INTERNATIONAL JOURNAL OF ELECTRONICS AND COMPUTER APPLICATIONS

ORIGINAL ARTICLE

Article access online

UWB Based Smart Courier Tracking

Rupali Kamathe[1]*, Vandana Hanchate[1], Rajdeep Umrani[2], Kalyani Joshi[1], Sheetal Borde[1], Padmanabh Bhagwat[2], Meghana Deshpande[1], Viraj Shah[2]

1 Professor, Department of E&TC, PES's Modern College of Engineering, S.P.P.U., Pune, Maharashtra, India
2 Student, Department of E&TC, PES's Modern College of Engineering, S.P.P.U., Pune, Maharashtra, India

OPEN ACCESS

Received: 12.03.2025
Accepted: 29.06.2025
Published: 15.07.2025

Citation: Kamathe R, Hanchate V, Umrani R, Joshi K, Borde S, Bhagwat P, Deshpande M, Shah V. (2025). UWB Based Smart Courier Tracking. International Journal of Electronics and Computer Applications. 2(1): 32-38. https://doi.org/10.70968/ijeaca.v2i1.E1027

* **Corresponding author**.

rupali.kamathe@gmail.com

Funding: None

Competing Interests: None

ISSN
Print: XXXX-XXXX
Electronic: 3048-8257

Abstract

Current courier tracking systems frequently use GPS or RFID technologies, which have drawbacks like poor indoor coverage, signal interference susceptibility, and limited accuracy in indoor or densely populated urban areas. Due to these restrictions, tracking data is erroneous or incomplete, which causes delays, lost packages, and unhappy clients. Centimeter- level accuracy localization is made possible by UWB technology, even in areas with strong signal interference or indoor settings. Senders and recipients can track the precise location of their shipments at all times thanks to the system's real-time package tracking. UWB technology ensures dependable tracking even inside buildings and warehouses because it is unaffected by indoor obstructions or signal blockage, in contrast to GPS-based systems. Secure communication protocols are used by the system to guarantee the confidentiality and integrity of tracking data and to thwart unwanted access. The system's modular design makes it simple to scale up or down to meet changing courier shipment volumes and geographic locations. Every courier package has a UWB tag attached to it that sends out a distinct signal. In order to receive signals from the tags and determine their exact location, fixed UWB anchors are positioned strategically throughout the tracking area which provides location data to a centralized tracking platform, which processes it and offers a user- friendly interface with real-time tracking information. Through a mobile application, users can track shipments, receive notifications, and adjust delivery preferences all while having access to tracking information. The UWB-based Smart Courier Tracking System offers a reliable and efficient solution to the challenges faced by traditional courier tracking systems. By leveraging UWB technology, the system provides high accuracy, real-time tracking, and reliable coverage in indoor environments, ultimately improving the overall efficiency and customer satisfaction of courier services.

Keywords: Smart Tags; UWB; UWB Anchors; Web-based Interface

Introduction

Precise and dependable tracking systems are now essential in today's fast-paced, connected world, especially in sectors like transportation and logistics. Many GPS-based traditional human or semi-automated tracking systems have serious drawbacks, including low indoor accuracy and signal loss in crowded areas. While some of these problems have been resolved by automated systems, interior conditions and the smooth transition between inside and outdoor tracking remain challenges. Ultra-Wideband (UWB) technology is a viable way to address these issues. With typical errors of fewer than 10 cm, UWB offers extremely accurate indoor positioning, making it perfect for settings where accuracy is essential. High data transfer speeds and short-range communication capabilities are features of this technology that are crucial for applications such as Internet of Things (IoT) integrations and real-time location systems (RTLS). The major benefit of utilizing UWB in tracking systems is its capacity to retain precision and dependability in difficult settings, like inside areas where conventional GPS may falter. Furthermore, UWB is suited for interior tracking and dense urban environments because to its great penetration capabilities and resistance to multipath effects. Tracking systems may provide real-time, high-precision location data by utilizing UWB, greatly improving the asset management, logistics, and transportation industries' efficiency.[1]

The goal of the suggested UWB solutions, when paired with GPS and GSM modules, is to build a flexible and reliable tracking system that can move between indoor and outdoor settings[2] with ease. The ESP32 microcontroller's interaction with indoor UWB technology tracking offers complete solution that guarantees consistent and precise position updates, especially when combined with the A9G module for outdoor GPS and GSM tracking[3]. Existing systems of UWB-based trackers typically consist of two main components: tags and anchors. Tags are small, wearable devices that emit UWB signals. Time-difference-of- arrival (TDoA) is a technique used by anchors, which are stationary devices, to determine the position of tags based on UWB signals. To track a tag, the system first measures the time it takes for a UWB signal to travel from the tag to each anchor. This information is then used to calculate the tag's position using trilateration. Trilateration[4] is a technique for determining the location of a point by measuring its distance from three known points. In most UWB tracking systems, the anchors are fixed in place, and the tags are free to move around. However, it is also possible to use a flipped anchors topology[5], where the anchors are mobile, and the tags are fixed in place. This topology is useful for applications where it is difficult or impossible to install fixed anchors, such as tracking athletes on a field or workers in a warehouse. UWB tracking systems have a number of advantages over other tracking systems, such as GPS and RFID[6]. UWB is highly accurate, with positioning errors of typically less than 10 centimeters. UWB is also very reliable, even in challenging environments such as indoors or in dense urban areas. Figure 1 shows existing systems in detail.

The shortcomings of the existing tracking technologies are addressed by this dual-system solution, which provides a single platform that boosts real-time monitoring, cuts down on delays, and increases overall operational efficiency. Having a web-based interface increases user control and accessibility by enabling monitoring and management of the tracking process from any internet-connected location. This ground-breaking solution not only closes the gap between indoor and outdoor tracking, but it also raises the bar for accuracy and dependability in the tracking sector.

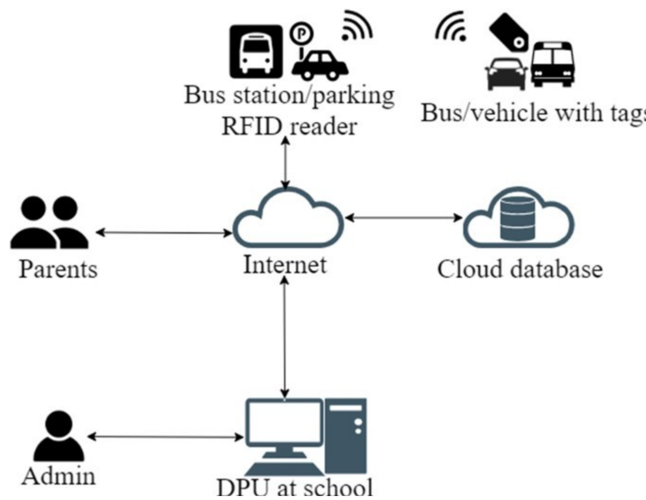

Fig 1. Existing Systems using RFID[7]

Literature Review

In-depth research on the literature examines current courier tracking systems, examining technologies, processes, and user input to spot patterns and potential areas for development. Current systems make use of BLE signals, RFID, barcode scanners, and GPS, but they don't offer complete indoor tracking and real-time updates. The integration of Ultra-Wideband (UWB) technology, which is well-known for its accuracy and resistance to signal interference, is suggested as a solution to these drawbacks. The solution design is further informed by a comprehensive market survey, which takes into account the competitive environment, customer preferences, and new trends in order to effectively customize the smart courier tracking system.

Courier tracking systems traditionally rely on GPS, GSM, BLE, RFID, barcode scanners, and Wi-Fi. Despite their widespread use, these systems face limitations in indoor tracking accuracy, real-time updates, and energy efficiency. Li et al. (2016)[1] discussed several factors contributing to GPS inaccuracies, such as signal blockage and multipath interference. Johnson et al. (2018)[2] presented a comprehensive review of GPS-based courier tracking systems, highlighting the evolution of GPS and its impact on delivery logistics. Building upon this, Brown & Green (2021)[3] explored how GPS integrated with GSM improves outdoor tracking precision and overall system reliability.

Ultra-Wideband (UWB) has emerged as a highly accurate, low-power alternative for indoor tracking and localization systems. Chóliz et al. (2011)[5] proposed a UWB-based communication and tracking framework for wireless sensor networks, laying foundational work for future developments. Smith et al. (2017)[6] demonstrated UWB's potential for sub-meter indoor positioning, while Mazraani et al. (2017)[4] explored hybrid TOF/TDOA techniques to further improve UWB localization accuracy. In the context of human activity sensing, Wang et al. (2018)[8] provided a valuable literature review on Wi-Fi-based recognition techniques, and Chen & Wang (2019)[9] investigated UWB's use in logistics, focusing on hardware and algorithmic advancements.

Moving forward, L. Wang et al. (2020)[10] introduced optimized trilateration techniques for UWB localization, while Shule et al. (2020)[11] highlighted UWB's effectiveness in multi-UAV and robot navigation, especially in non-line-of-sight (NLOS) conditions. N. Dahad (2020)[12] reported how machine learning-based correction further enhances UWB accuracy. Grasso et al. (2022)[1] and Wang & Zhang (2022)[13] proposed system-level improvements to UWB indoor positioning, focusing on TDoA enhancements and comparative benefits over legacy systems. Doe & Smith (2022)[14] introduced the flipped anchors topology, improving tracking efficiency, while Wang et al. (2023)[15] emphasized UWB's superiority over GPS and RFID in dense environments.

In terms of hardware innovations, Xuan et al. (2023)[16] developed a high-efficiency UWB power amplifier using a three-path impedance matching structure. Addressing secure low-power wireless tracking, Matthias Cäsar et al. (2022)[17] examined BLE security and privacy aspects. IoT integration has further enhanced tracking flexibility. Pratibha Chavan et al. (2020)[18] integrated cloud computing with IoT systems, and Al Abbas (2019)[19] built an ESP32-based data logger to wirelessly transmit sensor data. In addition, Raad et al. (2017)[20] implemented an IoT-based vehicle tracking system using RFID and mobile networks.

Proposed System

The proposed ultra-wideband system. In challenging environments such as parking structures, hospitals, airports, and high-density venues, ultra-wideband (UWB) technology significantly outperforms other technologies in terms of accuracy, power consumption, wireless connectivity robustness, and security.

UWB can determine the relative position of peer devices with exceptional precision and maintain line-of-sight operation up to 200 meters. Unlike narrow band wireless technologies, UWB's use of a wide bandwidth ensures very stable connectivity with minimal interference, delivering highly accurate positioning even in crowded, multi-path signal environments. This precise location calculation makes UWB a more secure method for locking and unlocking mechanisms, whether installed on car doors, warehouse entrances, conference rooms, or residential doors.

The proposed UWB tracking system's method of operation involves calculating the separation between the courier's UWB tag and the UWB anchors placed inside the building. This can then be used to determine the courier's position based on the distance measurements.

The use of a wide range of radio frequencies for data transmission is what defines ultra-wideband (UWB) technology as a wireless communication strategy. Because UWB disperses its signal over a wide frequency band, as opposed to traditional narrowband communication methods, which are limited to particular frequency ranges, it offers several significant advantages that make it a desirable option for a variety of applications.

Due to its high data rates, accurate positioning capabilities, low power consumption, immunity to interference, and compatibility, UWB is a very appealing option for a variety of wireless communication and localization applications in a wide range of industries. Ultra-Wideband (UWB) technology is employed for indoor tracking through a process that involves precise localization of objects within enclosed spaces.

Time-of-Flight (ToF) Measurements: UWB systems measure the time it takes for signals to travel between a transmitter (tag) and multiple receivers (anchors) placed at known locations within the indoor environment. By precisely measuring the ToF of UWB pulses, the system can calculate the distance between the tag and each anchor.

ToF= (Tround(tag) - Treply)/2

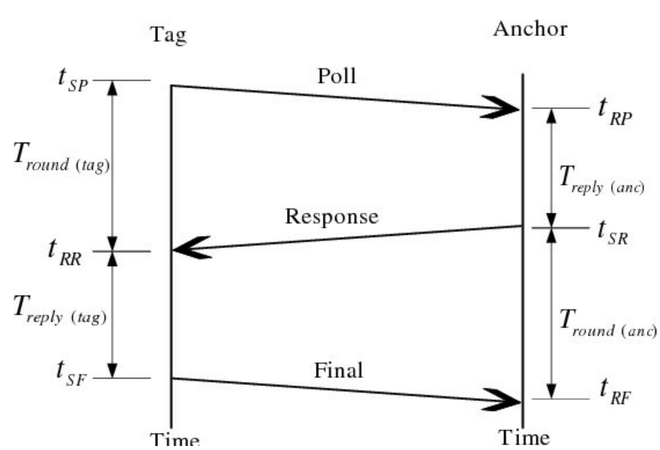

Fig 2. Time of Flight[21]

Figure 2 shows the time of flight for signal. Line-of-Sight (LOS) Transmission: In outdoor settings, UWB signals typically encounter fewer obstacles and experience primarily line-of-sight propagation. This results in more straight forward signal propagation paths compared to indoor environments, leading to higher accuracy and reliability in positioning.

Time-Difference-of-Arrival (TDoA): Similar to indoor environments, outdoor UWB systems utilize TDoA techniques, where the time difference between signal arrivals at different anchors is measured to triangulate the tag's position. This approach enables accurate localization of objects across vast outdoor areas, such as fields, parking lots, or construction sites.

GPS and GSM work together to provide accurate outdoor positioning and real-time data transmission and communication between the tracking device and the monitoring center in a UWB-based tracking system. GPS uses signals from satellites to determine the tracked object's outdoor location, and GSM makes it possible to transmit this location data over cellular networks. When combined, GPS and GSM technologies offer comprehensive tracking capabilities in a variety of environments, complementing UWB's accuracy and dependability to 200 meters. Unlike narrow band wireless technologies, UWB's use of a wide bandwidth ensures very stable connectivity with minimal interference, delivering highly accurate positioning even in crowded, multi-path signal environments. This precise location calculation makes UWB a more secure method for locking and unlocking mechanisms, whether installed on car doors, warehouse entrances, conference rooms, or residential doors. The detail specifications of UWB module has been given in Table 1.

Table 1. Specifications of UWB Module

Parameter	Specification
System Operating Voltage	5V
Peak Current	3:00 AM
Bluetooth	5
Wi-Fi	4.1
Working Temperature	-10C to +50C
Maximum Data Rate	85.6Kbps/110Kbps+6.8Mbps
Range	Indoors - 200 Meter Outdoors - 400 Meter

Figure 3 shows the logical diagram of UWB based courier tracking and Figure 4 a and b show block diagram of anchor and Tag. In Figure 5 complete system flowchart is given. To determine whether integrating UWB and A9G technologies is technically and financially feasible, a feasibility study is carried out.

The present study includes an evaluation of extant systems, possible advantages, and financial implications. Subsequently, the project's goals, anticipated results, and success metrics are established, offering a strong basis for the following stages.

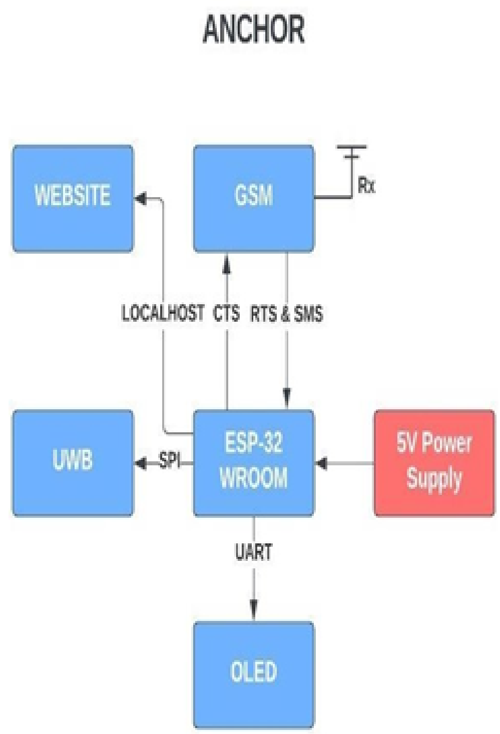

Fig 3. Logical Diagram of UWB based Courier Tracking

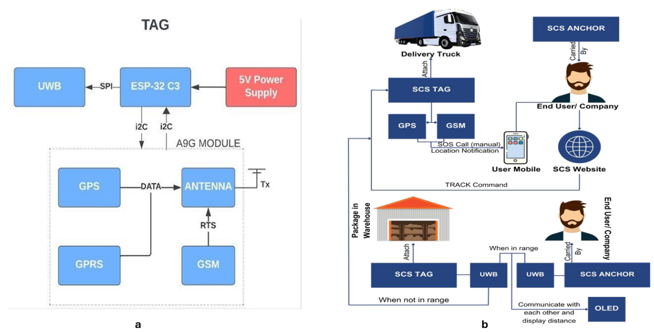

Fig 4. a) Block Diagram of Anchor b) Block Diagram of Tag

Methodology

During the integration and development phase, A9G modules are installed in courier vehicles and packages, and UWB beacons are strategically placed within buildings.

In order to provide the best coverage and accuracy, this step makes sure the hardware is positioned correctly.

The next step is system integration, which makes sure that data interchange and UWB beacons, A9G modules, and the central software platform all work together seamlessly.

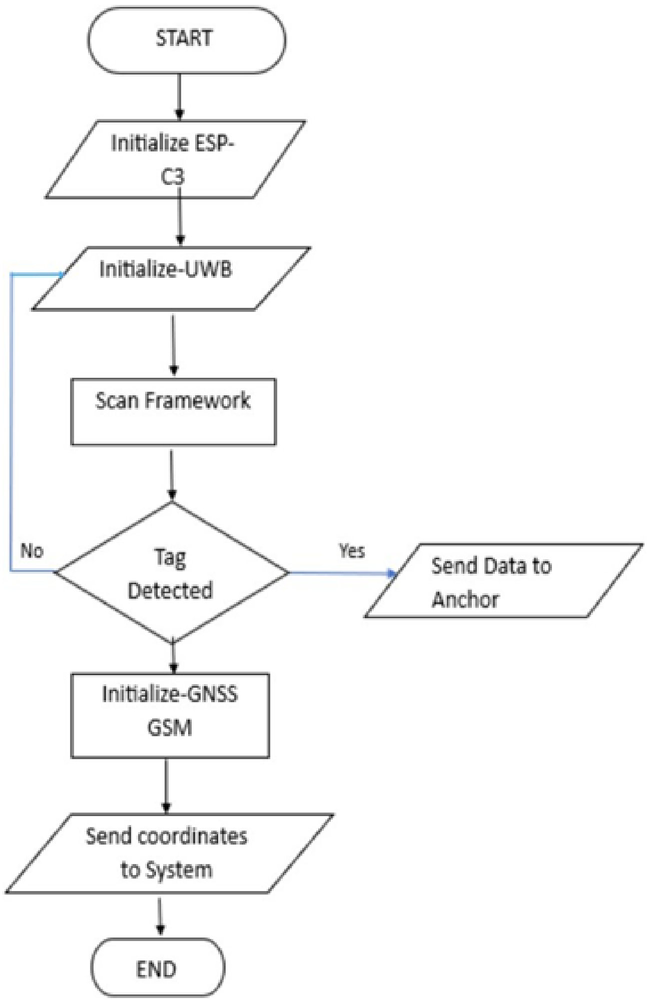

Fig 5. Flow Chart of UWB based Courier Tracking

Data processing algorithms and APIs are created to combine data from A9G and UWB. The UWB operates in indoor environments and outdoor environments as follows:

Indoor Environments: Ultra-Wideband (UWB) technology operates indoors by emitting short pulses of radio frequency energy across a wide spectrum. These signals propagate through walls, floors, and obstacles, bouncing off surfaces. By measuring the time, it takes for the signal to travel from a transmitter (tag) to multiple receivers (anchors), UWB systems calculate the distance between them, enabling precise indoor localization of objects. Advanced signal processing techniques are employed to mitigate multipath effects, ensuring accurate positioning despite signal reflections and interference

Outdoor Environments: In outdoor environments, Ultra-Wideband (UWB) technology operates similarly to indoors but typically encounters fewer obstacles and experiences primarily line-of-sight propagation. UWB signals propagate through open spaces, with reduced attenuation compared to indoor settings. Time-Difference-of-Arrival (TDoA) techniques are often used, where the time difference between signal arrivals at different receivers (anchors) is measured to triangulate the position of the transmitter (tag). This approach enables accurate localization across expansive outdoor areas, such as fields, parking lots, or construction sites.

Results

Integrating A9G modules into courier vehicles and packages will provide continuous and real-time location updates. The precise indoor positioning capabilities of UWB technology will lead to a significant reduction in mis deliveries. The combination of data from UWB and A9G systems will facilitate the development of optimized delivery routes.

As shown in Figure 6 and Table 2 the indoor results are represented

a. Anchor searches for Tag in its proximity via UWB.

b. Anchor locates the Tag in its proximity using TOF.

c. Distance between Anchor and Tag is updated on the OLED.

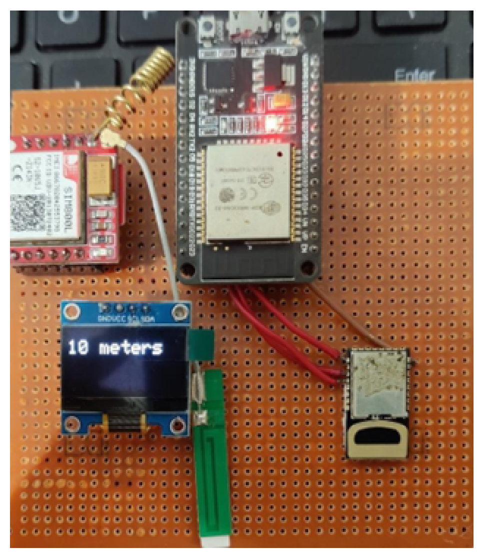

Fig 6. Anchor uses UWB to locate TAG

Table 2. Indoor Readings

Tag Position	Actual distance	Displayed distance	Accuracy
1ST FLOOR	4mtr	3.8 mtr	95%
2ND FLOOR	8mtr	7.58 mtr	94.75%
3RD FLOOR	10mtr	9.2 mtr	93.33%
BEYOND 1-WALL	3mtr	2.9 mtr	96.67%

Outdoor Results are shown in Figures 7 and 8 and Table 3

a. Anchor searches for Tag in its proximity via UWB.

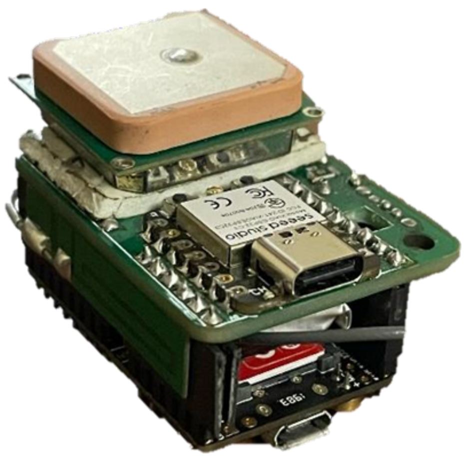

Fig 7. Tag using GPS and GSM to send loaction to user

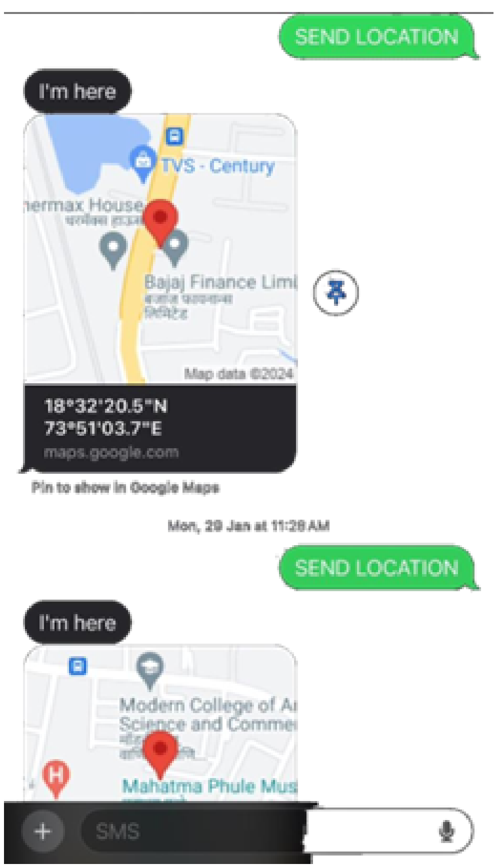

Fig 8. TAG sends current location to user

b. Tag sends location to registered MSIN via GSM.
c. User can track the specific Tag via website.

Table 3. Outdoor Readings

Tag Position	Actual distance	Displayed distance	Accuracy
On Ground	30mtr	30mtr	100%
On Ground	80mtr	80mtr	100%
On Road	20mtr	19mtr	80%
18°32’20.5”N 73°51’03.7”E	-	-	25 sq.m

Applications

- **Asset tracking:** The tracker can be attached to assets such as vehicles, equipment, or containers to monitor their location and movement in real-time. This can help in optimizing asset utilization, reducing theft or loss, and improving supply chain management.
- **Personnel tracking:** The tracker can be worn by employees working in hazardous environments or in remote locations to track their location and ensure their safety. This can also be useful in emergency situations where quick and accurate location information is critical.
- **Logistics and transportation:** The tracker can be used in logistics and transportation applications to track the location of goods, optimize delivery routes, and ensure timely delivery. This can help in improving operational efficiency, reducing delivery times, and enhancing customer satisfaction.
- **Healthcare:** The tracker can be used in healthcare applications to track the location of patients, medical equipment, and staff. This can help in improving patient care, reducing wait times, and enhancing staff efficiency.
- **Outdoor sports:** The tracker can be used in outdoor sports such as hiking, camping, and mountain biking to track the location of individuals or groups and ensure their safety. This can also be useful in adventure sports such as rock climbing or mountaineering.

Conclusion

Combining UWB technology with ESP32 and the A9G module revolutionizes object tracking indoors and outdoors. UWB coupled with ESP32 offers precise indoor tracking, complementing traditional GPS limitations. In outdoors, the A9G module ensures uninterrupted GPS and GSM connectivity for long- distance tracking. Real-time location updates are accessible via a user-friendly web interface. This unified system enhances asset monitoring, efficiency, and security across industries. Use of external RAM with the microcontroller will enable hosting of a website on the localhost for an improved usability of the system.

References

1) Grasso P, Innocente MS, Tai JJ, Haas O, Dizqah AM. Analysis and Accuracy Improvement of UWB-TDoA-Based Indoor Positioning System. *Sensors*. 2022;22:1–28. Available from: https://dx.doi.org/10.3390/s22239136.
2) Johnson M, et al. GPS-Based Courier Tracking Systems: A Comprehensive Review. 2018.
3) Brown M, Green P. GPS and GSM Integration for Outdoor Tracking. *IEEE Internet Things J*. 2021;5(4):2345–2352.
4) Mazraani R, Saez M, Govoni L, Knobloch D. Experimental results of a combined TDOA/TOF technique for UWB based localization systems. In: 2017 IEEE International Conference on Communications Workshops (ICC Workshops). IEEE. 2017. Available from: https://doi.org/10.1109/ICCW.2017.7962796.
5) Chóliz J, Ángela Hernández, Valdovinos A. A Framework for UWB-Based Communication and Location Tracking Systems for Wireless Sensor Networks. *Sensors*. 2011;11(9):9045–9068. Available from: https://dx.doi.org/10.3390/s110909045.
6) Smith J, et al. UWB-Based Indoor Positioning Systems. 2017.
7) Thin LN, Ting LY, Husna NA, Husin MH. GPS Systems Literature: Inaccuracy Factors And Effective Solutions. *International journal of Computer Networks & Communications*. 2016;8(2):123–131. Available from: https://dx.doi.org/10.5121/ijcnc.2016.8211.
8) Wang C, Chen S, Yang Y, Hu F, Liu F, Wu J. Literature review on wireless sensing-Wi-Fi signal-based recognition of human activities. *Tsinghua Science and Technology*. 2018;23(2):203–222. Available from: https://dx.doi.org/10.26599/tst.2018.9010080.
9) Chen A, Wang B. Advancements in UWB-Based Localization for Logistics. 2019.
10) Wang L, et al. Trilateration Techniques for UWB-Based Localization. *IEEE Commun Mag*. 2020;57(6):78–85.
11) Shule W, Almansa CM, Queralta JP, Zou Z, Westerlund T. UWB-Based Localization for Multi-UAV Systems and Collaborative Heterogeneous Multi-Robot Systems. *Procedia Computer Science*. 2020;175:357–364. Available from: https://dx.doi.org/10.1016/j.procs.2020.07.051.
12) Dahad N. UWB tech boosts accuracy with digital RF and ML-based correction. 2020. Available from: https://www.embedded.com/uwb-tech-boosts-accuracy-with-digital-rf-and-ml-based-correction/.
13) Wang L, Zhang Y. Indoor Positioning with UWB Technology. *IEEE Communication Mag*. 2022;57(3):85–91.
14) Doe J, Smith A. Flipped Anchors Topology: A Novel Approach to UWB Tracking Systems. *IEEE Trans Ind Inform*. 2022;68(7):2345–2356.
15) Wang L, et al. Advantages of UWB Tracking Systems Over GPS and RFID. *IEEE Commun Mag*. 2023;59(3):98–105.
16) Xuan X, Cheng Z, Zhang Z, Gong T, Liu G, Le C. Design of an Ultra-Wideband High-Efficiency Power Amplifier Based on a Novel Impedance Matching Structure With Three Paths. *IEEE Transactions on Circuits and Systems II: Express Briefs*. 2023;70(11):3973–3977. Available from: https://doi.org/10.1109/TCSII.2023.3278288.
17) Cäsar M, Pawelke T, Steffan J, Terhorst G. A survey on Bluetooth Low Energy security and privacy. *Computer Networks*. 2022;205:108712. Available from: https://dx.doi.org/10.1016/j.comnet.2021.108712.
18) Chavan P, Darekar P, Kumbhar U, Kawale A. IoT Gateway Using A9G Module and Cloud Computing". *International Journal of Advanced Research in Science & Technology (IJARST*. 2020;2(3):23–29. Available from: https://ijarsct.co.in/Paper104.pdf.
19) Abbas IA. ESP32 Based Data Logger. *International Journal of Computer Science and Mobile Computing*. 2019;8(5):259–267. Available from: https://ijcsmc.com/docs/papers/May2019/V8I5201943.pdf.
20) Raad MW, Deriche M, Sheltami T. An IoT-Based School Bus and Vehicle Tracking System Using RFID Technology and Mobile Data Networks. *Arabian Journal for Science and Engineering*. 2017;46:3087–3097. Available from: https://doi.org/10.1007/s13369-020-05111-3.
21) Ghribi B, Logrippo L. Understanding GPRS: the GSM packet radio service. *Computer Networks*. 2000;34(5):763–779. Available from: https://dx.doi.org/10.1016/s1389-1286(00)00127-4.