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# 3D millimeter-Wave Sensing vs Ultra-Wideband Positioning

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***Abstract*—Indoor positioning and sensing using millimeter-wave (mmWave) and Ultra-Wideband (UWB) technologies have garnered significant attention in the literature. While extensive research exists on 2D positioning with these technologies, a notable gap remains in addressing 3D positioning. Existing studies predominantly focus on the horizontal plane of localization, overlooking the necessity of vertical dimension integration. This paper identifies this and directly compares mmWave and UWB for 3D localisation. Addressing this gap, our work conducts a comparative analysis of 3D sensing with mmWave and 3D positioning with UWB technologies, evaluating the accuracy, robustness, efficiency, and associated challenges. This research underscores the need for future investigations to explore and assess the performance of these technologies in three dimensions.**

***Index Terms*—3D, indoor, localization, millimeter-Wave, ultra-wideband, sensing, positioning**

## I. Introduction

Over the past few decades, extensive research was conducted to address the challenge of localization in satellite-obstructed environments, utilizing various radio technologies. Many solutions and methodologies have been proposed, however, the majority of these solutions focus solely on estimating positions along the horizontal ($x - y$) plane, disregarding the vertical ($z$) dimension. This lack of vertical information poses challenges, particularly in achieving precise positioning of Unmanned Aerial Vehicles (UAVs) in 3D space. In such scenarios, accuracy better than the sub-meter level is imperative to prevent collisions. We provide in [1] a comprehensive survey of technologies and approaches for 3D localization.

To address this demand, millimeter-wave (mmWave) and Ultra-Wideband (UWB) positioning systems emerged as promising technologies, offering high accuracy and robustness in complex environments. mmWave is currently used in some Wi-Fi systems (e.g. IEEE802.11ad) while it is planned to be used in 5G communications due to its flexibility to use wider bandwidths and hence its strong potential in achieving much higher data rates and capacity. mmWave systems typically operate in frequencies between 26 to 300$GHz$. Their very large availability of bandwidth which leads to fine timing (and hence ranging) resolution and together with the ease of using phase array antennas (at those frequencies) that enable the estimation of the phase (and hence the angle) could be used for achieving decimeter 3D positioning accuracy or better [2]. UWB is a short-range wireless technology which uses much wider bandwidths compared to narrow-band transmissions typically used in Wi-Fi systems. UWB systems typically use frequencies ranging from 3.1 to 10.6 $GHz$ but the bandwidth needs to be at least 20% of the central frequency. In addition, instead of measuring the signal strengths (RSS), the positioning is achieved by using Time of Arrival (ToA). The advantage of UWB technology over other narrowband Radio Access Technologies is the "spatial awareness" it facilitates since the wide bandwidth allows for better resolution in the time domain hence better range estimates. The localization accuracy could reach the decimeter level (10-30$cm$), in comparison to GPS (1-3$m$) or legacy Wi-Fi techniques (2-10$m$) [3].

The use of UWB and mmWave for indoor positioning and sensing respectively has been reported extensively in the literature. While there has been considerable research in 2D using these technologies, there is a recognized gap when it comes to 3D positioning. Achieving accurate and reliable 3D positioning presents additional challenges due to the need to consider vertical dimensions as well [4] requiring more data, more degrees of freedom and more complex geometrical mathematical solutions. To the best of our knowledge, there have not been studies directly comparing mmWave and UWB for 3D indoor localization. This work focuses on the comparison between the 3D sensing using mmWave and 3D positioning using the UWB technologies. The comparison includes the accuracy, robustness and efficiency of each approach as well as discusses the challenges that come with each technology.

The utilization of mmWave in various applications has undeniably demonstrated its potential for high precision and accuracy [5]. However, unlike technologies that use receiver-transmitter relationships such as UWB, a notable challenge associated with mmWave arises from its radar-like operation, especially in the context of identifying multiple objects. The mmWave sensor emits high-frequency electromagnetic waves that bounce off surrounding objects and return as echoes. These echoes can become mixed together in complicated environments, making it difficult to differentiate specific objects. This becomes especially more challenging when using multiple sensors and is particularly critical in applications like indoor people activity tracking or autonomous vehicle navigation, where the ability to discern and track multiple objects with precision is paramount. On the other hand, an issue with UWB (also with mmWave) is the limited range and the necessity for an unobstructed Line-of-Sight (LoS) between the anchor and target. This constraint necessitates a higher number of transmitters within indoor environments, consequently elevating the overall implementation cost.

The remainder of this paper is organized as follows: in Section II the recent related works and developments in 3D localization using mmWave and UWB technologies are presented while Section III describes the methodology and setup used for the precision analysis and the 3D positioning accuracy experimentation. Section IV presents the results of the range precision analysis conducted using two off-the-shelf mmWave and UWB sensors as well as the accuracy achieved using a 3D multilateration approach. Finally, in Section V we provide a critical discussion and conclusion.

## II. Related Work

In recent years, UWB has received a lot of interest for indoor localization. Several systems were implemented commercially, while many others are being utilised in experimental testbeds such as those provided by Decawave and Bespoon. These systems have been thoroughly researched and validated for specific purposes. Other activities were focused on the Non-Line-of-Sight (NLOS) problem that is a primary source of inaccuracy in UWB ranging and positioning and is still an open topic of research [6]. The authors of [7] propose an UWB positioning system which utilizes a two-way-time-of-flight (TWTF) for range measurements which, when used in a multilateration estimation algorithm, yielded an average 3D accuracy of 100±25$mm$. In [8], the authors propose a 3D ToA algorithm using UWB in which they replaced the quadratic term in the positioning estimation with a new variable using the weighted least squares linear estimation followed by a Kalman filter. The simulation results indicated that the positioning accuracy can reach 5-10$cm$. [9] presents a novel approach for UWB self-localizing anchor-system calibration that uses a calibration unit (CU) for improved localization accuracy. This study confirmed that the use of the CU decreases the average positional error of the anchors in 3D UWB localization systems and hence achieving better positioning accuracy of around $0.32m$.

Given this accuracy potential, UWB is established as a promising technology for robust high-precision positioning, and hence is used in various applications; one of them is Mobile Laser Scanning (MLS). MLS is widely used in 3D city modelling data collection, such as Google Maps that include Building Information Modelling (BIM) to create 3D building models. Static laser scanning is usually used to generate BIM 3D models, but this method appears inefficient if buildings are large or complex. The researchers in [10] propose the use of MLS for BIM 3D data collection while they use high-precision UWB tags to determine the positions and attitudes of the mobile laser scanner which are important for the correct georeferencing of the 3D models. The accuracy of UWB-based MLS 3D models is assessed by comparing the coordinates of target points, as measured by static laser scanning and a total station survey. Results indicate a centimetre positioning accuracy on the horizontal plane (around $8cm$), but decimetre accuracy on the vertical plane (around $19cm$).

From the mmWave positioning perspective, while research is still in its early stages, early works reveal its potential to deliver the high accuracy demanded by modern smart applications. In our recent works, we demonstrated the potentials and challenges for mmWave 3D single-target positioning [3], [5] demonstrating accuracy in the decimeter level (around $17cm$). Some other works include systems which utilize a single mmWave base station setup as described in [11] in which the authors propose a method that fuses user equipment (UE) motion features, mmWave Line-of-Sight (LoS), and first-order reflection paths' AoA and ToA for indoor positioning. They present an improved Least Mean Square (LMS) algorithm to refine multipath AoA estimation and a modified multipath unscented Kalman filter (UKF) for position tracking. The results of these methods show significant enhancements in LoS-AoA estimation and centimeter-level 3D positioning accuracy of around $60cm$. Notably, this strategy is effective even in scenarios with insufficient anchor nodes. A similar approach, in [12], leverages multipath channels, with Multiple-Input Multiple-Output (MIMO) antennas estimating the AoA of multipath coherent signals, while Spatial smoothing algorithms are applied in the frequency domain to estimate the Time Difference of Arrival (TDoA) of those signals. This approach has been validated through simulations in a $6m$ x $8m$ x $4.5m$ indoor space. The results indicate that positioning accuracy using a single sensor reaches sub-meter levels in 95% of cases and is less than $0.4m$ in 60% of cases. The richness of multipath components in mmWave systems is also exploited in [13] which introduces a Multipath-Assisted Localization (MAL) model based on the mmWave radar approach for indoor electronic device localization. This model effectively incorporates multipath effects when describing reflected signals, enabling precise target position determination using the MAL area formed by the reflected signal. Importantly, this model can provide 3D target information even when traditional Single-Input Single-Output (SISO) radar falls short. A $60GHz$ signal-based positioning and tracking system is discussed in [14], which effectively filters out multiple reflections and diffuse scattering, ensuring a high level of accuracy. Operating within a longitudinal range of $0.46m$ to $5.55m$ and a lateral span from $1.91m$ to $3.04m$, the system determines the target's position by calculating the local centroid in the associated point cloud. Overall, the system achieves a plane positioning accuracy with a 99% confidence level and an error of approximately 30–40$cm$. Another AoA-based work is presented in [15] in which authors conduct AoA and signal measurements in a $35m \times 65.5m$ open space, achieving position accuracy ranging from $16cm$ to $3.25m$. A hybrid approach is presented in [16], where a novel 3D indoor positioning scheme using mmWave massive MIMO systems is based on the combination of Received Signal Strength (RSS) and AoA positioning scheme, which employs only a single access point equipped with a large-scale uniform cylindrical antenna array. They demonstrate that their approach achieves azimuth and elevation precision around 0.5 degrees depending on the quality of the received signal.

mmWave-sensing has started being combined with various other communication technologies following the modern trend of Integrated Sensing and Communication (ISAC) trend, like the Reconfigurable Intelligent Surfaces (RIS). RIS renowned for their ability to controllably manipulate radio propagation are also gaining attention from researchers working on positioning. For instance, in [17], the authors propose a 3D positioning algorithm for a mmWave system leveraging RIS. They use a Two-Stage Weight Least Square (TSWLS) algorithm to obtain the mobile user position. Similarly in [18] the authors address the channel estimation for RIS-aided mmWave communication systems based on a localization method. They propose the concept of Reflecting Unit Set (RUS) to improve the flexibility of RIS. The authors then propose a novel coplanar maximum likelihood-based (CML) 3D positioning method based on the RUS and derive the Cramer-Rao lower bound (CRLB) for the positioning method. They demonstrate that cm-level accuracy can be achieved averaging around $5cm$ depending on the received signal quality.

Applicaiton-wise, drone 3D localization is popular within the research community. For example, in [19] the authors presented a self-localization system for autonomous drones that utilizes a single mmWave anchor demonstrating a median localization error of $7cm$ and a $90^{th}$ percentile less than $15cm$, even in NLOS scenarios. Similarly, [20] presents an active drone detection system that uses a mmWave radar mounted on a drone to estimate 3D position of a drone using 2D measurements indicating an average 3D positioning error of $2.17m$. In [21] the authors developed a 3GPP-compliant drone-based 3D indoor localization solution employing an integration of time-based and angle-based techniques to improve the position awareness in emergency situations and support emergency services. They have managed to achieve a horizontal and vertical positional error $1.05m$ and $0.7m$ at $26GHz$. A similar work is presented in [22] where the authors propose a security system based on a mmWave radar, using Machine Learning (ML) techniques, achieving 99.32% accuracy and 99.54% F1 score. Another work utilizing ML is presented in [23], where a custom CNN model achieves an accuracy of 95%. Other interesting works include [24], where the authors theoretically derive the Cramér-Rao Bound (CRB) for position and rotation angle estimation uncertainty using mmWave signals from a single transmitter, even in the presence of scatterers. They demonstrate that under open Line of Sight (LoS) conditions, it is feasible to estimate a target's position and orientation angle by leveraging information from multipath signals. However, this approach comes with a noticeable performance penalty. Additionally, the authors of [25] showcase the advantages of array antennas in determining a device's orientation. Notably, the accuracy of mmWave technology-based positioning appears to be closely linked to the distance from the target.

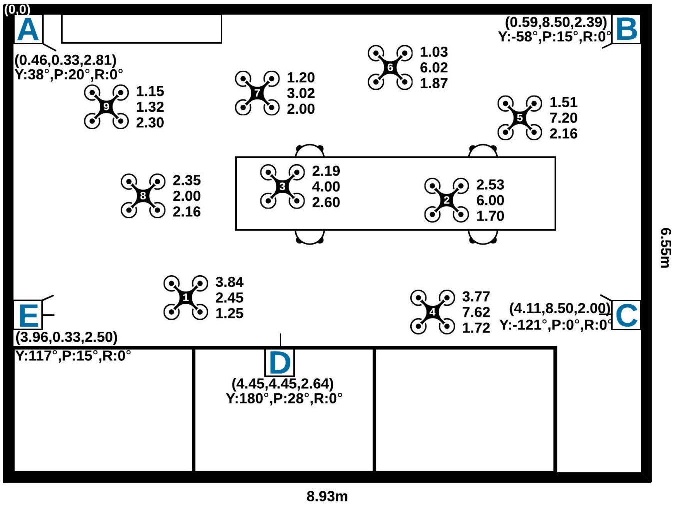


Fig. 1. mmWave and UWB 3D Positioning Experimental Setup (Y: Yaw, P: Pitch, R: Roll)

## III. Methodology

### A. System Overview

The methodology to conduct the research comparison posed in the introduction is presented in this section, describing the experimental system setup and equipment used while considering the particular challenges the available mmWave and UWB products impose towards achieving the desired 3D positioning accuracy. For each of these technologies, we performed a precision analysis of the most predominantly-used mmWave and UWB ranging sensors currently in the market and thereafter used ranging estimates collected during the experimental process to conduct positioning using a standard 3D multilateration approach.

### B. Equipment

The UWB sensor that was used was the Nanotron's BN01SWBEP Swarm Bee ER Module. The sensor operates at frequencies between 3.5-6.5$GHz$ with ranging capabilities of up to 50 meters. Considering the receiver-transmitter relationship of the UWB sensors, the modules can measure the distance between each other using the Time-of-Flight (TOF) approach and according to the manufacturer they achieve ranging precision of around $10cm$. On the other side, the mmWave radar sensor used was the Texas Instruments (TI) IWR1843BOOST. The TI sensor has 4 Receiving (Rx) and 3 Transmitting (Tx) antennas operating at frequencies between 76-81$GHz$ with a 120-degree field of view and ranging capabilities of up to 72 meters. The sensor possesses a Frequency Modulated Continuous Wave (FMCW) transceiver which enables the measurement of range, velocity, azimuth and elevation angles of the target. Each sensor is connected to a Raspberry PI that parses the collected data and sends it to a central PC through a UDP connection. The experimental setup involved utilizing a DJI Air 2S drone as the target for ranging and angular measurements. It is a compact drone with dimensions of $183.0{\times}77.0{\times}253.0mm$.

### C. Experimental Setup

Both the precision analysis and the 3D positioning accuracy experimentation using both sensors were carried out in an $8.85m \times 6.85m$ engineering laboratory (height: $3.5m$) the top-view of which is shown in Figure 1. The setup includes five IWR1843BOOST mmWave sensors and five BN01SWBEP swarm bee UWB sensors, each positioned and oriented differently while targeting the center of the room (indicated with different capital letters in Figure 1). The UWB sensors are placed directly above the mmWave sensors to ensure identical experimentation and facilitate fair comparison. Due to the receiver-transmitter architecture of the UWB sensors, an additional sensor was mounted on top of the drone to establish communication between all the sensors.

*1) Precision Analysis:* The precision analysis was conducted to compare the ranging capabilities of the two sensors. Range measurements were collected every $0.5m$ while the drone flew in a straight line in front of the sensors (0.5 to $6.5m$). To assess the ability of the sensors to conduct range measurements at different angles, the orientation of the sensor was systematically varied from 0 to 45 degrees (15-degree step). This comprehensive analysis aimed to gather precise data on the sensors' precision, resolution, and reliability at different distances and angles.

*2) 3D Positioning Accuracy:* Regarding the positioning accuracy investigation, an experiment was set up to assess the accuracy and efficiency of positioning using UWB and mmWave sensors. The objective was to precisely determine the 3D position of the hovering drone by estimating its local coordinates based on range measurements obtained from the sensors. The setup commenced with the deployment of the drone which had a UWB sensor strategically positioned atop the drone's frame, capable of emitting and receiving UWB signals. Conversely, mmWave sensors, functioning similarly to radar systems, independently detected the drone without the need for an additional onboard sensor, utilizing a radar-like technique to discern its position. Randomly scattered points within the laboratory served as target locations for the hovering drone. These points were selected to encompass varying heights to simulate real-world scenarios. As the drone hovered over each designated point, the UWB and mmWave sensors continuously measured the distances between the drone and each of the fixed sensors in the corners of the lab. The collected distance measurements from both the UWB and mmWave sensors were then used in a multilateration algorithm [26], designed to calculate the 3D position of the drone relative to the fixed reference points in the laboratory. The process was repeated for multiple randomly scattered points, spanning various heights, to validate the robustness and accuracy of the multilateration technique under diverse conditions.

## IV. RESULTS

*1) Precision Analysis:* To evaluate the range estimation performance of the BN01SWBEP and IWR843BOOST a range precision experimentation was carried out using the setup described in section III-C. This study was meticulously designed to assess the accuracy and reliability of these sensors under controlled conditions. Both sensors were securely mounted on a tripod, which remained stationary throughout the experiment. Our objective was to determine how effectively each sensor could detect the range of an object, in this case, a drone, as it was gradually moved away from the sensors. The precision analysis was conducted in a linear progression, where the drone, equipped with a UWB sensor to facilitate detection by the UWB setup on the tripod, was incrementally moved back from an initial position of 0 to $6.5m$, at intervals of $0.5m$, concurrently adjusting the orientation angle of the sensor from 0 to 45 degrees to assess the impact of orientation on measurement accuracy. This methodological approach allowed us to collect data at each half-meter step, providing a detailed analysis of the sensors' performance over a range of distances. The mounting of a UWB sensor on the drone was critical for the setup, as UWB technology operates on a receiver-transmitter principle, necessitating direct communication between the two UWB devices to measure distances accurately.

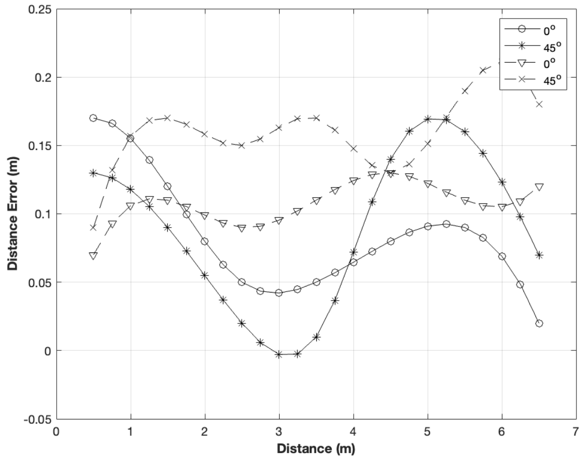


Fig. 2. UWB vs mmWave Precision Analysis

The results of the precision analysis offered useful insights into the ranging capabilities of mmWave and UWB sensors. Overall, both sensors demonstrated fairly good ranging precision within the values suggested by their manufacturers both

TABLE I
MMWAVE VS UWB PRECISION ANALYSIS

| Distance $(m)$ | UWB Precision $(m)$ | | mmWavePrecision $(m)$ | |
|---|---|---|---|---|
| | **0 degrees** | **45 degrees** | **0 degrees** | **45 degrees** |
| 0.5 | 0.17 | 0.13 | 0.07 | 0.09 |
| 1.5 | 0.12 | 0.09 | 0.11 | 0.17 |
| 2.5 | 0.05 | 0.02 | 0.09 | 0.15 |
| 3.5 | 0.05 | 0.01 | 0.11 | 0.17 |
| 4.5 | 0.08 | 0.14 | 0.13 | 0.13 |
| 5.5 | 0.09 | 0.16 | 0.11 | 0.19 |
| 6.5 | 0.02 | 0.07 | 0.12 | 0.18 |
| ***Average*** | ***0.08*** | ***0.09*** | ***0.11*** | ***0.15*** |
| ***St Dev*** | ***0.05*** | ***0.06*** | ***0.02*** | ***0.03*** |

TABLE II
MMWAVE VS UWB 3D MULTILATERATION POSITIONING ACCURACY

| **Point** | **mmWave** | | | | **UWB** | | | |
|---|---|---|---|---|---|---|---|---|
| | **XYZ Error($m$)** | | | **3D Error($m$)** | **XYZ Error($m$)** | | | **3D Error($m$)** |
| | **x** | **y** | **z** | | **x** | **y** | **z** | |
| 1 | 0.10 | 0.04 | 0.25 | 0.27 | 0.36 | 0.38 | 0.15 | 0.54 |
| 2 | 0.30 | 0.16 | 0.46 | 0.57 | 0.16 | 0.15 | 0.10 | 0.24 |
| 3 | 0.15 | 0.04 | 0.05 | 0.16 | 0.09 | 0.00 | 0.20 | 0.22 |
| 4 | 0.32 | 0.02 | 0.62 | 0.70 | 0.31 | 0.06 | 0.08 | 0.33 |
| 5 | 0.09 | 0.10 | 0.31 | 0.34 | 0.14 | 0.15 | 0.26 | 0.33 |
| 6 | 0.16 | 0.09 | 0.08 | 0.20 | 0.10 | 0.00 | 0.03 | 0.10 |
| 7 | 0.05 | 0.06 | 0.09 | 0.12 | 0.14 | 0.11 | 0.30 | 0.35 |
| 8 | 0.10 | 0.09 | 0.01 | 0.13 | 0.13 | 0.05 | 0.24 | 0.28 |
| 9 | 0.03 | 0.09 | 0.08 | 0.13 | 0.21 | 0.11 | 0.10 | 0.26 |
| ***Average*** | ***0.14*** | ***0.08*** | ***0.22*** | ***0.29*** | ***0.18*** | ***0.11*** | ***0.16*** | ***0.30*** |
| ***St Dev*** | ***0.10*** | ***0.04*** | ***0.21*** | ***0.21*** | ***0.09*** | ***0.11*** | ***0.09*** | ***0.12*** |

at 0 degrees as well as at 45 degrees up to distances of 6.5$m$ as indicated in Table I and Figure 2. Specifically, the UWB sensor demonstrated an average range error of 8$cm$ at $0^o$ and 9$cm$ at $45^o$ with standard deviation of 5$cm$ and 6$cm$ respectively. On the other side, the mmWave sensor demonstrated an average range error of 11$cm$ at $0^o$ and 15$cm$ at $45^o$ with standard deviation of 2$cm$ and 3$cm$ respectively. A first conclusion out of these results is the fact that UWB sensors are quite insensitive to the angle between the anchor and the target which is attributed to the transmitter-receiver operation of this technology. On the other hand, mmWave sensors precision appears to decay as the target starts to move aside from foresight ($0^o$) which is reasonable given the radar-like operation of mmWave sensors. It is worth noting that the manufacturer of the mmWave sensors indicates a field of view of $60^o$ for this specific sensor. Another critical observation is the superior accuracy of the UWB sensor over the mmWave sensor, a trend that held true across both tested angles. This discrepancy highlights the UWB sensor's enhanced sensitivity and precision in detecting distances even at the most straightforward, direct alignment. This superior ranging performance of the UWB sensors could be attributed to the fundamental differences in the ranging principles of mmWave and UWB. mmWave operates based on the principle of reflection from the drone's surface, meaning the error is influenced by the dimensions of the drone since reflections can originate from any point on its surface. The average ranging error of the mmWave sensor is less than the dimensions of the drone which indicates that the measurements are within reasonable limits. In contrast, UWB sensors measure the range from the specific point where the sensor is mounted on the drone. Consequently, considering the drone's dimensions, the observed differences in accuracy may not be as significant as they initially appear.

*2) 3D Positioning Accuracy:* The mmWave and UWB sensors demonstrated relatively similar performance as shown in Table II, with mmWave achieving an average 3D positioning accuracy of 0.29$m$ and UWB averaging around 0.30$m$. This was surprising, as UWB sensors typically slightly outperform mmWave in precision analysis. However, it was observed that during the positioning experiments, when all 6 UWB sensors were connected and functioning simultaneously, the ranging distances sometimes exhibited jitter, resulting in sensor reading inaccuracies which could potentially affect the overall positioning accuracy. Another observation is that mmWave demonstrated better accuracy in the X and Y axes, with errors of 0.14$m$ for X and 0.08$m$ for Y, compared to UWB's 0.18$m$ and 0.11$m$, respectively. Conversely, UWB showed superior accuracy in the Z axis, with an error of around 0.16$m$ compared to mmWave's 0.22$m$. Thus, while the overall 3D positioning errors were relatively similar, each technology exhibited distinct performance characteristics in different axes. Also UWB's lower value of standard deviation indicated that it is more consistent.

## V. DISCUSSION & CONCLUSION

In this paper, we have compared the potential of mmWave and UWB sensory technologies for accurate cm-level 3D indoor localization by performing a ranging precision analysis and a 3D indoor localization experimentation using a standard multilateration approach. Each technology imposes several challenges, difficulties, and limitations when it comes to setting up and using a multi-sensor 3D positioning system. Considering the fact that UWB has slightly out performed mmWave during the precision analysis, both mmWave and UWB have managed to achieve a relatively similar 3D accuracy of 0.29$m$ and 0.3$m$ respectively.

mmWave sensing and UWB positioning each offer unique advantages and disadvantages, particularly in the context of 3D positioning. Given its radar-like operation, mmWave sensing does not require an additional sensor on the device, enabling it to detect and position any object within its field of view. This makes it highly suitable for detecting non-radio-enabled targets (e.g. humans in crowd-sourcing applications). This versatility, however, comes with the challenge that only moving objects can be detected utilizing the Doppler shift principle ensuring that reflections from the surrounding clutter are not regarded as targets. It even gets more difficult in multi-target scenarios where sophisticated clustering and filtering solutions are needed to accurately identify the various targets. Additionally, mmWave technology ranging precision can vary depending on which part of the object it reflects from, potentially affecting measurement consistency, a crucial factor in 3D positioning as shown during the precision analysis. UWB positioning, by contrast, excels in its ability to penetrate obstacles, providing a more reliable signal in complex environments. Its receiver-transmitter setup ensures that the device is always detected at the same point, yielding more stable and consistent results compared to mmWave. This consistency is particularly beneficial in 3D positioning, where maintaining accurate vertical measurements is crucial. Although UWB requires an additional sensor on the target, this setup can be more robust and reliable in multi-target situations. Moreover, literature reports that with UWB sensors, autocalibration of anchor locations becomes possible, making it a very attractive solution when positioning networks need to be set up opportunistically and quickly, such as in locating first responders in emergency situations. In conclusion, while both technologies offer comparable overall 3D positioning accuracy, the choice between mmWave and UWB depends on specific application needs. mmWave is advantageous for its broad detection capability without needing additional sensors, which is beneficial for applications requiring the tracking of various objects within a space. Conversely, UWB excels in providing consistent and reliable measurements in cluttered environments, making it a more robust solution for precise 3D positioning, particularly when rapid deployment and autocalibration are required. The distinctions between the two technologies highlight the trade-offs between sensing flexibility and measurement consistency, each offering unique benefits for different 3D positioning scenarios. Additionally, the inherent differences between sensing with mmWave and positioning with UWB stem from their operational principles. mmWave, functioning without a dedicated sensor, requires advanced data processing to identify objects accurately, particularly in three dimensions. UWB's reliance on a receiver-transmitter setup ensures fixed detection points, which is advantageous for maintaining accuracy in all three spatial dimensions. These differences underscore how the choice of technology impacts the approach to achieving precise 3D localization.

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