A Wireless Localization Network for 6D Pose Estimation

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***Abstract*—We present a wireless localization network (WLN) for the estimation of the 3D position and 3D orientation of an object. It consists of at least one reference radar node with known pose and a mobile node on the localized object. Using round-trip time of flight measurements and digital beamforming, the reference nodes can determine the distance and both spatial angles to the mobile node, thus locating it in 3D. We use an extended Kalman filter (EKF) to fuse these results with the readings from the mobile node and an inclinometer to determine the complete 6D pose of the mobile robot. Measurements in a realistic scenario proved the feasibility of the proposed concept.**

Keywords—wireless localization; 6D pose estimation; secondary radar; sensor fusion

I. Introduction

The wireless localization network (WLN) consists of two or more radar nodes (cf. Fig. 1). Every node is a single input multiple output (SIMO) frequency-modulated continuous-wave (FMCW) secondary radar with a center frequency of 24.125 GHz and a bandwidth of 250 MHz. As described in [1], the distance between two nodes is determined by the round-trip time of flight (RTOF) measurement principle using FMCW ramps. Each device has 1 Tx and 8 Rx channels suitable for digital beamforming. All nodes are identical in hardware, but run different software and are equipped with different antenna arrays depending on their role in the network.

II. Radar Nodes

Compared to state-of-the-art wireless local positioning techniques based on TDOA / TOA / RTOF ([2], [3]), the proposed WLN has the advantage of higher reliability and lower infrastructure cost, since a single measurement by a single reference node is in general sufficient for a 3D localization of the target. However, the use of multiple reference nodes at appropriate positions increases the accuracy of the localization.

A. Reference Node with Planar Antenna Array

The reference nodes are equipped with sparse planar antenna arrays. Each array comprises 8 patch antennas in an optimized 2D arrangement which enables the estimation of both the azimuth and elevation angles of arrival of the received signal. At broadside direction, the array has a sidelobe level (SLL) of −3.7 dB and a main beam width (MBW) of approximately 10°. The array has a compact aperture size of 70×47 mm. As described in [4] the array was connected to the radar node and a calibration procedure was applied. In a series of measurements in an office building foyer the unambiguous measurement range was determined to more than ±45° in both azimuth and elevation angles using the delay-and-sum beamformer. By combining the measured angles with the measured distance, the 3D position of the mobile node relative to a reference node can be estimated.

B. Mobile Node with Ring Antenna Array

The reference nodes are situated around the measurement site and only need to cover the area in front of them, i.e. in a measurement range of ±45° in azimuth and elevation. In contrast, the mobile node can be moved and rotated freely in the measurement site. For a complete coverage in every position of interest, it needs a measurement range of 360° in azimuth and

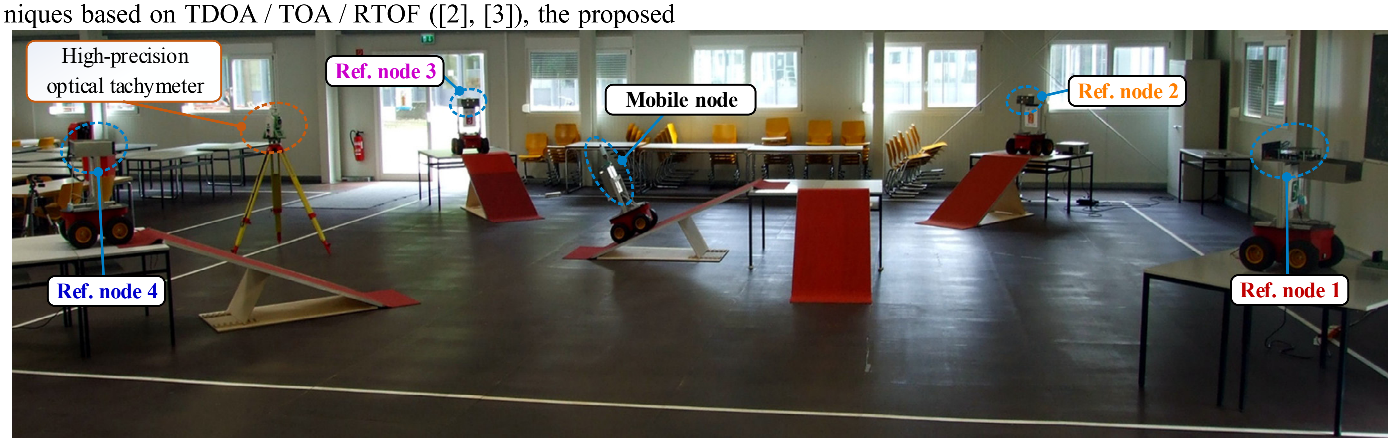

Fig. 1. Measurement scenario consisting of 4 reference radar nodes with known positions and a mobile node which is localized in 3D. The robots carrying the reference nodes are to be replaced by tripods or other infrastructure in the localization competition.

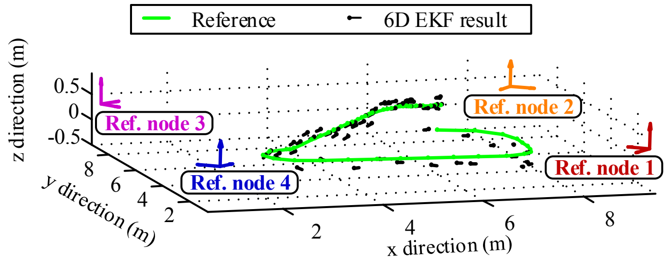

Fig. 2. Measured trajectory at Friedrich-Alexander-University Erlangen-Nürnberg (FAU) (3D view).

±45° in elevation. It uses a so-called ring antenna array consisting of 8 Rx patch antennas placed on the walls of an octagonal prism and a Tx antenna with omnidirectional coverage in azimuth. Using this arrangement, there always are at least three patch antennas receiving the line-of-sight signal from the target over the complete azimuth range. However, no elevation angle measurements are possible.

In order to fuse the results of the three sensor types (reference node, mobile node, inclinometer), an extended Kalman filter (EKF) is used.

III. Measurement Results

The 6D-EKF localization result of a mobile robot in the test scenario in Fig. 1 is depicted in Fig. 2. The black dots denote the 3D position and the black lines the 3D orientation of the mobile robot. The robot started on the table and drove down the ramp. This result demonstrates the very good overall WLN reliability and accuracy. The resulting 3D position root-mean square error (RMSE) was 16.8 cm and the maximum error 46.8 cm compared to a tracking high-precision optical tachymeter Leica TS30 [5]. As this is a dynamic scenario and the measurement rate was very limited in the used prototypes, we expect better results in a static measurement scenario. A further error source in this scenario are multipath reflections at the table and the ramps. An increase in the channel count can improve the localization accuracy. The result of the long-range measurement in Fig. 3 shows the applicability of the system also at longer distances. The RMSE of the distance measurement in this scenario was 6.2 cm.

IV. Deployment Requirements

The radar nodes are in aluminum casings sized 29×28×11 cm. The weight of a node is 2.5 kg. The power consumption is 30 W. If necessary, a LiPo battery can be used for cable-free operation. The reference nodes should be situated

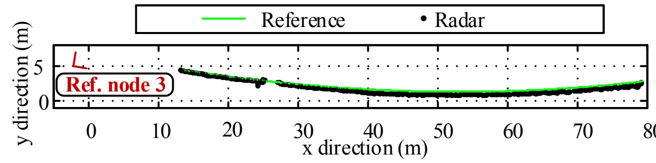

Fig. 3. Long-range measurement at distance of up to approximately 80 m.

around the measurement site as high as possible on tripods, resp. fixed to existing infrastructure using vises. Their 3D positions and orientations need to be accurately measured in a chosen frame of reference using a tachymeter. The signal processing takes place on the nodes and the result can be displayed on a laptop.

V. Conclusion

We presented a wireless localization network for 6D pose estimation. We successfully verified the system accuracy and reliability. For this reason, we believe that it can be an interesting proposal for the 2016 Indoor Localization Competition.

Acknowledgment

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