2D Measurement with Single Known Reference Position for Indoor Localization in European UWB Band

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Index: Angle-of-Arrival, FMCW radar, indoor environment

Abstract

In this paper, a hybrid 2D-Measurement technique is presented for the estimation of the remote position of an active reflector unit (Tag), in terms of radial distance and azimuth angle. The technique is based on Interferometry and FMCW multistatic radar system which operates in the European UWB frequency band [6-8.5 GHz]. The measurements have been performed in a real indoor environment for the line-of-sight case with respect to a single known reference position. The estimated root-mean-square errors observed are 2.1cm & 7.1° over [1 1.6] m & [45° 90°], respectively.

Introduction

The Indoor Localization with an accuracy under a meter-scale is a great challenge. Although, an accuracy of a meter-scale may be interesting to help people to find ways around museums, airports, malls but it is not adequate for many other situations [1]. Most of known techniques are based on radio-signature or time delay measurement which presents an accuracy of more than a meter. Another drawback is that the number of known references/anchors and their positions play an important role in the localization estimation. Generally, it requires at least three known positions for the location [2-3]. The presented system just requires a single known position for 2D localization and it uses a hybrid-technique based on Frequency-of-Arrival (FOA) and Frequency-Difference-of-Arrival (FDOA). The architecture, the technique and the system performance are presented in this paper which is used for the 2D position estimation of a remote active-Tag in a real Indoor Environment for a Line-of-Sight (LOS) case.

1. System Design Consideration and Implementation

1.1. System design and consideration

This paper describes a system using two jointly techniques, FMCW multistatic radar and optic's interferometry techniques, for 2D localization of a remote active-Tag. The main advantages of this system, compared to [1-3] are: only one known reference position is used for location-estimation and simultaneously, the multipath effects can be strongly reduced by shifting the frequency spectrum by the active-Tag (to be localized). This technique requires the measurements of the FOA and FDOA which lead to the computation of radial distance and azimuth-angle as Angle-of-Arrival (AoA), simultaneously. The system design consists of two main subsystems: Localization Base Station & the active-Tag. The schematic of the LBS, allowing the localization of an active-Tag by using FMCW radar technique, is shown in Fig 1.
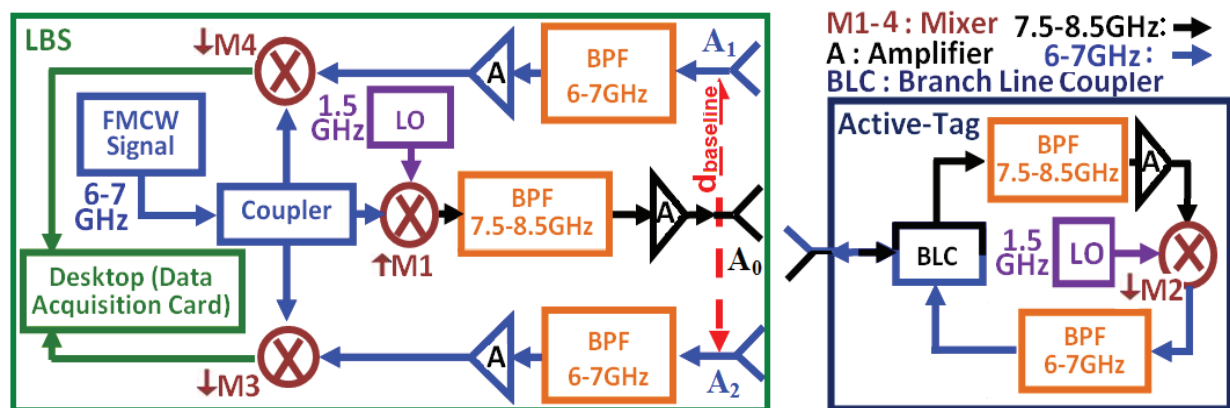

Fig. 1. On the left: Architecture defined for the LBS & active-Tag.

It consists of one transmitting antenna (A_0) and two receiving antennas (A_1 & A_2) which are placed closely on the same axis. A linearly swept sinusoidal FMCW signal covering the 6-7 GHz ($\Delta f=1$GHz) frequency is generated with a sweep time, $T_m=10$ msec, and then this signal is up-converted to 7.5-8.5 GHz and finally amplified before being transmitted by the antenna A_0 towards the active-Tag. The up-conversion is done with a Local Oscillator (1.5 GHz) and a mixer. Each RF chain of the LBS (two receivers and one transmitter) is connected to a dedicated circular polarized antenna [4-5]. The transmitter antenna is connected to a linearly

sinusoidal FMCW signal (6-7 GHz) generator via a 10dB coupler. The output of the coupled-port is taken as the reference signal, and that of the transmitter-port is attached to the transmitter antenna (A_0, see Fig 1-2). The transmitted antenna has used the LHCP waveform and the reception of the signal is considered as the RHCP waveform via an active-Tag.

The Active-Tag is used as a remote active-reflector. It includes a frequency down-converter (1.5GHz), two amplifiers, two bandpass filters (BPF), and a dual circular polarised antenna [6]. The incoming signal, from A_0, is down-shifted by 1.5GHz frequency. It helps in cancelling & suppressing the feedback in Tag and multipath effects produced by the radio channel as well as in reducing the coupling effects among the antennas- A_0, A_1, & A_2. The two bandpass filters ([7.5-8.5 GHz] & [6-7 GHz] frequency bands) are used to filter the downlink and uplink channels at the active-Tag. The retransmitted FMCW signal (6-7 GHz) from the tag is received by the two antennas (A_1 & A_2) separated by a distance denoted $d_{baseline}$ (Fig 1). The delays to reach A_1 and A_2 from the tag are T_{Delay1} & T_{Delay2}, respectively. The two receiver chains (Rx-Chain) of the LBS are identical and based on a heterodyne structure. Each one consists of a bandpass filter (6-7 GHz), a low noise amplifier and a mixer for the down conversion of incoming signals from 6-7 GHz to baseband signals by mixing with the reference signal (generated FMCW signal, 6-7 GHz).

The realized Indoor Localization System (ILS) is shown in Fig 2; the active-Tag and LBS are shown on the left and right sides, respectively.
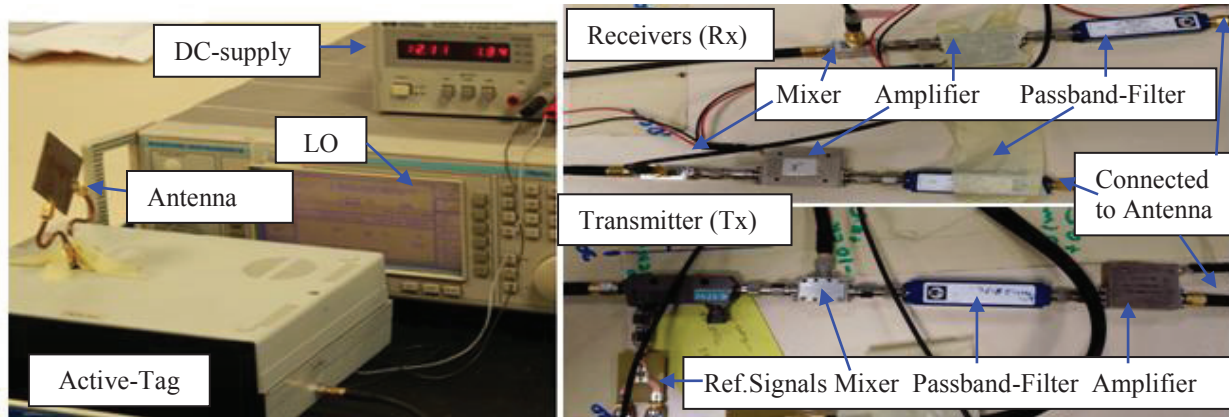

Fig. 2.   Realized ILS: Active-Tag & LBS.

The photo of the active-Tag shows the antenna mounted on a white-box which contains the filters and mixers as the architecture presented in Fig 1. The active-Tag uses a dedicated dual circular polarized antenna designed for the European UWB band, 6-8.5GHz [6]. For the active-Tag, a single antenna is used for the reception and transmission of the signals with different circularly polarizations of radio-frequency waveforms. The RHCP (right hand circular polarized) waveform (7.5-8.5 GHz) is used for the signal's reception and the LHCP (left hand circular polarized) waveform is used for the retransmission of the down-shifted signal (7.5-8.5 GHz), simultaneously.

The dedicated waveforms (RHCP & LHCP) and frequency spectrums (6-7 & 7.5-8.5 GHz's) for the wireless link between LBS and active-Tag will help in reducing the mutual coupling among the antennas at the LBS as well as in suppressing the strong echoes/backscatters of an indoor environment.

1.2. Technique for 2D-Measurement [7]

The transmitted signal from A_0 reaches to A_1 & A_2 via the active-Tag with some delays- T_{Delay1} & T_{Delay2}, respectively. Therefore, the calculation of the radial distance d between the LBS and the Tag can be done by measuring the average value of the paths A_0-Tag-A_1 and A_0-Tag-A_2 which is computed with the help of FMCW Radar technique for the delays (T_{Delay1} & T_{Delay2}) as

$$F_{S1} = \frac{\Delta f * T_{Delay1}}{T_m} ; F_{S2} = \frac{\Delta f * T_{Delay2}}{T_m} \tag{1}$$

Where, Tm is sweep time of FMCW signal (10msec), Δf is equal to 1GHz, and the frequency-shifts (F_{S1} and F_{S2}) are measured by the FMCW radar for the paths A_0-Tag-A_1 and A_0-Tag-A_2, respectively.

$$Range, d = \frac{c * T_{Delay}}{2} \tag{2}$$

Where, c is the speed of light and T_{Delay} as the average value, respectively.

The AoA computation is based on the interferometry techniques. Using the FMCW radar of the Fig.2, the frequency difference ($F_{S2}-F_{S1}$) between two independent incoming signals gives the path difference (Path_dif) between them, and the Path_dif gives the azimuth angle (α, AoA) at A_0 to the baseline as

$$Path\_dif = d_{baseline} * \cos\alpha \qquad (3)$$

Using the relation (1) in (2), the path difference between can be expressed as:

$$Path\_dif = \frac{(F_{S2} - F_{S1}) * c * T_m}{2 * \Delta f} \qquad (4)$$

From, the relation (3) and (4), the AoA (α) is obtained as,

$$\alpha = \cos^{-1}\left\{\frac{(F_{S2} - F_{S1}) * c * T_m}{2 * \Delta f * d_{baseline}}\right\} \qquad (5)$$

Further, the frequency shifts can be evaluated as the phase shifts over the time as

$$F_{S1} = \frac{d\phi_1(t)/dt}{2\pi}; F_{S2} = \frac{d\phi_2(t)/dt}{2\pi} \qquad (6)$$

The frequency difference may be written as

$$F_{S21} = F_{S2} - F_{S1} \qquad (7)$$

$$F_{S21} = \frac{(d\phi_2(t) - d\phi_1(t))/dt}{2\pi} \qquad (8)$$

Assuming that $\phi_{1,2}(t)$ has linear relationship with time and its initial value is zero that is: $\phi_{1,2}(t)=0$. Hence, over the sweep time T_m, F_{S21} can be expressed as:

$$F_{S21} = \frac{\phi_2(Tm) - \phi_1(Tm)}{2\pi * T_m} \qquad (9)$$

Therefore, the AoA given by (5) can be expressed as

$$\alpha = \cos^{-1}\left\{\frac{\Delta\phi_{21} * c}{4\pi * \Delta f * d_{baseline}}\right\} \qquad (10)$$

Where $\Delta\phi_{21} = \phi_2(T_m) - \phi_1(T_m)$ over T_m.

Hence, the computation of α gives the azimuth angle of the target by measuring the phase shift over the sweep time Tm for the two incoming parallel signals with the use of radar interferometry.

The relation (2) and (10) can be used for the 2D measurement in the polar form with-'d' and 'α' as range and angle parameters.

2. Measurements And Results

The estimation of the range and angle-of-arrival in a real indoor environment for the LOS case are presented in this section. The position of the remote active-Tag has been estimated in polar form, i.e. range and its angle with respect to the known position of LBS.

2.1. System's caibration

The calibration of the ILS is performed in order to validate the system's measurement performance by determining the delays in ILS's circuit (transmitter, Tag & receivers). The measurements taken by the ILS are compared with the reference position of the tag. The configuration used for the calibration is depicted on the left side of Fig 3.

The transmitter antenna (A_0) is kept at the midpoint of the baseline's length ($d_{baseline}$) and the two receiver antennas (A_1 & A_2) are placed at the each end of the baseline. All antennas' positions lie on a collinear line that passes through the three antennas (A_1, A_2 & A_0), and active-Tag is positioned at an equidistance from the two receiver antennas, that is, orthogonal to the baseline as shown on the left side of Fig 3.
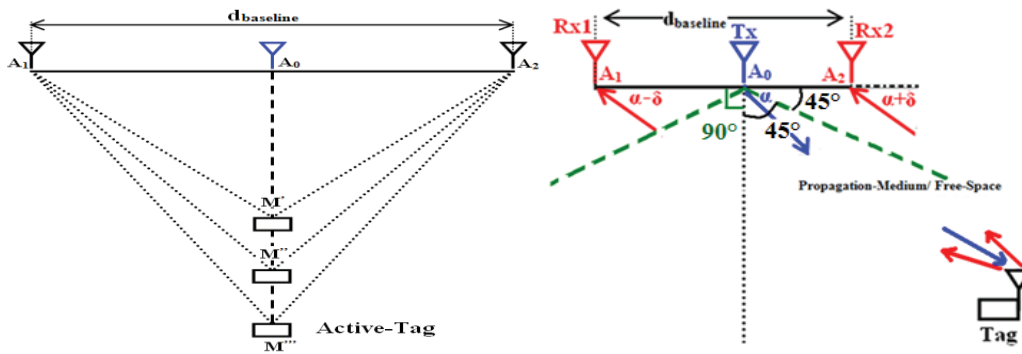
Fig. 3. On the left: Scheme for system calibration, and on the right: Scheme for range & angle-of-arrival measurements.

The calibration is performed for the fixed length of baseline, i.e. $d_{baseline}$=0.30m. The active-Tag is moved on the A_0-M``` axis. Hence, the distance measured by the two receiver antennas, at A_1 & A_2 from A_0 via the active-Tag, must remains identical. Also, the angle-of-arrival (AoA) measured by the receiver antennas must always remain the same, i.e. 90°, with respect to the collinear line (baseline) passing through A_1-A_0-A_2. The relationships 1 & 2 have been used for the one-way range estimation. The observed mean delay by the receivers- A_1 & A_2 in terms of distance are 3.56m & 3.59m, respectively; the mismatch observed by the receivers (with antennas- A_1 & A_2) in terms of the distance is 3cm. These calibrated delays have been used during the estimation of unknown position of the active-Tag.

2.2. Range and Angle-of-Arrival estimation

The measurement has been done by keeping the active-Tag at different positions with respect to a fixed position of the LBS (at origin). The various parameters used in the signal transmitting and during processing are: a) Bandwidth of the FMCW Signal: 1GHz, b) Modulation time (time of sweep): 10msec, c) Sampling Frequency (data acquisition card): 22.5MHz, and baseline length ($d_{baseline}$): 0.30m, respectively.

The known random position has been considered for the active-Tag while the position of LBS remains fixed at one point. Then the estimation of Tag's position in terms of range and angle are simultaneously computed according to relation 11 & 10. Thereafter, the estimated positions are compared with the known ones for the error determination.

Since the ILS structure is symmetric about the orthogonal axis to the baseline, therefore, the measurement carried out for one quadrant will also be valid for the adjacent quadrant on the same side of baseline. Hence, the measurement is only done for a single quadrant for a sector of 45° (from 45° to 90°) and hence, it represents the sector of 90° as marked on the right side of Fig 3.

2.3. Results

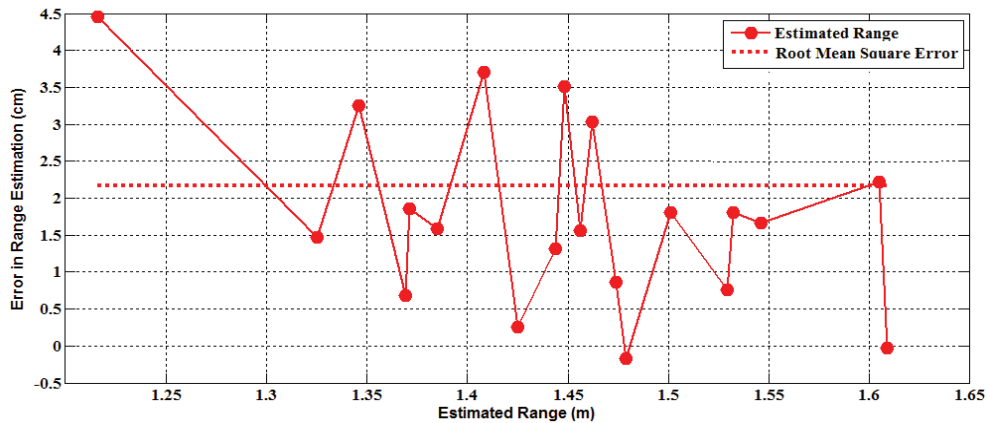The estimated range and angle-of-arrival are shown in Fig 4 & 5, respectively.

Fig. 4. Estimated range and its root-mean-square error

The estimated ranges (Fig. 4) are represented in red-colour along the x-axis and its corresponding errors are represented by the y-axis. The observed root-mean-square error is 2.1cm which is shown in red dotted line, and the observed maximum error is 4.5cm around 1.22m (estimated range). The reason behind such a variation from other results may be due the harsh conditions of an indoor environment as the fading effect. All other estimated data have an absolute error within 3.6cm. Hence, this shows the robustness of the system in a real indoor environment for the LOS case. Moreover, this 3.6 cm figure is perhaps overestimated as the known active-Tag position is given by using a meter-tape.

Similarly, the x-axis of Fig 5 shows the estimated AoA while y-axis shows the error in AoA estimation. The observed root-mean-square error is equal to 7.1° and its maximum error is 16.6°. The variation of the deviation comes from the measurement of the frequencies F_{S1} & F_{S2} for the computation of the path-difference (difference in distance measured by the two receiver chains). As it was oberved in the range estimation case (error 4.5cm), a single large error 16.6° is also present here which might be accounted for the fading because of harsh indoor conditions while rest of the data are under 10°.
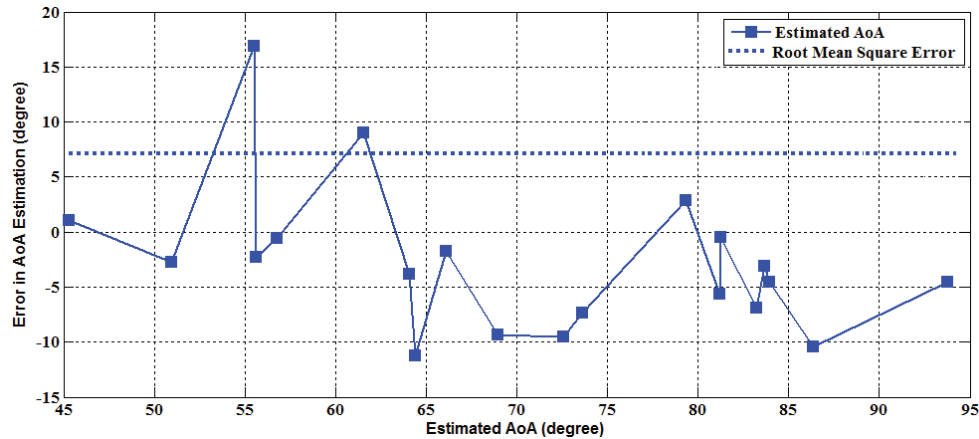

Fig. 5.   Estimated AoA and its root-mean-square error

3.   Conclusion

This paper presents a hybrid technique for 2D position estimation of an active-Tag in a real indoor environment for a LOS case with accuracy around few centimetres (2cm). The estimated parameters (range & angle) demonstrate the robustness of the system for minimizing the multipath and back-scattering effects while utilizing a single known reference (anchor) position as LBS for 2D measurement. Using a single known reference position gives a great advantage in terms of synchronization-free system as compared to other methods, like in triangulation, where a good synchronization among the different reference positions becomes a necessary condition to obtain a good performance. Thus, the use of one known reference position makes the presented system into a less complex with an accuracy of few centimetres.

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