Real Time Locating System Using Ultra-Wide Band Communication

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***Abstract*—The project aims to develop a Real-Time Locating System (RTLS) using Ultra-Wideband (UWB) technology to address the increasing demand for 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.**

Keywords: Ultrawide Band, RTLS, accuracy, asset tracking, real-time implemtation.

I. 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, 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.

The capacity of UWB to transfer data across a broad spectrum gives it a distinct edge 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. Furthermore, UWB's capacity to withstand interference 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 how important it is to have sophisticated tracking capabilities, the UWB-powered RTLS stands out as a complete solution that offers 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 made resistant to jamming. Ultra-short pulses are transmitted over a broad frequency range by UWB to function. The low power density and broad 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 shortterm 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.

II. Related Work

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.

III. Overview of 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. 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.

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.

IV. Proposed Methodology

A. 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.

B. 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.

C. 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.

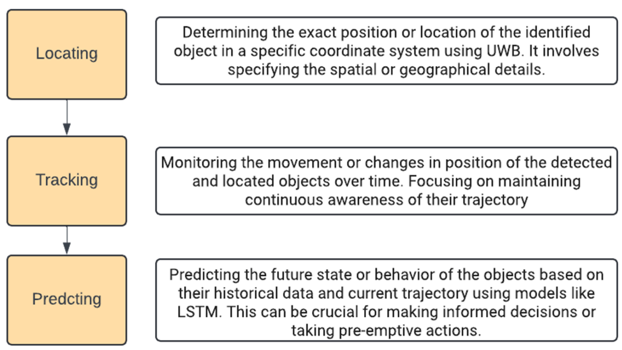

Fig. 1 Proposed Methodology

V. Proposed Architecture

The Fig.2 shows a UWB-based indoor positioning system.

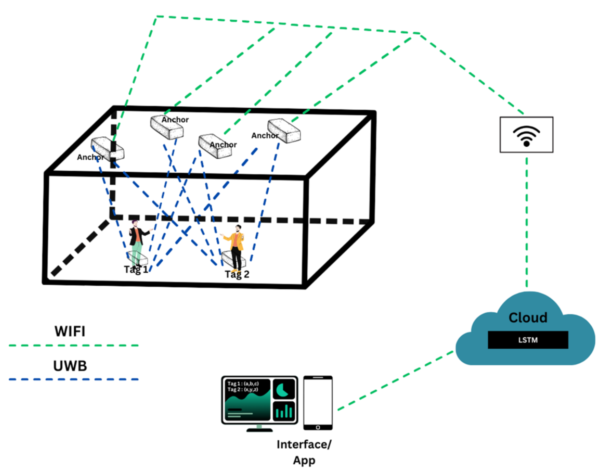

Fig. 2 Proposed Architecture

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.

VI. 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.

Algorithm 1: Proposed Algorithm

```
Procedure locate()
    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))

Procedure update()
    while true do
        if distance(tag, anchor) < 200 meters then
            object position ← update(position(tag, anchor))
            track(object position)
        else
            pause tracking()

Procedure train()
    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)
```

VII. Results

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.

A. Static Case

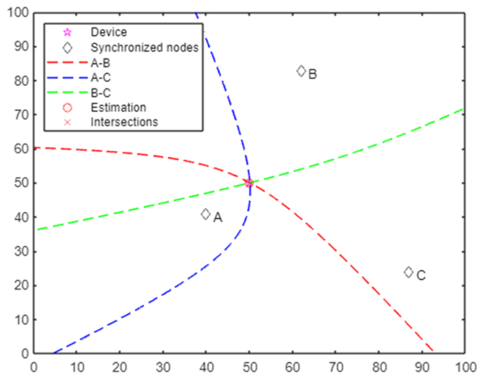

Fig. 3   Localization of the tag in static case using UWB

In this case, both the anchors and tag are not moving and are fixed. Fig.3 shows the tag position as it is localized at the intersection of hyperbolas drawn using the anchors.

B. 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.4 and Fig.5 show the tag positions as it moves which are localized at the intersection of hyperbolas drawn using the anchors at each step.

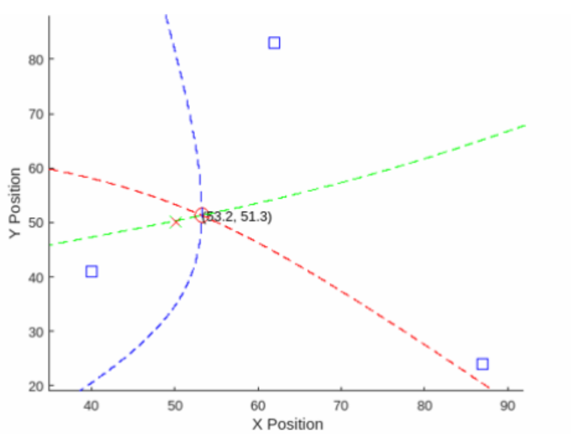

Fig. 4   Dynamic case at the Start

C. 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

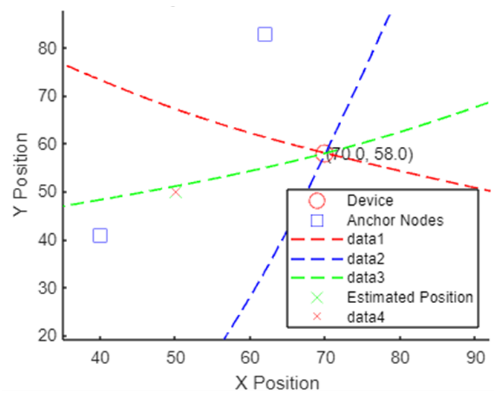

Fig. 5   Dynamic case at the end

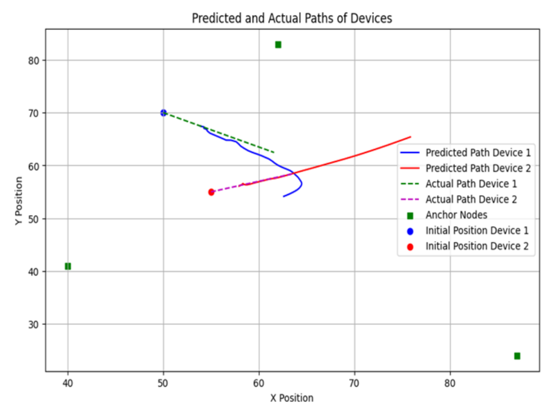

Fig. 6   Trajectory Prediction Using LSTM Model

was performed and the proposed model has shown an accuracy of 96 % for device 1 and 95.7 % for device 2.

Fig.7 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.

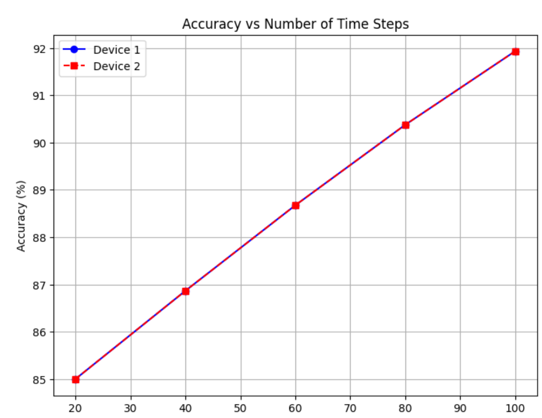

Fig. 7   Accuracy vs Number of Steps

VIII. Conclusion

In this study, simulations were conducted 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.

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