TOWARDS AUTONOMOUS UWB-BASED UAV INDOOR NAVIGATION

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ABSTRACT

This paper presents a system for autonomous indoor navigation of the DJI Mini 3 drone by combining an Android-based control application with ultra-wideband (UWB) technology for precise localization. The development process involved two main phases: (1) enabling drone control and sensor access through the DJI Mobile SDK and (2) integrating UWB-based positioning data for reliable indoor navigation. Three autonomous navigation methods were designed and evaluated, each leveraging UWB data to a different extent. The results demonstrate that incorporating UWB significantly improves positioning accuracy for our solution compared to relying solely on the drone's built-in sensors. Overall, this work highlights the potential of UWB technology to enhance drone operations in environments where GPS is unavailable, paving the way for advanced applications in indoor logistics, monitoring, and other industrial or service-oriented scenarios.

Keywords: *uwb, uav, drone, indoor navigation, android*

1. INTRODUCTION

Unmanned aerial vehicles (UAVs), or drones, have become integral to the modern world. Their uses range from entertainment activities and photography to complex industrial applications such as infrastructure monitoring, search and rescue, or even parcel delivery. Most of these applications, however, focus on the outdoor environment, where drones use the Global Positioning System (GPS) and other satellite systems for navigation.

The indoor environment presents an entirely different set of challenges for drones. Drone navigation in indoor environments is a complex task that requires precise localization and mapping in environments without a reliable GPS signal. Walls, ceilings and other obstacles block satellite signals, creating a challenge for drones in the environment. Additionally, indoor environments can be dynamic, with moving objects and people, making navigation even more difficult. Despite these challenges, there is a growing demand for drones capable of operating autonomously in indoor environments, including industrial, service, and security applications. Ultra-wideband (UWB) technology has gained attention as a promising solution to solve indoor localization challenges for UAVs.

This work analyses the possibilities of localizing and navigating drones in indoor environments using UWB and other different technologies and methods. The objective of this study is to design a mobile application and navigation system for the DJI Mini 3 drone, focusing on evaluating the potential to improve the accuracy of its navigation in indoor environments through the use of UWB technology. The goal is to create a system that allows the drone to navigate the indoor environment safely and efficiently and perform the specified navigation tasks.

2. RELATED WORK

UWB technology uses very short radiofrequency (RF) pulses with a period under one nanosecond, transmitted over a wide bandwidth and low duty cycle. Its immunity to path loss and interference has led to its expansion beyond communication, particularly for indoor positioning through Time of Arrival techniques. Position is estimated by measuring RF wave travel between reference and target nodes. UWB is preferred over Bluetooth and Wi-Fi for high-accuracy localization, achieving precision up to 10 cm using Time of Flight approximation under optimal conditions [1]. UWB has become suitable for indoor applications that demand high accuracy, such as factories, advanced robotic navigation systems, and human tracking [2] with diverse use cases like monitoring patients and hospital equipment.

UWB-assisted navigation systems are essential for drone operations in warehouses and large industrial settings, where precise localization is needed for tasks such as inventory management [3] and equipment monitoring. An example of its application includes automated delivery systems [4] wherein UAVs navigate through indoor corridors, leveraging UWB to align with specific drop-off points without human intervention, thereby streamlining operations and enhancing efficiency. To make UAV-UWB solutions robust for multiple UAVs, researchers in [5] proposed a communication network with infrastructure-free cooperative relative localization (RL), estimating relative coordinates with onboard UWBs to both sense the inter-UAV distance and exchange information for RL estimation in 2D spaces.

To overcome UWB shortcomings and improve accuracy and robustness to positioning errors, researchers use multi-sensor fusion localization and use data fusion approach. For example, in [6], an indoor localization method is presented that combines the Inertial Measurement Unit (IMU) with UWB localization technology. This combination aims to effectively minimize the IMU error accumulation and improve positioning accuracy. In the quadcopter UAV route planning framework, a technology is proposed that integrates multiple sensors using unscented Kalman filter (UKF). Similarly, a fusion of machine learning with UWB localization in [7] improved UAV navigation accuracy by enabling online error correction, reducing multi-path effect errors, and enhancing performance in dynamic environments.

3. SOLUTION DESIGN

The focus of this use case was to design and develop an application for locating and navigating a drone in an indoor environment. In the case of the drone, it is a drone of the brand DJI, specifically the DJI Mini 3 [8]. The DJI Mini 3 drone can be controlled using a mobile Android application using DJI Mobile SDK V5, which is written in Kotlin programming language. UWB sensors were used in localization to determine the drone's position in space using multilateration. The UWB sensors are integrated on ESP32 UWB DW3000 MCU boards [9], which allows programming them using C/C++ programming languages in the Arduino IDE development environment. To create a mobile application with a navigation system, we first focused on controlling the drone using the application and accessing its built-in sensors, and then we focused on integrating localization and drone navigation.

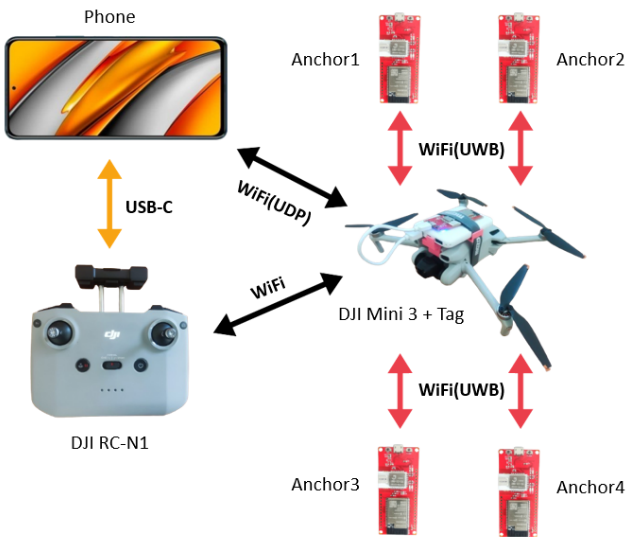

Fig. 1 Communication architecture of the UWB-based navigation system

In order to control the drone using the app, we need to provide communication between the drone and the app. Using a DJI drone Mini 3 and the Android app for control, communication can only be ensured using a wired connection between the mobile device and the DJI RC-N1 wireless controller, which provides wireless communication between the drone and the controller. The great advantage of this application design approach is that the DJI RC-N1 controller operates in both the 2.4 GHz and 5.8 GHz, and can also automatically select the appropriate channel.

Fig. 1 shows the architecture of our solution that provides communication between the application, the wireless controller, the drone and the UWB localization system with the ESP32 devices with UWB chip. In the end, we used four Anchor modules and one Tag module, which was fixed on the drone. The Anchor modules were arranged in a 4.7m × 2.1m rectangular area in the lab, with three anchors placed at a height of 0.75m and the fourth at 1.25m. The Android application running on a mobile device calculated the drone's position in three-dimensional space. The UDP protocol was chosen for its relative simplicity, robustness, and compatibility with ESP32 devices.

The next point in this section that needs to be addressed is the fixing and power supply of the ESP32 with UWB chip on the DJI Mini 3 drone. At this point, we had to deal with more hurdles as the mounting and power supply method had to be removable and not permanently interfere with the drone's appearance or functionality. For this purpose, a 3D-printed mount model with Velcro was used.

Fulfilling the previous points allowed us to proceed to the actual design of the autonomous navigation algorithms. We decided to create three ways of autonomous navigation, each with a different level of complexity and simultaneously with different levels of implementation of the UWB localization system to fully evaluate navigation accuracy without and with UWB. The proposed algorithms are:

- Autonomous navigation without using a UWB localization system
- Autonomous navigation with partial use of a UWB localization system
- Autonomous navigation with full use of the UWB localization system

4. IMPLEMENTATION AND EVALUATION

This section describes and evaluates the proposed navigation algorithms mentioned in the previous section. For the definition of navigation goals, navigation commands consist of the movements to be performed by

Table 1 Results for navigation accuracy without using the UWB positioning system

ID	Target Position [X, Y, Z] (cm)	Measured position [X, Y, Z] (cm)	Error [X, Y, Z] (%)
1	[150, 250, 60]	[145, 260, 50]	2%, 2%, 5%
2	[150, 200, 100]	[115, 225, 100]	17%, 5%, 0%
3	[200, 200, 150]	[250, 230, 140]	24%, 6%, 5%
4	[180, 250, 100]	[175, 245, 100]	2%, 1%, 0%
5	[200, 300, 110]	[190, 310, 100]	5%, 2%, 5%

Table 2 Results for navigation accuracy with partial use of UWB localization system

ID	Target Position [X, Y, Z](cm)	Measured position [X, Y, Z](cm)	Error [X, Y, Z] (%)
1	[150, 250, 60]	[170, 215, 60]	10%, 7%, 0%
2	[150, 200, 100]	[190, 175, 100]	19%, 5%, 0%
3	[200, 200, 150]	[235, 180, 150]	17%, 4%, 0%
4	[180, 250, 100]	[160, 250, 100]	10%, 0%, 0%
5	[200, 300, 110]	[190, 330, 100]	5%, 6%, 5%

the drone. These can be forward/reverse movement, turning right/left or moving up/down. To compute the drone's position with UWB, we implemented a multilateration method using the least squares method. The measurement error for each of the three axes was calculated using a target and measured positions, as well as a fixed maximum range of the axis. An example of the X-axis error calculation can be seen in Equation 1.

$$\text{Error X (\%)} = \frac{|\text{Target X} - \text{Measured X}|}{\text{Maximum Range of X}} \times 100\% \qquad (1)$$

4.1. Autonomous navigation without using a localization system

The first algorithm does not use the UWB localization system in its execution, and to detect its location, it relies solely on data from the drone's sensors, specifically the compass and ultrasonic sensor, to ensure movement altitude. The route to be traversed by the drone is given to the drone using a QR code that contains the detailed path in the form of a string of characters or directly in the Android app code. The movement itself is provided by Virtual Stick function. In the case of this method, the desired position is not specified since we do not know where the drone is located, but the exact path the drone has to take is given. We can calculate the distance required for precise movement using speed and time. Table 1 shows the desired position we want to achieve using navigation and also the actual position the drone has reached.

4.2. Autonomous navigation with partial use of the UWB localization system

In this autonomous navigation algorithm, the UWB localization system is already used, but only to a limited extent. This algorithm uses the localization system to find the drone's position after take-off. Once the initial position is obtained, it is used to calculate the route to the end point specified by the user in the mobile app. In the case of this autonomous navigation method, a point in three-dimensional space is selected as the target. Using the calculated distance from the target, the drone is controlled similarly to the first method.

For evaluation, unlike the previous method, this method allows the drone to be placed arbitrarily in space. The target points remained the same as in the previous method. Results of measurements are shown in Table 2.

4.3. Autonomous navigation with full use of the UWB localization system

The last navigation algorithm implemented is navigation with full use of UWB localization system. For this algorithm, the localization system is used during the entire flight path of the drone. It is also necessary to specify the target point in a three-dimensional space. The method of entering the target point is the same as in the second autonomous navigation algorithm. Therefore, it is specified by the user in the app with a text window. The position of the drone obtained by the localization system is used to ensure the movement of the drone to the target point. Movement along a given axis in three-dimensional space is performed until the drone is near the target point on that axis. Movement is performed along the X-axis, then along the Y-axis, and last along the Z-axis.

Table 3 Results for navigation accuracy with full use of the UWB localization system

ID	Target Position [X, Y, Z](cm)	Measured position [X, Y, Z](cm)	Error [X, Y, Z] (%)
1	[150, 250, 60]	[165, 275, 0]	7%, 5%, 30%
2	[150, 200, 100]	[165, 215, 0]	7%, 3%, 50%
3	[200, 200, 150]	[210, 205, 0]	5%, 1%, 75%
4	[180, 250, 100]	[180, 245, 0]	0%, 1%, 50%
5	[200, 300, 110]	[210, 320, 0]	5%, 4%, 55%

In the last method of localization, the drone can also be arbitrarily placed in space as in the previous method. This method already uses a UWB localization system for Z-axis localization versus the ultrasonic sensor of the previous method. However, the system was unable to determine the Z-axis position accurately, making Z-axis navigation unsuccessful. Therefore, the Z-axis values were substituted for zero in all measurements. As seen in the Table 3, full use of UWB navigation had the lowest error in both X and Y axes, making it the best autonomous navigation system for our case.

5. CONCLUSION

This paper dealt with the issue of autonomous DJI Mini 3 drone navigation in an indoor environment. The main objective was to design and implement a system allowing the drone to safely and efficiently navigate in space without a GPS signal. We designed and implemented a mobile Android application with a UWB localization system, which allows for the drone control and integration of localization data from UWB sensors. We have designed and implemented three different autonomous navigation algorithms with varying levels of UWB integration. We performed measurements and evaluated the accuracy of implemented navigation algorithms. The results of the measurements showed that navigation accuracy increased with the use of the UWB localization system, but the Z-axis accuracy is still problematic.

While our system may not represent the state-of-the-art indoor drone localization or navigation, our goal was to explore a cost-effective, modular solution using UWB and Android-based control in constrained indoor spaces. While we report positional errors as percentages, more standardized metrics, such as mean error, accuracy variance, and latency, would enable more direct comparisons with state-of-the-art methods.

In future work, we aim to address the Z-axis accuracy limitations, which we believe are caused by the flat placement of anchors, by testing a configuration with at least one anchor positioned significantly higher to improve vertical geometric diversity. In addition, we plan to explore sensor fusion by combining UWB data with inputs from barometers, IMUs, or altimeters, using filtering techniques like Kalman filters to improve stability and accuracy. We also see potential in AI-based methods, such as neural networks, to learn and correct position errors across all axes.

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REFERENCES

[1] BILLA, A. – SHAYEA, I. – ALHAMMADI, A. – ABDULLAH, Q.– ROSLEE, M.: *An overview of indoor localization technologies: Toward IoT navigation services*, 2020 IEEE 5th International Symposium on Telecommunication Technologies (ISTT) , No. 76–81 (2020) IEEE

[2] KRUPÁŠ, M. – ORLOVSKÝ, V. – ZOLOTOVÁ, I.: *Integration of Human Localization into Augmented Reality Applications*, 2025 IEEE 23rd World Symposium on Applied Machine Intelligence and Informatics (SAMI) , No. 000453–000458 (2025) IEEE

[3] MACOIR, N. – BAUWENS, J. – JOORIS, B. – VAN HERBRUGGEN, B. – ROSSEY, J. – HOEBEKE, J.– DE POORTER, E.: *UWB localization with battery-powered wireless backbone for drone-based inventory management*, Sensors **19**, No. 3 (2019) 467

[4] MIRANDA, V. R. F. – REZENDE, A. M. C. – ROCHA, T. L. – AZPÚRUA, H. – PIMENTA, L. C. A. – FREITAS, G. M.: *Autonomous navigation system for a delivery drone*, Journal of Control, Automation and Electrical Systems **33**, No. 141–155 (2022) Springer

[5] GUO, K. – LI, X. – XIE, L.: *Ultra-wideband and odometry-based cooperative relative localization with application to multi-UAV formation control*, IEEE Transactions on Cybernetics **50**, No. 6 (2019) 2590–2603

[6] YOU, W. – LI, F. – LIAO, L. – HUANG, M.: *Data fusion of UWB and IMU based on unscented Kalman filter for indoor localization of quadrotor UAV*, IEEE Access **8**, No. 64971–64981 (2020) IEEE

[7] FONTAINE, J. – RIDOLFI, M. – VAN HERBRUGGEN, B. – SHAHID, A. – DE POORTER, E.: *Edge inference for UWB ranging error correction using autoencoders*, IEEE Access **8**, No. 139143–139155 (2020) IEEE

[8] DJI.: *DJI Mini 3*, , No. (2024) Available at: `https://www.dji.com/sk/mini-3` [Accessed: 04-Apr-2024]

[9] MAKERFABS.: *ESP32 UWB DW3000 (Ultra Wideband)*, , No. (2024) Available at: `https://www.makerfabs.com/esp32-uwb-dw3000.html` [Accessed: 30-Apr-2024]

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