

Performance Comparison of Radio Frequency-based Angle-of-arrival and Ranging Solutions

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This project conducts an extensive indoor analysis to assess the performance of several radio frequency (RF) based technologies that estimate the angle-of-arrival (AoA) and the distance of a tag with respect to an anchor. In addition, these technologies are compared with a vision-based solution using a camera and an ArUco marker. The aim is to benchmark state-of-the-art solutions in view of industrial applications such as asset tracking, industrial IoT and robotics

The received signal strength indicator (RSSI) has been widely used for localization in wireless communication systems. However, RSSI is influenced by various environmental factors such as multipath propagation, interference, and shadowing, which can lead to unpredictable fluctuations in signal strength even within a relatively stable environment. These fluctuations result in inaccurate position estimations. This project investigates state-of-the-art RF-based solutions for AoA and ranging (distance estimation) to achieve robust and accurate localization. We benchmarked them against a vision-based solution because of its reliability. Figure 1 presents the system architecture.

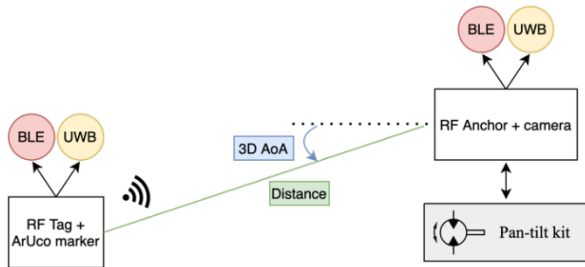


Figure 1: System architecture of RF and vision setup.

The system consists of a RF tag and anchor. While the tag has a single antenna, the anchor has up to 16 antennas to be able to estimate the 3D AoA based on their phase difference. We assess the performance of both an off-the-shelf Bluetooth Low Energy (BLE) and Ultra-wideband (UWB) solution. As opposed to the UWB solution from NXP which provides both AoA and distance, for the BLE we use two different boards: one from Silicon Labs for the AoA (standardized in Bluetooth 5.1) and one from Nordic for distance (not standardized yet). For all solutions, we use the AoA and distance algorithms provided by the supplier.

The anchor is installed on a pan-tilt kit to automatically adapt its orientation during the measurements in both the horizontal direction (azimuth) and vertical direction (elevation). In addition, a reference vision-based solution consisting of an ArUco marker and a camera is used as ground truth. Based on the position of the marker on the camera frame, the AoA and distance is determined. Using this setup in Figure 2, we conducted an indoor measurement campaign at the CSEM headquarters.

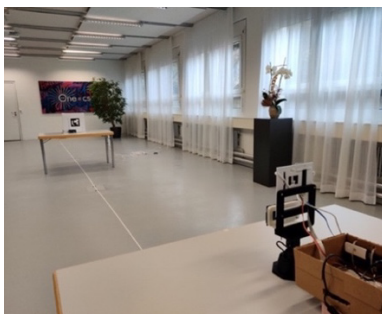


Figure 2: Indoor measurement setup at CSEM headquarters.

We place the RF tag and ArUco marker at different distances in a range of 0.2 m to 12 m with respect to the anchor and camera. The three RF solutions are installed sequentially on the pan-tilt kit. For every distance, we move the pan-tilt kit to a set of predefined orientations, varying its azimuth and elevation angle in a range of -60° to 60° . For every orientation, 50 data points are collected (distance/angle estimates) for the installed RF solution. Once these measurements are finished, the pan-tilt kit moves to the next desired orientation and the process is repeated.

Figure 3 shows the estimated azimuth angle of the UWB solution at 6 m. We observe that overall, the estimations match well with the ground truth provided by the pan-tilt kit. Furthermore, we see an increasing error in the estimation at the extreme angles.

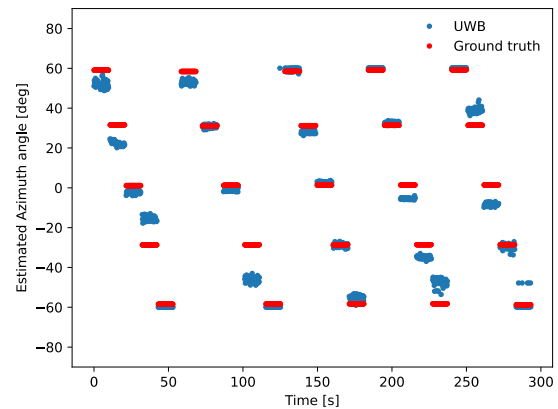


Figure 3: Estimated azimuth angle by UWB solution at 6 m.

Table 1 shows the average error and standard deviation of the estimations for all tested solutions. We conclude that the UWB solution outperforms BLE in both the absolute mean error (measure of trueness) and the standard deviation (measure of precision). Especially the UWB distance estimation shows a low standard deviation, enabling highly repeatable measurements.

Table 1: Performance result for AoA and distance estimation at 6 m.

	BLE azimuth [°]	BLE elevation [°]	BLE distance [m]	UWB azimuth [°]	UWB elevation [°]	UWB distance [m]
Absolute mean error	17.73	14.77	0.71	4.80	7.68	0.36
Standard deviation	6.03	3.43	0.23	1.61	1.84	0.01

As the indoor measurements were performed in a controlled environment, it might not reflect realistic conditions. Therefore, the next step includes performing measurements in real environments (both indoor and outdoor) to further validate the performance of BLE and UWB. We will especially focus on UWB due to its superior performance in the conducted measurements, making it suitable for industrial applications that require robust and accurate localization.