SIMPLE METHOD OF UCOOPERATIVE HUMAN BEINGS LOCALISATION IN 3D SPACE BY UWB RADAR

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ABSTRACT

In this paper, we will present a method for through-the-wall localisation of targets in 3D space by ultra-wideband (UWB) radar. The targets are moving or static uncooperative human beings and the localisation is based on the time-of-arrival (TOA) measurement. The presented method is based on the use of a specific antenna array layout, which simplifies the problem of the 3D multilateration method to the solution of two 2D localisation problems. Through-the-wall as well as the line-of-sight measurements were done for both static and moving person scenarios and the results of the selected scenarios are described in this paper.

Keywords: *ultra-wideband, radar, sensor, line-of-sight, through-the-wall, uncooperative target*

1. INTRODUCTION

The ability to detect and localise human beings through obstacles may significantly increase the chances of success in many emergency situations. Such situations may include search and rescue operations during building fire, building collapse after earthquake, or even a homeland security operations, hostage or other situations.

A large number of research papers intent on sensing heartbeat and breathing rate [1] [2] [3], person detection, localization and tracking in 2-dimesional (2D) space [4–7], commercial UWB systems available on the market dedicated to military and security applications [8], and the large application potential of 3-dimesional (3D) scanners indicate, that the 3D localization of human beings by short-range UWB radars is very attractive and challenging for the research industrial institutions and final users as well.

Usually, at military, security and rescue operations it is required to detect, localize and track human targets carrying no active tags i.e. which are not able or not willing "to cooperate" with positioning devices. Such targets will be reffered to as uncooperative targets and it is much more challenging to localise such targets.

However, to our best knowledge, the localisation of uncooperative targets in 3D space has not been widely studied. In this paper, we will substantiate the following:

- We will identify the problems associated with the use of the time-of-arrival (TOA) based methods for short-range 3D target localisation in Section 2.
- In Section 3 we will propose an effective solution for 3D localisation problem by defining a proper antenna array layout, which reduces the multilateration problem to solution of two 2D localisation tasks.
- We will demonstrate the viability of the proposed method by presenting the results obtained in a set of measurements consisting of the through-the-wall and the line-of-sight measurements for both static and moving person scenarios in Section 4.

2. 3D LOCALISATION PROBLEM STATEMENT

To localise an uncooperative target, the TOA based methods are used most commonly. Let TOA_i be the measured propagation time of the UWB signal transmitted by $T_x = [0,0,0]$, reflected by the target (of unknown coordinates) $T = [x,y,z]$ and received by $Rx_i = [x_i,y_i,z_i]$ for $i = 1,2,\ldots N$, where $N \geq 3$ represents the number of receiving antennas. The distance between Tx, unknown position of target T and Rx_i can be computed as

$$d_i = c \cdot TOA_i \qquad i = 1,2,\ldots,N \tag{1}$$

where c is the speed of the light. Because of errors in TOA measurements, the distance d_i computed using (1) is different from the true distance. The estimated distance (1) can be therefore expressed as

$$d_i = r_i + e_i \qquad i = 1,2,\ldots,N \tag{2}$$

where r_i is the true distance between $Tx - T - Rx$ and d_i represents the zero mean white Gaussian noise with variance σ_i^2.

In the Cartesian system, the distance d_i corresponds to

$$d_i = \sqrt{x^2+y^2+z^2} + \sqrt{(x-x_i)^2+(y-y_i)^2+(z-z_i)^2} \qquad i = 1,2,\ldots,N \tag{3}$$

where the square roots express the Euclidean distances $|Tx-T|$ and $|T-Rx_i|$, respectively.

In order to estimate 3D position of the target, the set of at least 3 simultaneous equations (3) need to be solved. For that purpose, two groups of the localization methods referred to as non-iterative and iterative methods can be used.

The most straightforward non-iterative localization method is the direct calculation method, which directly solves a set of three non-linear equations for 3D target position estimation using TOA measurements. From the point of a physical meaning, in 3D space the distance Formula defines an ellipsoid, foci of which are Tx and Rx_i. The task is to compute an intersection of all three ellipsoids, as shown in Fig. 1. However, considering that the distances Formula are estimated with the measurement errors Formula, such joint intersection does not always exist. In such a case, the intersection of two ellipsoids defines a conic section in the 3D space. The problem of target localization then transforms to task of finding a point in 3D space, in which the conic sections are the closest to each other.

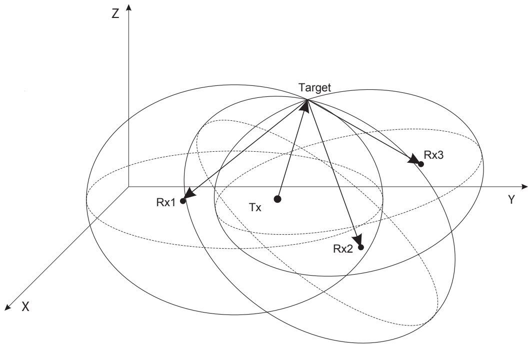

Fig. 1 Multilateration based 3D localisation

3. METHOD PROPOSAL

According to (3), at least two receiving antennas are needed to localise the target in a plane. The antenna array layout most commonly used for localisation of persons in 2D space is to place the transmitting antenna and two receiving antennas in a line, usually parallel to the ground, with transmitting antenna in the middle. In such layout, the target position is calculated in the XY - plane which represents the floor of the monitored area.

The solution to problem of person localisation in 3D space is based on the use of another pair of receiving antennas placed perpendicular to the horizontally placed antenna array. In such layout, the vertically placed receiving antennas can behave as a separate 2D localisation system, which provides the target position in the YZ - plane perpendicular to the ground. Such antenna array layout is shown in Fig. 2. The main advantage of such system is that it is possible to directly use the signal processing methodology [9] intent for 2D localisation of moving and/or static uncooperative targets.

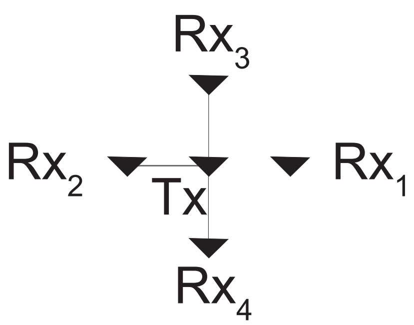

Fig. 2 Proposed antenna array layout

The proposed antenna array layout consists of two pairs of receiving antennas. Each of these pairs provides partial information about target position in 3D space. Horizontally placed receivers provide the $[x, y_1]$ coordinates of the target, while the vertically placed receivers provide the $[y_2, z]$ coordinates of the target at the same time instance. Then, the target coordinates can be approximated as:

$$T = [x, y_1 + y_2/2, z] \tag{4}$$

Such situation obtained by a line-of-sight measurement is shown in Fig3.

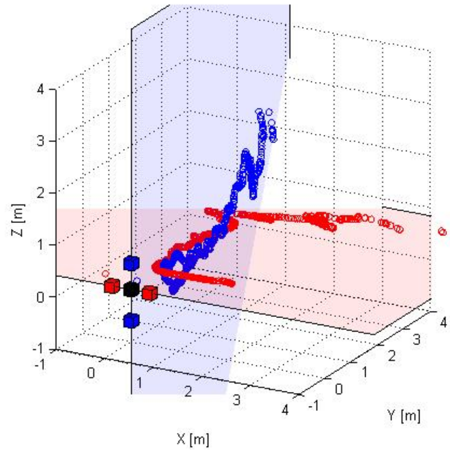

Fig. 3 Localisation of the moving target - partial results

4. MEASUREMENT DESCRIPTION AND RESULTS

This section is dedicated to experimental evaluation of the proposed method. The measurements described in this section were obtained in cooperation with members of Ilmenau University of Technology, Electronic Measurement Engineering Group. The specification of an M-sequence UWB sensor used in these measurements is provided in Table 4.

Table 1 M-sequence sensor technical specification

M-sequence order	12th order
Bandwith (-10dB cut-off)	3.4 GHz
M-sequence length	4095 samples (chips)
Master clock rate	6.95 GHz
No. of receiver channels	4
Unambiguous range	137 m

The line-of-sight measurement location was an L-shaped staircase in the basement of Ilmenau University of

Technology building, shown in Fig. 4. The radar was placed in the 1.67m distance from the base of the staircase. The antenna array was placed to match the proposed antenna array layout, with transmitting antenna in the center, 1.2m above the ground. The distance between transmitting and receiving antennas was 0.48m.

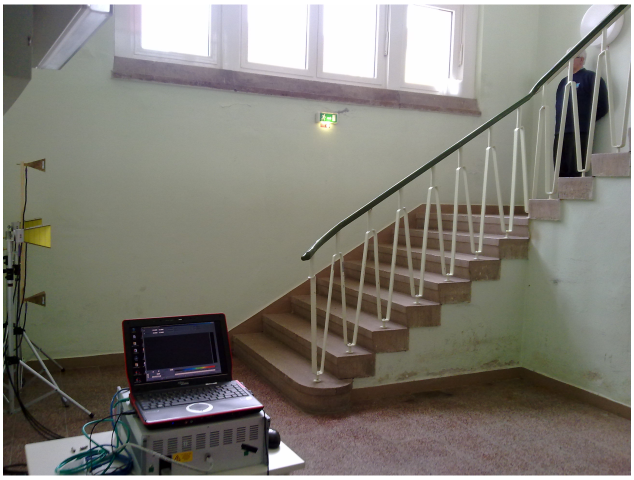

Fig. 4 Measurement location for line-of-sight measurement

The location for the throuh-the-wall measurements was an U-shaped staircase shown in Fig. 5. The sensor was located behind 0.4m thick brick wall with plaster. The distance between transmitting and horizontally placed antennas was 0.39m, and the vertically placed antennas were 0.5m distant.

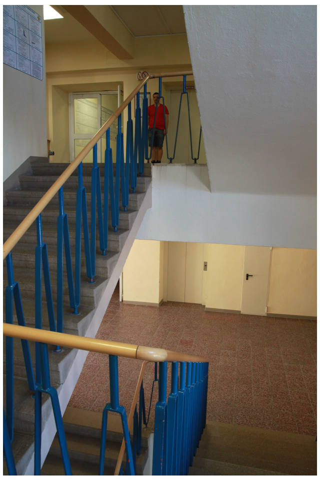

Fig. 5 Measurement location for through-the-wall measurement

The measurement locations represent highly challenging real life situations. The presence of the metallic staircase rail and the shape of the staircase itself produces number of relatively strong multipath signal components and the WIFI hotspots acts as a source of strong narrowband signal interference.

4.1. Localisation of the moving target

In the moving target line-of-sight scenario, the person descended from the upper floor and walked past the radar system. The partial results for the horizontally and vertically placed receiving antennas are shown in Fig.3. The complete track of the target movement is shown in Fig.6.

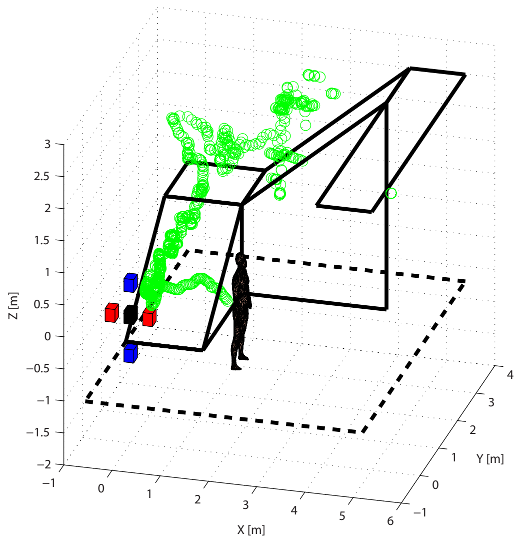

Fig. 6 Result of line-of-sight moving target localisation

In the through-the-wall measurement scenario, the person was walking from the distant wall, towards the radar system and then descended down the U-shaped stairs. The complete movement is shown in Fig.7.

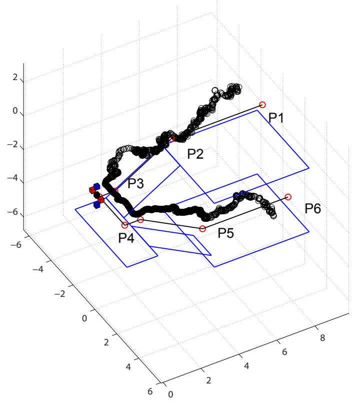

Fig. 7 Result of through-the-wall moving target localisation

In both scenarios, the target movement was succesfully detected and tracked. In the line-of-sight measurement results, we can observe the later stabilisation of the tracking algorithm, possibly due to the staircase rail, but we can clearly recognise a typical bouncing movement of the person going down the stairs. In the through-the-wall measurement, we can observe the start of the target movement from the distance of 9m and we can clearly track its movement towards the radar system, down the two sets of stairs, along the radar system and away from the radar system.

4.2. Localisation of the static target

In the static target scenarios, the person was sitting motionlessly on the highest of the set of stairs. The measurement interval was 1 minute. The person distance from the radar was approx. 3.8m in the line-of-sight measurement, and 5m (wall thickness included) in the through-the-wall measurement. The static target position is depicted as a human model and the calculated position of the target thorax is depicted as the red cross. The localisation error was approx. 30cm for the line-of-sight scenario and approx. 50cm for the through-the-wall scenario. The results are shown in Fig.8 and Fig.9 respectivelly.

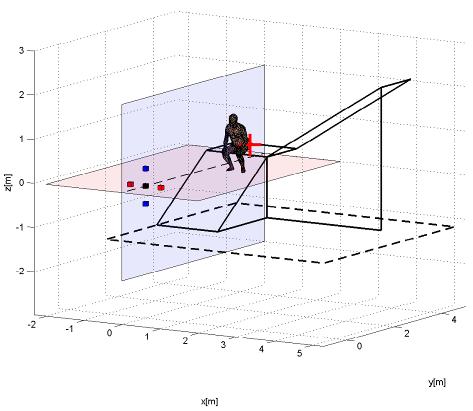

Fig. 8 Result of line-of-sight moving target localisation

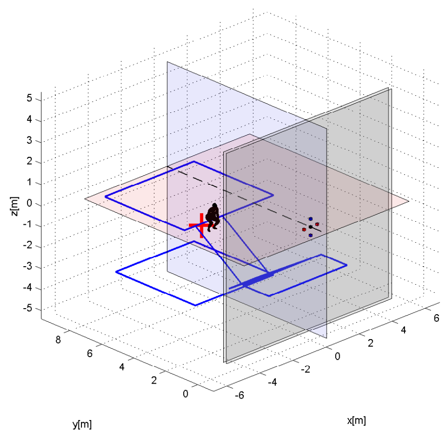

Fig. 9 Result of through-the-wall moving target localisation

5. CONCLUSIONS

The UWB sensors have been recently successfully used to locate moving and motionless uncooperative targets. The use of the antenna array layout proposed in this paper enables the transformation of the existing methodology for the 2D target localisation to localise targets in 3D space and answers the problems of the TOA based multilateration techniques. The presented real-life measurement scenarios prove the viability of the method.

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BIOGRAPHIES

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Dušan Kocur was born in 1961 in Košice, Slovakia. He received his Ing. (M.Sc.) and CSc. (Ph.D.) degrees in Radioelectronics from the Faculty of Electrical Engineering, Technical University of Kosice, in 1985 and 1990, respectively. Now, he is the full professor at the Department of Electronics and Multimedia Communications of his Alma Mater. His research interests are radar signal processing, UWB technologies and physical layer of wireless communication systems.