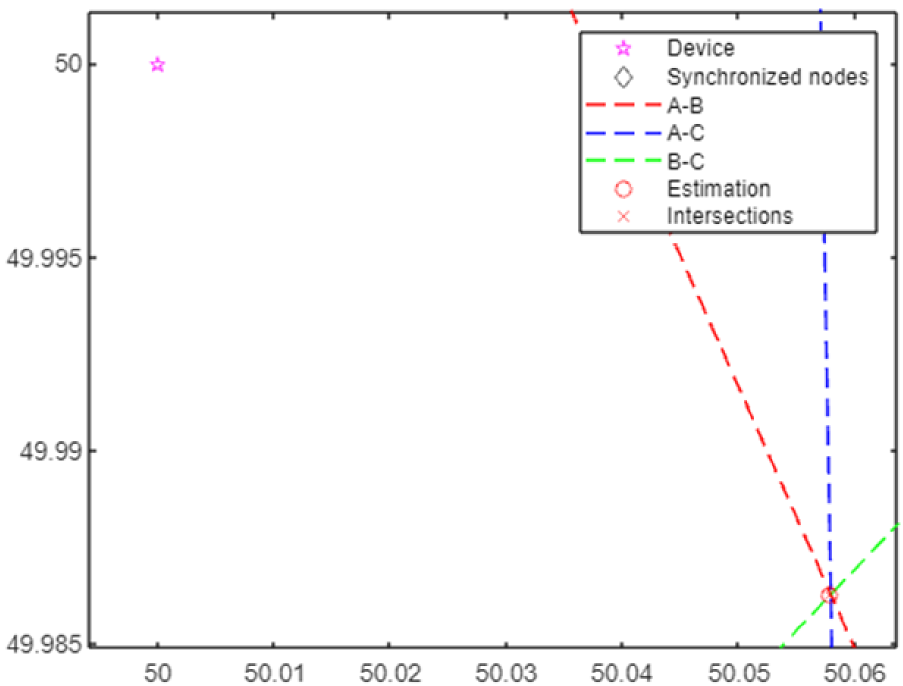


Figure 9.3: Zoomed in Version of Fig 10.2

Fig.9.3 shows the zoomed-in version of Fig.9.2, to know the coordinates predicted by the simulation exactly. This gives the predicted position of the tag.

9.1.2 Dynamic Case

In this case, the anchors remain static or fixed and the tag is moving which means the tag is mobile and changes from time to time. Fig.9.4 and Fig.9.5 show the tag positions as it moves which are localized at the intersection of hyperbolas drawn using the anchors at each step.

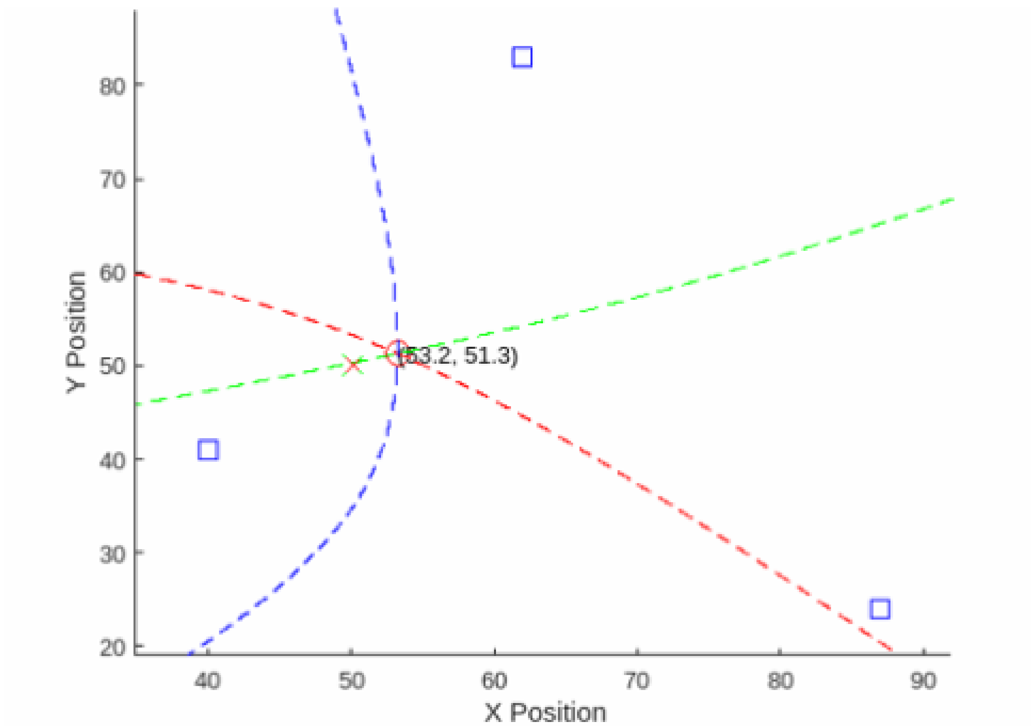


Figure 9.4: Dynamic case at the Start

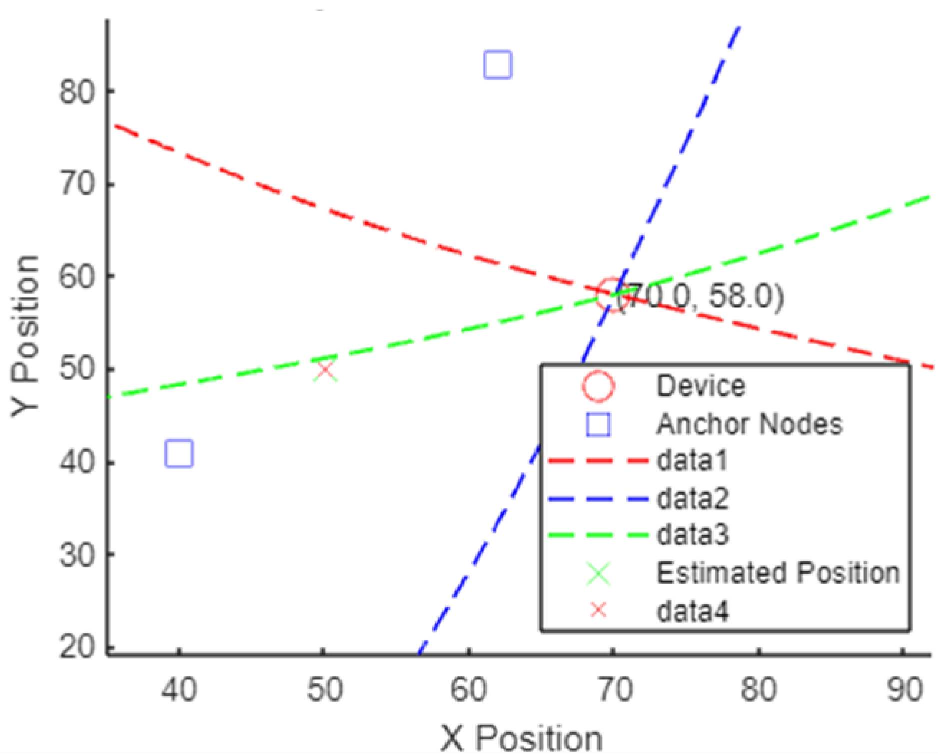


Figure 9.5: Dynamic case at the end

9.2 LOS and NLOS Scenarios

Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) scenarios and their impact in localization are discussed. Designed experiments to simulate LOS and NLOS conditions. Comparing the performance of localization techniques in LOS vs. NLOS scenarios we can observe that there is a little decrease in the accuracy but that does not have much impact much as UWB also supports penetration. Fig.9.6 refers to the LOS Scenario and Fig.9.7 refers to the NLOS Scenario.

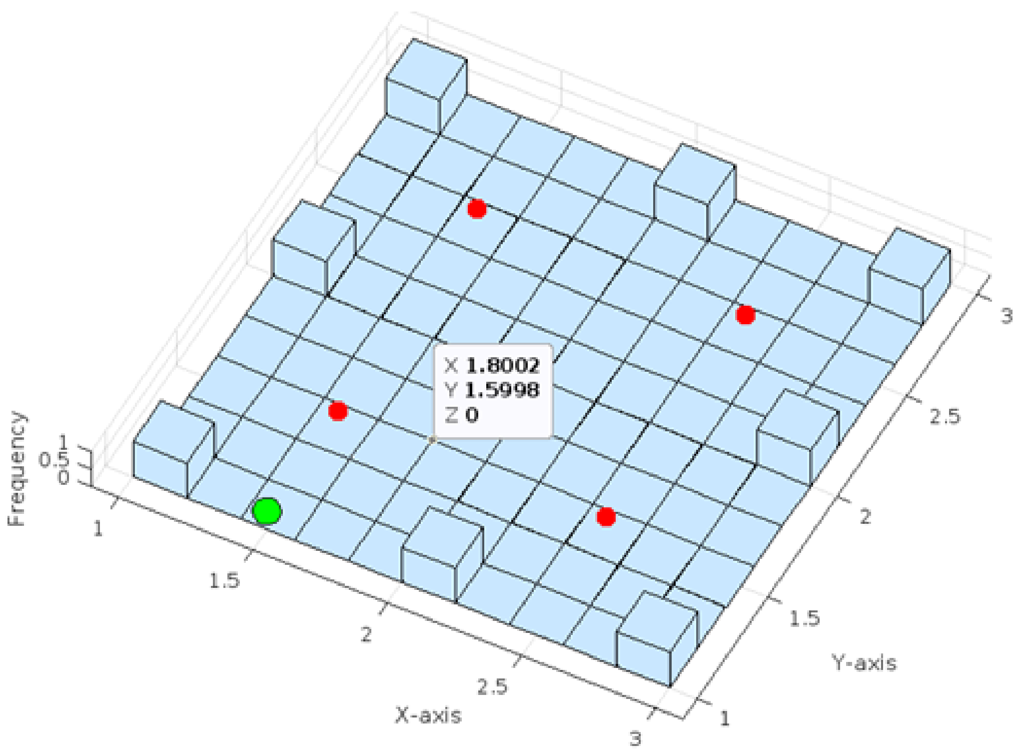


Figure 9.6: Line Of Sight Scenario

The results are shown in Fig.9.8 and Fig.9.8 for LOS and NLOS Scenarios

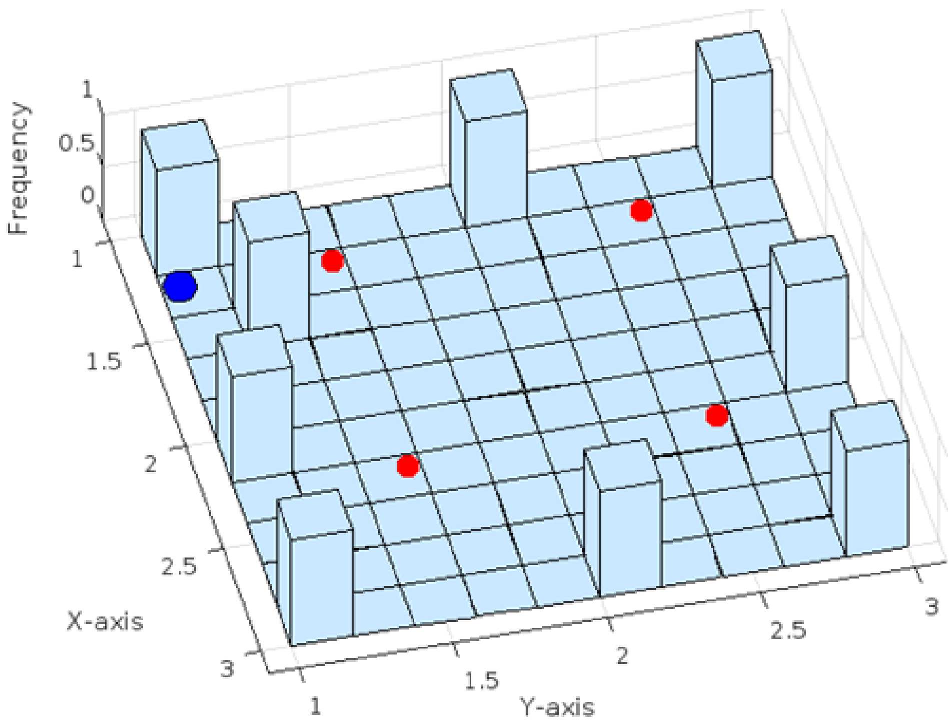


Figure 9.7: Non Line Of Sight Scenario

```
TOF for LOS (seconds):
   1.0e-08 *

    0.1667    0.6009    0.5000    0.3727

Error for Tag 1 (LOS) in meters: 0.0050
Error for Tag 2 (LOS) in meters: 0.0180
Error for Tag 3 (LOS) in meters: 0.0150
Error for Tag 4 (LOS) in meters: 0.0112
```

Figure 9.8: Results for LOS Scenario

```
TOF for NLOS (seconds):
   1.0e-08 *

    0.3333    0.6009    0.5000    0.3727

Error for Tag 1 (NLOS) in meters: 0.0061
Error for Tag 2 (LOS) in meters: 0.0180
Error for Tag 3 (LOS) in meters: 0.0150
Error for Tag 4 (LOS) in meters: 0.0112
```

Figure 9.9: Results for NLOS Scenario

respectively. Only Tag 1 had the NLOS scenario and the rest all were the same, the results indicate that there is an increase in the time taken as well as a slight increase in the error.

9.3 Importance of Number of Anchors

The importance of the number of anchors in the UWB localization system is discussed below using two scenarios as shown in Fig.9.10 and Fig.9.11. Firstly LOS Scenarios where there is one anchor in the first case and two anchors in another case are taken into consideration.The results are shown in Fig.9.12 and Fig.9.13 for LOS scenario with one and two anchors respectively. The results indicate that there is an increase in the accuracy as well as a decrease in the error as there is an increase in the number of anchors.

.

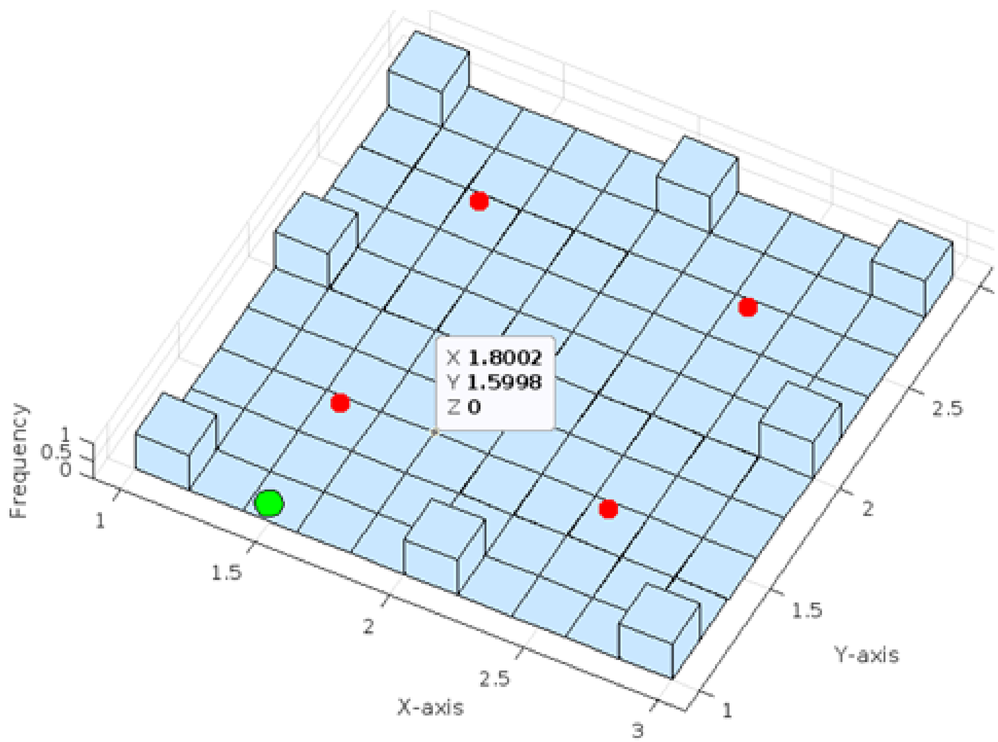


Figure 9.10: LOS Scenario with one anchor

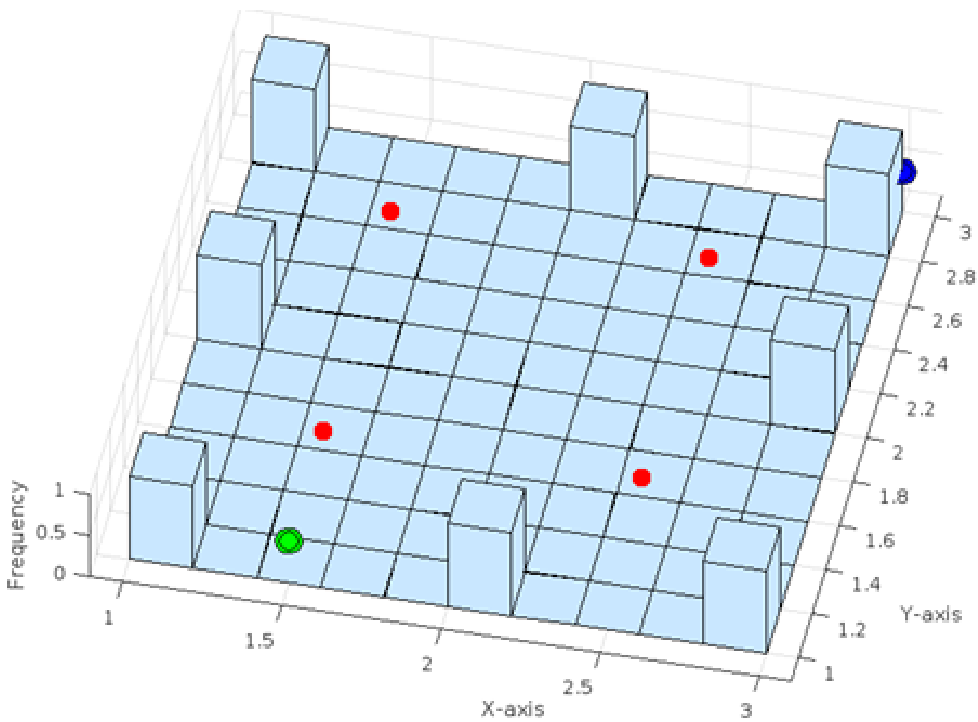


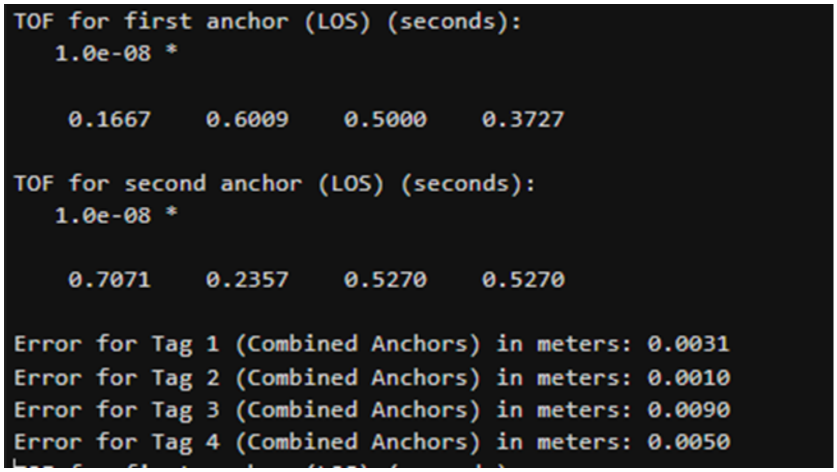
Figure 9.11: LOS Scenario with two anchors

```
TOF for LOS (seconds):
   1.0e-08 *

    0.1667    0.6009    0.5000    0.3727

Error for Tag 1 (LOS) in meters: 0.0050
Error for Tag 2 (LOS) in meters: 0.0180
Error for Tag 3 (LOS) in meters: 0.0150
Error for Tag 4 (LOS) in meters: 0.0112
```

Figure 9.12: Results for LOS scenario with one anchor



```
TOF for first anchor (LOS) (seconds):
   1.0e-08 *

    0.1667    0.6009    0.5000    0.3727

TOF for second anchor (LOS) (seconds):
   1.0e-08 *

    0.7071    0.2357    0.5270    0.5270

Error for Tag 1 (Combined Anchors) in meters: 0.0031
Error for Tag 2 (Combined Anchors) in meters: 0.0010
Error for Tag 3 (Combined Anchors) in meters: 0.0090
Error for Tag 4 (Combined Anchors) in meters: 0.0050
```

Figure 9.13: Results for LOS scenario with two anchors

9.4 Anchor Position Recommendation System

An anchor recommendation system was proposed where the algorithm suggests the optimal number of anchors and positions based on the tags available.

In the proposed system, the number of tags is determined by the user, allowing flexibility in the tracking and monitoring process. On the other hand, the number of anchors is automatically assigned by the algorithm based on the requirements of the environment and the coverage area. The positions of the 7 tags are generated randomly as shown in Fig.9.14 within the specified environment. This randomness ensures that the algorithm can handle various scenarios and adapt to different object distributions.

The positions of the anchors are predicted by the algorithm. Utilizing data collected during the initial locating phase or through prior knowledge of the environment, the algorithm predicts optimal anchor positions to ensure effective coverage and accurate localization of the tags. This predictive

```
Tag Positions:
Tag 1: (103, 135)
Tag 2: (353, 357)
Tag 3: (332, 136)
Tag 4: (185, 335)
Tag 5: (310, 105)
Tag 6: (273, 354)
Tag 7: (245, 169)
```

Figure 9.14: Tag Positions which are randomly generated

capability enhances the efficiency and reliability of the tracking system, enabling precise monitoring and prediction of object trajectories within the designated area. The Fig.9.15 shows the final positions recommended by the algorithm on the floor map, the suggested positions of the anchors by the algorithm are shown in Fig.9.16.

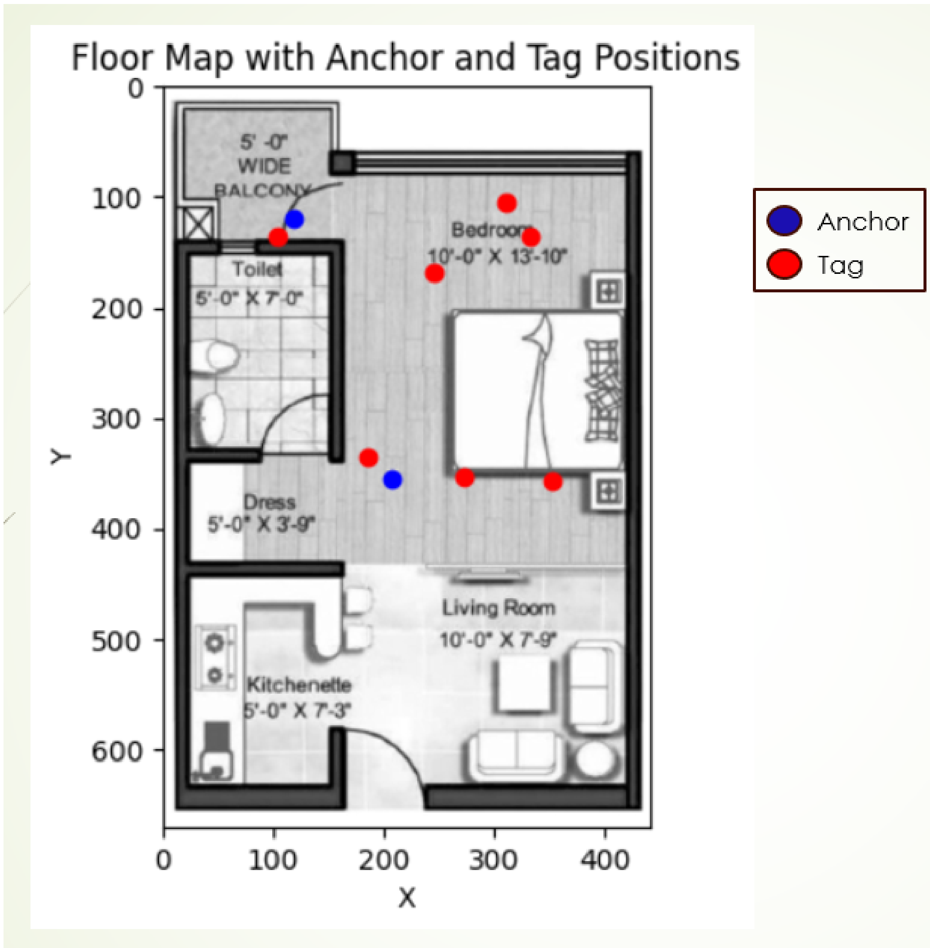


Figure 9.15: Floor Map with Tags and Anchors Positioned

```
Optimized Anchor Positions for 2 Anchors:
Anchor 1: (118.99996264063469, 118.99999596279923)
Anchor 2: (206.9999672730725, 354.9999954561899)
```

Figure 9.16: Predicted Anchor Positions

9.5 LSTM Simulations

Developed an LSTM model to predict the tag's path trajectory, which will help to understand the possibilities of the collisions and where the tags may be present in a given time. The LSTM model here uses the already collected data and predicts the individual trajectories of all tags. The simulation was performed and the proposed model has shown an accuracy of 96 % for device 1 and 95.7 % for device 2.

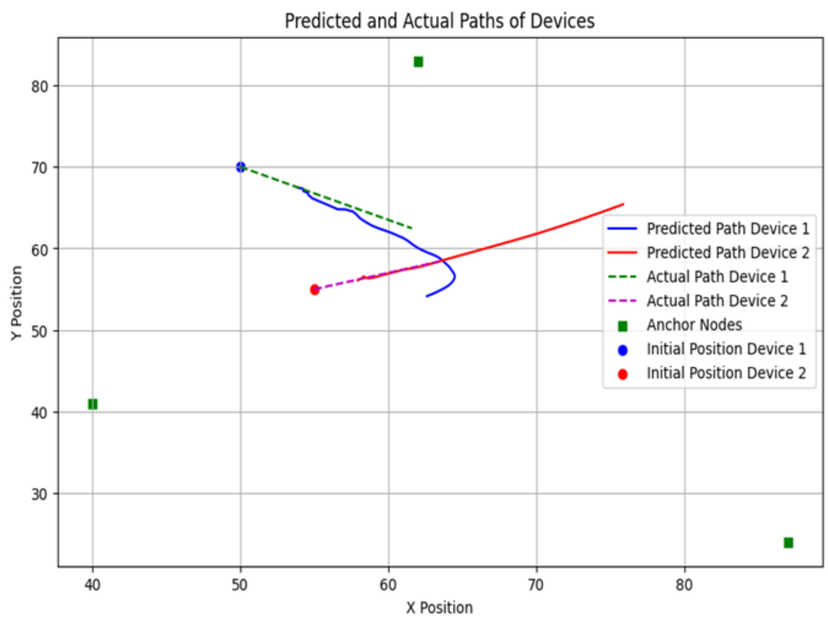


Figure 9.17: Trajectory Prediction Using LSTM Model

Fig.9.18 shows a graph plot between the number of steps taken by the LSTM Model and the accuracy of the model. The graph indicates that as the steps increase the accuracy also increases accordingly.

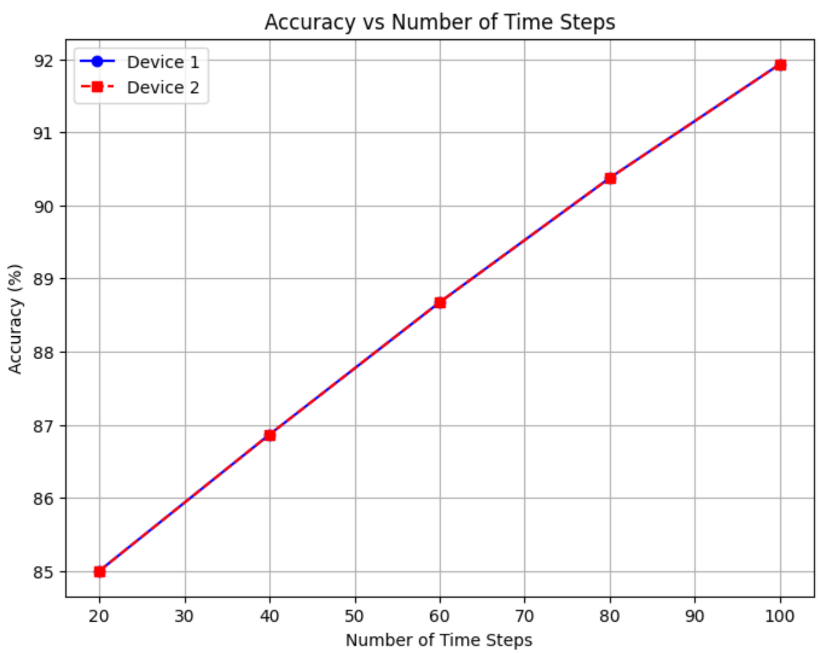


Figure 9.18: Accuracy vs Number of Steps

Chapter 10

Case Study of the proposed methodology

10.1 Detecting

If the communication range is above 250 meters, cellular communication or IEEE 802.11 p communication protocol can be used for identifying the UWB devices attached in the communication range of 250 to 500 meters. It identifies the presence of an object.

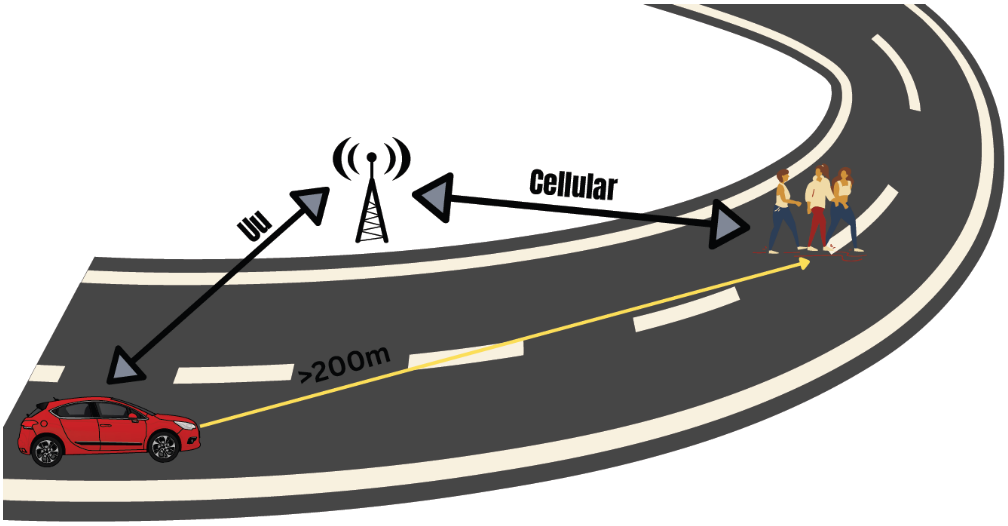


Figure 10.1: Detecting

10.2 Locating

If the communication range is below 250 meters UWB communication can come into action. It determines the exact position or location of the identified pedestrian/vehicle in a specific coordinate system. It involves specifying the spatial or geographical details.

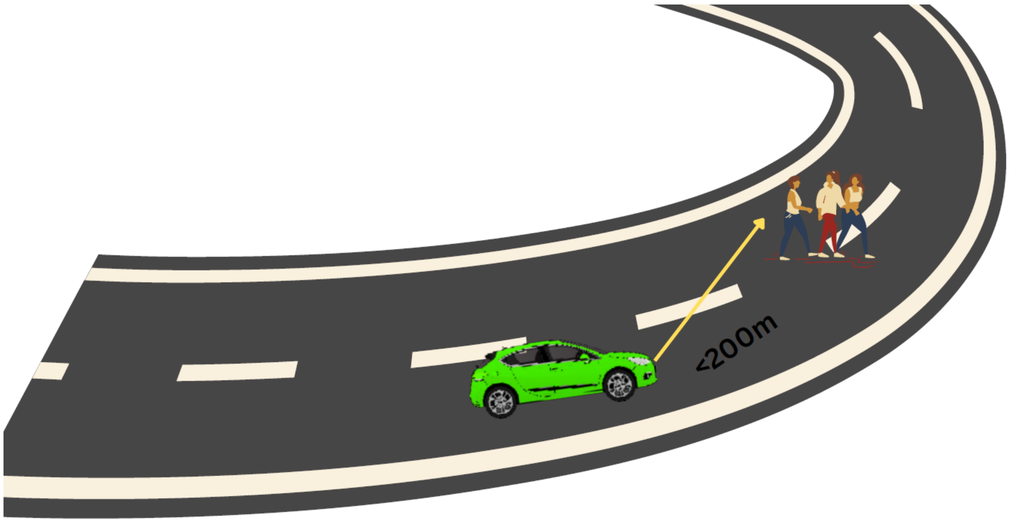


Figure 10.2: Locating

10.3 Tracking and Predicting

Now we will monitor the movement or changes in the position of the detected and located pedestrian/vehicle over time. It focuses on maintaining continuous awareness of their trajectory using UWB. Combining the data from multiple anchors and sensors can improve accuracy and reliability, using these data models like the LSTM ML model can perform path predictions and then forecast the future state or behaviour of the pedestrian/vehicle based on its historical data and current trajectory and this can also be sent to the pedestrians or users from the cloud which they can view using user dashboards or mobile apps. This can be crucial for making informed decisions or taking pre-emptive actions.

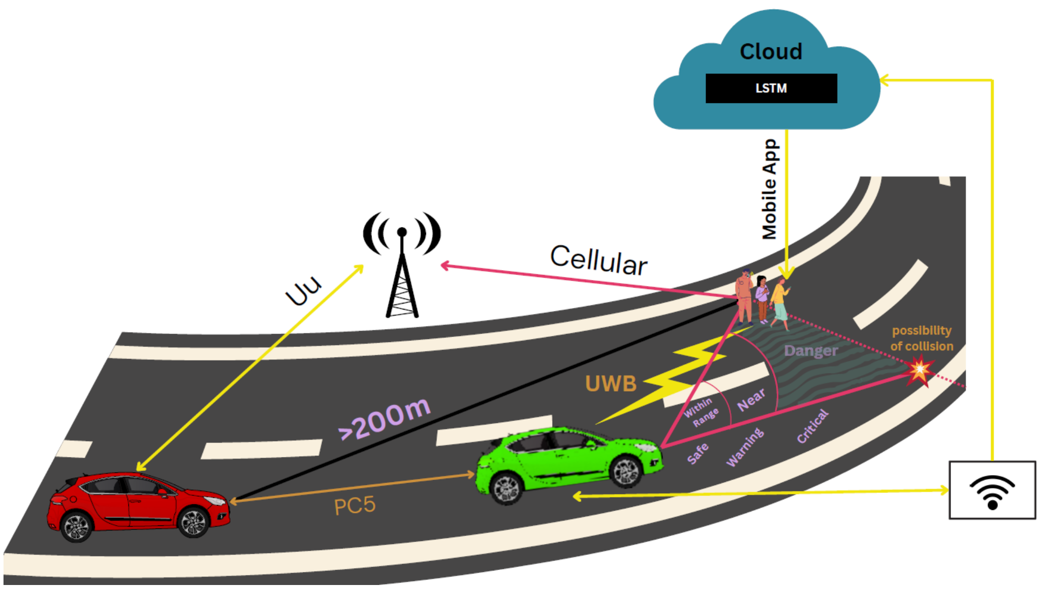


Figure 10.3: Tracking and Predicting

Chapter 11

Conclusion

In this study, we conducted simulations to assess the performance of Ultra-Wideband (UWB) localization, focusing on path trajectory prediction using an LSTM model. Our findings reveal promising results, indicating the effectiveness of the LSTM model in predicting UWB tag path trajectories. We evaluated various scenarios, including Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) environments, and highlighted the importance of the number of anchors in UWB localization systems. Additionally, we proposed an optimal anchor recommendation system to enhance localization accuracy. While our study primarily focused on simulations, future work will involve implementing UWB hardware for real-world validation.

Bibliography

[1] Al-Ammar MA, Alhadhrami S, Al-Salman A, Alarifi A, Al-Khalifa HS, Alnafessah A, Alsaleh M. Comparative survey of indoor positioning technologies, techniques, and algorithms. In2014 International Conference on Cyberworlds 2014 Oct 6 (pp. 245-252). IEEE.

[2] Djaja-Josko V, Kolakowski J. A new method for wireless synchronization and TDOA error reduction in UWB positioning system. In2016 21st International Conference on Microwave, Radar and Wireless Communications (MIKON) 2016 May 9 (pp. 1-4). IEEE.

[3] Zandian R, Witkowski U. Implementation challenges of synchronisation of UWB nodes in TDoA structures. In2018 International Conference on Indoor Positioning and Indoor Navigation (IPIN) 2018 Sep 24 (pp. 1-8). IEEE.

[4] Tiemann J, Eckermann F, Wietfeld C. Atlas-an open-source tdoa-based ultra-wideband localization system. In2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN) 2016 Oct 4 (pp. 1-6). IEEE.

[5] Chen J, Shi T, Liu Y, Wu S. A time-compensation TDOA-based wireless positioning method for multi-level IoT positioning. In2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC) 2019 Jun 24 (pp. 1731-1736). IEEE.

[6] Sidorenko J, Schatz V, Scherer-Negenborn N, Arens M, Hugentobler U. Error corrections for ultrawideband ranging. IEEE Transactions on Instrumentation and Measurement. 2020 May 22;69(11):9037-47.

[7] Sathyan T, Sinha A, Kirubarajan T. Passive geolocation and tracking of an unknown number of emitters. IEEE Transactions on Aerospace and Electronic Systems. 2006 Apr;42(2):740-50.

[8] Khan R, Sottile F, Spirito MA. Hybrid positioning through extended Kalman filter with inertial data fusion. International journal of information and electronics engineering. 2013 Jan;3(1):127-31.

[9] Comuniello A, Moschitta A, De Angelis A. Ultrasound TDoA positioning using the best linear unbiased estimator and efficient anchor placement. IEEE Transactions on Instrumentation and Measurement. 2019 Dec 5;69(5):2477-86.

[10] Ullah I, Shen Y, Su X, Esposito C, Choi C. A localization based on unscented Kalman filter and particle filter localization algorithms. IEEE Access. 2019 Dec 23;8:2233-46.