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Performance Comparison of Context Aware Range Based Indoor Real Time Localization for UWB Applications

[1]R. Jayabharathy, [2]V. Prithiviraj and [1]R. Varadarajan
[1]School of Electrical and Electronics Engineering, SASTRA University, 613401, India
[2]Pondicherry Engineering College, Puducherry, India

Corresponding Author: R. Jayabharathy, School of Electrical and Electronics Engineering, SASTRA University, 613401, India

ABSTRACT

The important goal of location based services is to fix accurately the position of the user or an object. Location based services are becoming attractive with the deployment of next generation wireless networks and broad band multimedia wireless technologies. In this study, an effort is made to compare the performance of different range based indoor localization for UWB radio. Location estimation systems are based on Received Signal Strength Indicator (RSSI), Time of Arrival (TOA) and Time Difference of Arrival (TDOA) methods. The Kalman filter is employed to estimate real time positioning of the user. Ultra Wide Band (UWB) radio is to provide high time resolution and very good accuracy in the case of time based techniques. Finally this paper compares the performance of these three different range based methods by simulation using MATLAB. Results show that the accuracy is better in TDOA using Generalized Cross Correlation method (GCC). The proposed system is composed of UWB nodes (Receiver or reference node whose position is known), UWB tags (Transmitter or source or unknown position of the target) and an UWB location server to calculate the position of the tags accurately.

Key words: RSSI, TOA, TDOA, triangulation, trilateration, GCC, taylor series and kalman filter

INTRODUCTION

People find it difficult to locate particular object, persons or place in an unfamiliar or complex environment such as airport, corporate office, exhibition, hospitals, museums, school campus, shopping malls, railway stations and urban area etc. Basic important difficulty in wireless networks is location awareness. Satellite based positioning has been used in outdoor environment (Jin *et al.*, 2003). GPS signal is not able to travel inside the buildings and hence location awareness becomes a more difficult issue in the indoor environment. The benefits of indoor positioning are the low power consumption and high accuracy.

The major function of any localization technique is the measurement of one or more observables, example signal strength, range sum and range difference or velocity which gives the spatial relation of a target relative to a number of fixed references in the surrounding environment. Usually, this determination is based on a certain method that depends on the type of observables used. They are measured by utilizing the physical fundamental of radio technology called radiolocation. Radio location system can be classified into direction finding and range based systems (Tuoriniemi and Allison, 1999; Prithiviraj *et al.*, 2005; Jayabharathy *et al.*, 2007;

Jayabharathy *et al*., 2009a, b).Context is increasingly important in the field of pervasive and ubiquitous computing (Abowd *et al*., 1999; Dey, 2001). General architecture of a context-aware system is shown in Fig. 1.

In the complex environment, UWB technology is able to provide highly accurate ranging (Di Benedetto and Giancola, 2004; Gezici *et al*., 2005) especially for range based localization. Thus this proposed work will be useful in handling emergency services, patient tracking, asset monitoring, saving the lives of people during natural disaster like earth quake and tsunamis.

This study is based on three different range based location techniques namely RSSI, TOA, TDOA using general and fang algorithm and TDOA using GCC. If the target is in motion, its future position can be determined by using linear predictive Kalman filters. The proposed system consists of three UWB enabled access points or nodes which are basically UWB receivers, UWB transmitters and Centralized server show in Fig. 2. The target to be tracked is given a UWB tags that transmits UWB pulses. The access points receive these signals and re-transmit them to the server to calculate the ranges of UWB signals using different Position Location (PL) systems.

Next section of this paper discusses RSSI based positioning, TOA based positioning, TDOA based positioning using three different algorithms namely general hyperbolic, fang algorithm and GCC, Kalman filter and simulated results.

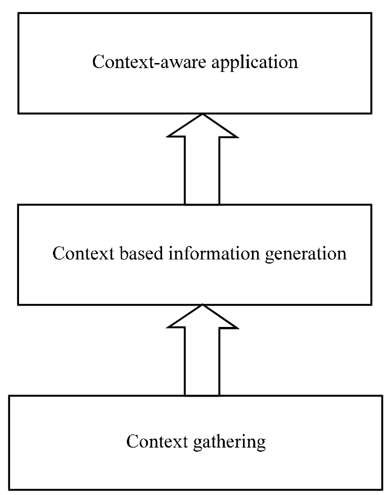

Fig. 1: Architecture of context-aware system

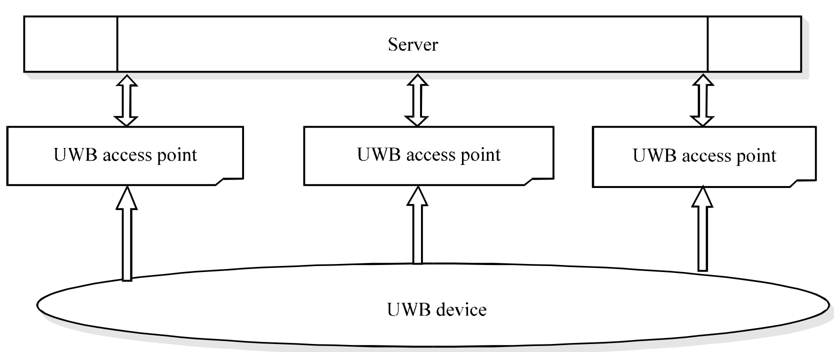

Fig. 2: Proposed system model

RSS POSITION LOCATION SYSTEM

Received signal strength (RSS) is defined as the voltage measured by a receiver's Received Signal Strength Indicator (RSSI) circuit. Often, RSS is equivalently reported as measured power, i.e., the squared magnitude of the signal strength. RSSI is a measure of R.F energy. Estimation of target position using Log-distance model is described by Tuoriniemi and Allison (1999) and Prithiviraj *et al.* (2005).Where, P(d)[dBm] = Power received at a distance d metre from transmitter, $P(d_o)$[dBm] = Power received at a reference distance d_o metre from transmitter and N = Path loss exponent.

Using this RSSI value from the UWB signal transmitted by UWB tags, range estimation between an UWB node (Known position of \receivers) and the UWB tag (target) is determined. It is then converted into distance, i.e the RSSI received at the transmitter from the UWB node i with coordinates (x_i, y_i) at time n is given by:

$$P_{n,d} = k_i\text{-}10\gamma\log(d_{n,i})+\psi_{n,i} \tag{1}$$

where, k_i is constant determined by the transmitter power, wavelength, antenna height and gain of the ith UWB node, γ is slope index varies between 2-5 depending on the environment, $\psi_{n,i}$ zero mean, stationary Gaussian process with standard deviation typically varied between 4-8 dB, $d_{n,i}$ is distance between the transmitter at (x_j, y_j) and ith receiver at (x_i, y_i) is given by:

$$d_{n,i} = \sqrt{(x_j\text{-}x_j)^2+(y_j\text{-}y_j)^2} \tag{2}$$

Triangulation technique is used to determine the target position in 2D that requires three distance measurements from the receivers and transmitter (Prithiviraj *et al.*, 2005; Jayabharathy *et al.*, 2007). The unknown position of the transmitter (unknown target position) is lying in the intersection point of the three circles. Each circle is centered at one of the receivers with radius as the distance between the transmitter and the receiver is described by Tuoriniemi and Allison (1999).

TOA BASED POSITIONING

Realization of highly accurate location awareness has two phases namely accurate ranging and localization (Liberti and Rappaport, 1999). Estimating the distance between two nodes represents ranging and finding the true position of an unknown node is called localization. The exact position of the unknown node is obtained with the help of known nodes position.

TOA based positioning measures the time taken by the UWB signal to propagate between the transmitter (unknown Target point) and receiver (known point) either on the uplink or on the down link, with receiver as a reference (Jayabharathy *et al.*, 2007). This measured TOA is the transmission time plus time delay due to propagation of UWB signal. This time delay $T_{i,j}$ between transmissions at UWB tags i and reception at UWB node j is equal to the transmitter-receiver separation distance $d_{i,j}$ divided by the propagation velocity.

The range measurements obtained from the arrival times are:

$$r_{TOA} = c\,\Delta T_{TOA} \tag{3}$$

where, c is speed of electromagnetic, wave is speed of light = 3×10^8 m sec^{-1}, r_{TOA} is range measurement, ΔT_{TOA} is time of arrival.

This measured TOA then is converted into distance $d_{i,j}$. If the receiver is at (x_i,y_i) and the unknown position of the transmitter is at (x_j, y_j) then the exact distance between transmitter and receiver is:

$$di,j = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{4}$$

where $d_{i,j}$ is the exact (true) distance between the transmitter(target) and the receiver.

Triangulation technique is used to determine the target position in 2D (Prithiviraj *et al.*, 2005; Jayabharathy *et al.*, 2007).

TDOA BASED POSITION LOCATION SYSTEMS

TDOA based PL systems computes the relative range difference between the transmitter and receiver and measure the TDOA of the propagating signal between two receivers (Mostefaoui *et al.*, 2004, Abowd and Mynatt, 2000). This time difference describes a hyperboloid with the receiver at the foci. Then the position estimation of the target is obtained at the intersection point of multiple hyperboloids (Jayabharathy *et al.*, 2009a). Hence, this PL system is also known as hyperbolic PL systems.

Hyperbolic position location (PL) estimation is accomplished in two stages.

- Time delay techniques are used to estimate the TDOA between the receivers. It is then converted into distance between them, gives a set of nonlinear equation hyperbolic equation
- Linearization of these nonlinear hyperbolic equations is obtained by using an efficient algorithm

The commonly used methods of linearizing the equations are by General Hyperbolic algorithm and Fang algorithm.

General hyperbolic algorithm: In this algorithm, locating the target in two dimensions requires four reference receivers of which one of the receivers is closer to the transmitter and assumed to be first to receive the transmitted UWB signal. To obtain the exact position of the transmitter, the system makes use of trilateration technique.

Let the source location be (x_j, y_j) and the known location of the receiver 'i' be (x_i, y_i).

The squared distance between this source and the ith receiver is given as:

$$Ri = \sqrt{(xi-xj)^2 + (yi-yj)^2} = \sqrt{(x_i^2 + y_i^2 - 2x_i x_j - 2y_i y_j + x_j^2 + y_j^2)} \tag{5}$$

The range difference between receivers with respect to the first receiver is:

$$R_{i,1} = c \times d_{i,1} = R_i - R_1 = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} - \sqrt{(x_1 - x_j)^2 + (y_1 - y_j)^2} \tag{6}$$

where, $R_{i,1}$ is the range difference between the first receiver and ith receiver.

R_1 is the distance between the first receiver and the transmitter.

$d_{i,1}$ is the estimated TDOA between the first receiver and ith receiver.

Considering other receivers, one can obtain a set of non-linear hyperbolic equations whose solution gives the 2D coordinates of the mobile transmitter. Solving non-linear equation is difficult.

Linearization of these equations is obtained by converting a set of nonlinear equations into another set of linear equations. Hence, the Eq. 6 becomes:

$$R_i^2 = (R_{i,1,}+R_1)^2 \tag{7}$$

This Eq. 7 can be rewritten as:

$$R_{i,1}^2+2R_{i,1}R_1+R_1^2 = x_i^2+y_i^2-2x_ix_j-2y_iy_j+x_j^2+y_j^2 \tag{8}$$

Subtracting Eq. 6 at i = 1 from Eq. 8:

$$R_{i,1}^2+2R_{i,1}R_1 = x_i^2+y_i^2-2x_{i,1}x_j-2y_{i,1}y_j-x_1^2-y_1^2 \tag{9}$$

Equation 9 gives a set of equation in linear form represents the transmitter location. These linear equations are easily solved even though the range of the first receiver to the transmitter (R_1) is not known.

Fang algorithm: This algorithm uses only three receivers to locate the transmitter in 2D (Fang, 1990). The location of these UWB receiver nodes are (0, 0), (x_2, 0) and (x_3, y_3). Then the Eq. 10 can be reduced as:

$$dx^2+ex+f = 0$$

$$y = gx+h \tag{10}$$

Solving Eq. 10, gives an estimate target (transmitter) coordinate (Jayabharathy *et al*., 2009a; Fang, 1990).

Generalized cross correlation method: In GCC technique, prefiltered version of UWB signal received by one receiver is cross correlated with the UWB signal received by another receiver. Then it is integrated and squared. This sequence of operation is repeated until the peak correlation has to be obtained for different values of time delay (Jayabharathy *et al*., 2009b). Estimation of TDOA is based on time delay caused by peak value of cross correlation. If two filters are identical, this estimated TDOA is unbiased. It is then converted into range difference between two UWB receivers of which one of the receivers is first to receive the transmitted UWB signal (Jayabharathy *et al*., 2009b) and the set of nonlinear equations is linearised using Taylor series. The solution of Taylor series relates the true position of the transmitter to its estimated value and induces error terms. If error terms are smaller with respect to the desired threshold, the estimated position of the transmitter is closure to its true (exact) value.

Let (x_j, y_j, z_j) be the true position of the transmitter and (x_v, y_v z_v) is its estimated value using GCC method, then the Mean Square Error (MSE) is:

$$MSE = E\ [(x_j-x_v)^2+(y_j-y_{v)}^2+(z_j-z_v)^2]$$

And its Root Mean Square value (MSE) is the square root of MSE and determines the accuracy of the position location systems (Jayabharathy *et al*., 2009b).

Kalman filter for real time estimation of the transmitter: The Kalman filter is an efficient recursive linear filter that estímates the state of a linear dynamic system from a series of noisy measurement (Haykin, 2001; Welch and Bishop, 2006). The solution is recursive i.e., each updated estímate of the state is computed from the previous estímate and the new input data. The current value of the variable has to be estimated with the knowledge of:

- Position location system and measurement device dynamic
- Type of system noise, measurement error and uncertainty in the model
- Initial condition of the variables used

Finally the Kalman filter equations are expressed in a matrix form (Jayabharathy *et al*., 2007; Jayabharathy *et al*., 2009a). Inspection of Kalman gain shows that if the measurement noise is large, process noise covariance will be large. So, kalman gain will be small and not much credibility is given to the measurement when computing the next estímate of state. On the other hand, if the measurement noise is small, measurement noise covariance will be small, kalman gain will be large and a lot of credibility is given to the measurement.

SIMULATION RESULTS

The initial position location of UWB transmitter (Target) has to be determined using Triangulation and trilateration procedure. The real time tracking of the mobile transmitter is then obtained using linear predictive Kalman filter for different range based PL systems. Table 1 gives the linear path to track the mobile transmitter.

Figure 3 and 4 show that the real time location estimation of the unknown position of the target using RSSI and TOA based PL systems for a linear path. The X and Y co-ordinates represents position of the mobile target in x and y directions in terms of meters. From the graph it is clear that the TOA based system gives better accuracy than RSSI based PL system, since UWB signal power transmitted by the transmitter decays proportional to the square of the distance between the transmitter and the receiver. The accuracy of the proposed techniques namely RSSI and TOA is better using UWB radio than techniques suggested by Yamamoto *et al*. (2001) and Qi *et al*. (2004).

Table 1: Show the true, measured and estimated position of the system to be considered

True value	Measured value	Estimated value
00	-0.0007 0.0054	
11	1.0047 1.0055	-0.003 0.0022
22	1.9940 1.9980	0.4162 0.4179
33	2.9985 2.9795	1.0702 1.0729
44	3.9957 4.0013	1.8699 1.8636
54	4.9992 4.0159	2.7521 2.7508
64	6.0154 4.0102	3.6856 3.2766
74	6.9939 3.9842	4.6544 3.5821
84	7.9865 3.9992	6.6117 3.8548
85	8.0047 4.9932	6.6117 3.8548
96	7.9910 5.9898	7.1944 4.3302

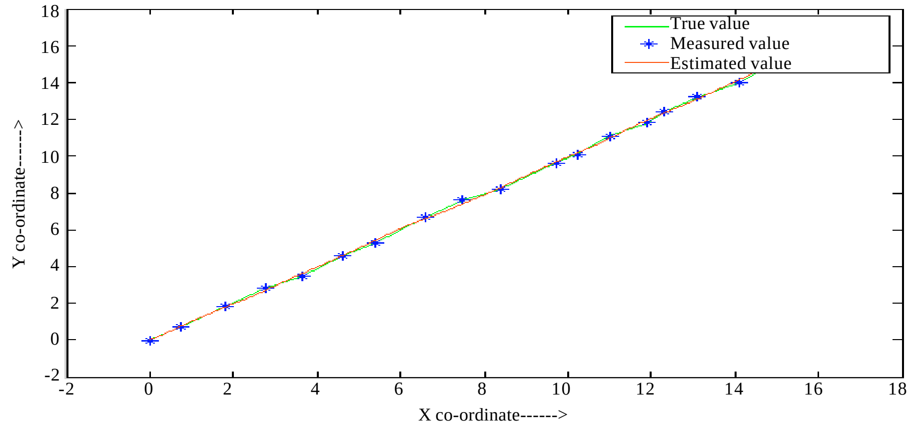

Fig. 3: True, measured and estimated mobile target position using RSSI

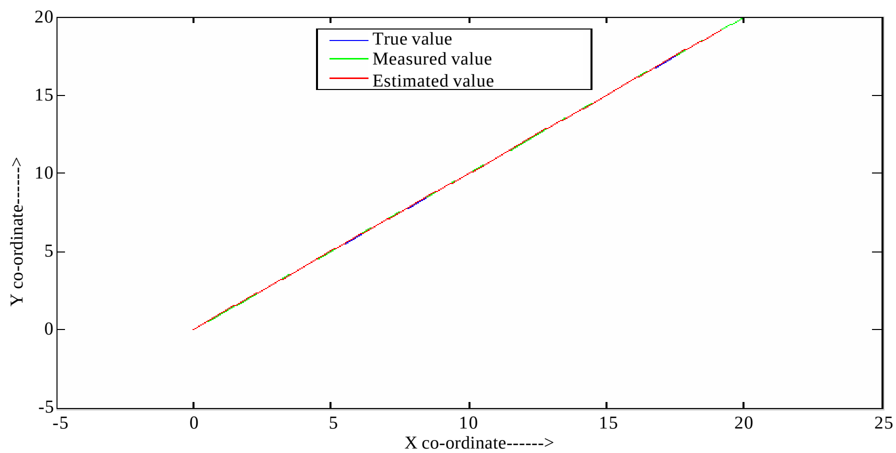

Fig. 4: True, measured and estimated mobile target position using TOA

Figure 5 and 6 show the position estimation of TOA based PL system with TDOA based PL systems using general Hyperbolic and Fang algorithm. Accuracy is better in the case of TDOA based PL system. Also in TOA based PL system, accurate time and range measurement require strict clock synchronization between the transmitter and the receivers. In Fang algorithm, one of the reference fixed receiver is kept at origin point that would further decreases the nonlinearity involved to locate moving target in two dimension as compared to general Hyperbolic algorithm.

In study of Al-Jazzar *et al*. (2002) and Al-Jazzar and Caffery (2002) positioning of mobile target is based on TOA using Bayesian estimation and also by Le *et al*. (2003) utilized the kalman fiter for smoothening the mobile target trajectory and not to improve the accuracy but the proposed system uses kalman estimator to mitigate the variance of location error and hence improves the accuracy of the proposed system as compare to ETDGE algorithm suggested by Yong *et al*. (2006).

Figure 7 and 8 show the intersection of hyperbola in 3D using GCC method to location of Transmitter without and with random error caused by unnecessary disturbance in the channel between the transmitter and the receiver.

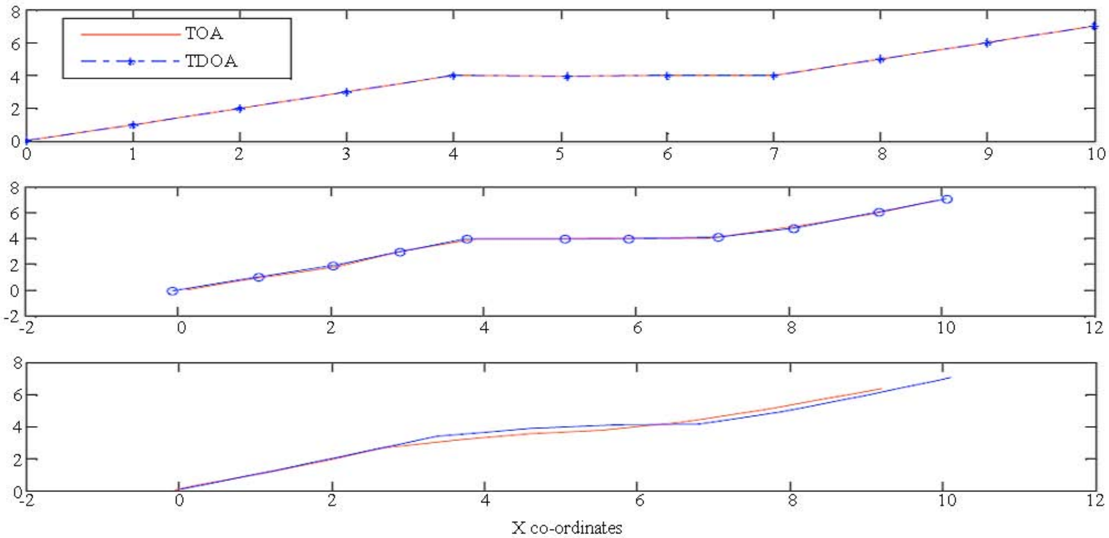

Fig. 5: True, measured and estimated mobile target position using TOA and general hyperbolic TDOA, X axis, Y axis----distance in meters

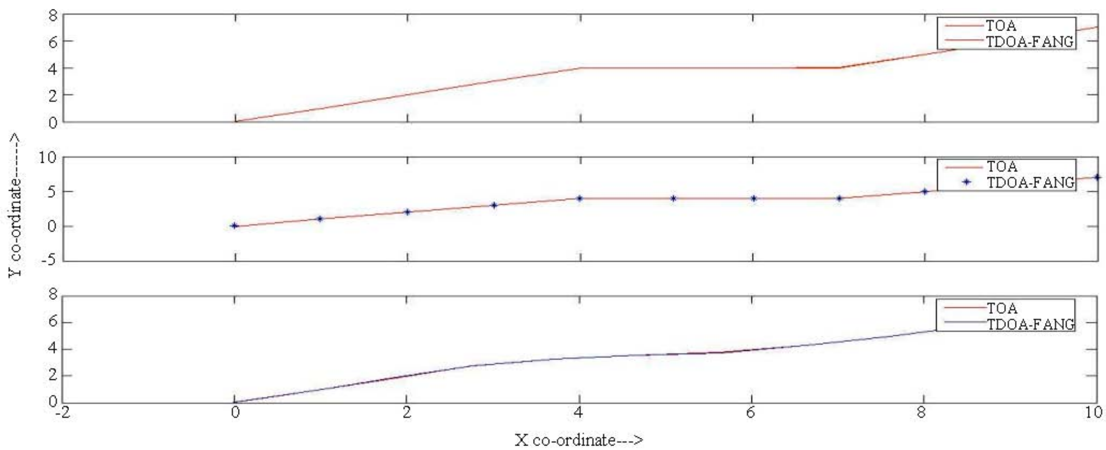

Fig. 6: True, measured and estimated mobile target position using TOA and Fang TDOA algorithm. X axis, Y axis----distance in meters

Figure 9 and 10 shows the location of the target in 3D using TDOA based on GCC method. To determine the location of the target in 3D, it requires at least four UWB receivers of which one of them being the reference receiver. Hence, the measurement has to be performed with respect to this reference receiver for both with and without noise.

Figure 11 and 12 represents the true and estimated position of the target in 3D using TDOA based PL system employing Fang algorithm.

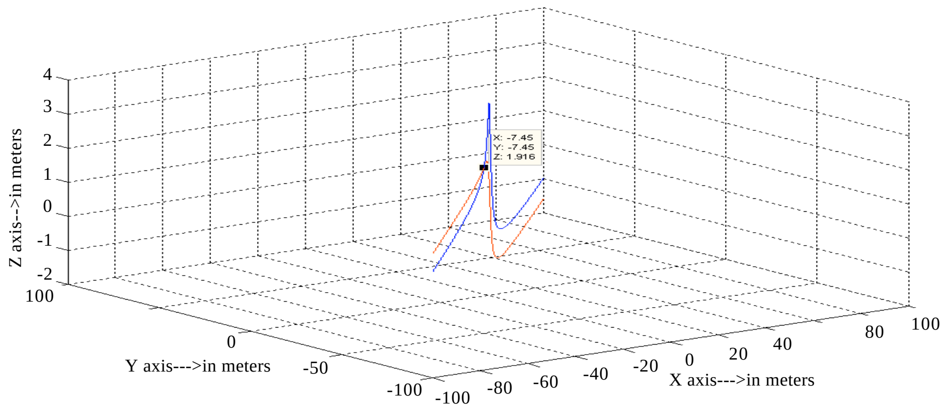

Fig. 7: Intersection of hyperbolas (target's position) without error, X axis, Y axis and Z axis-----distance in meters

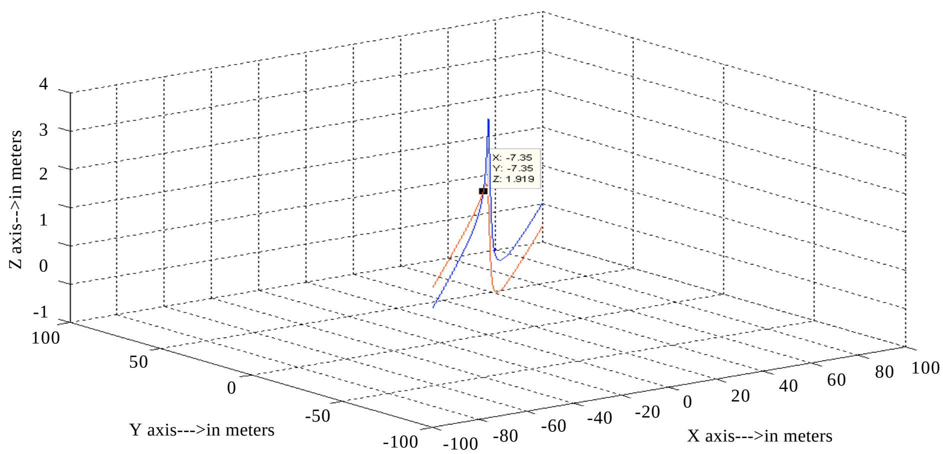

Fig. 8: Intersection of hyperbolas (target's position) with error, X axis, Y axis and Z axis-----distance in meters

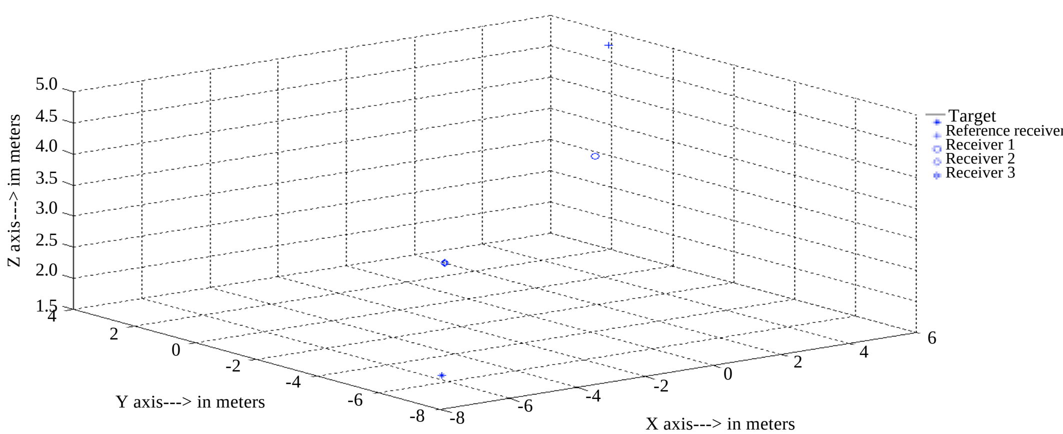

Fig. 9: Variation in the position of target before adding noise using GCC, X axis, Y axis and Z axis-----distance in meters

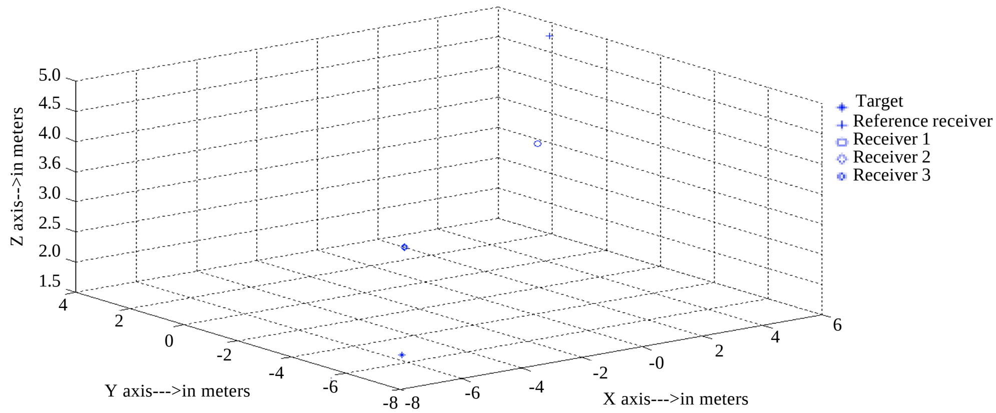

Fig. 10: Variation in the position of target after adding noise using GCC, X axis, Y axis and Z axis-----distance in meters

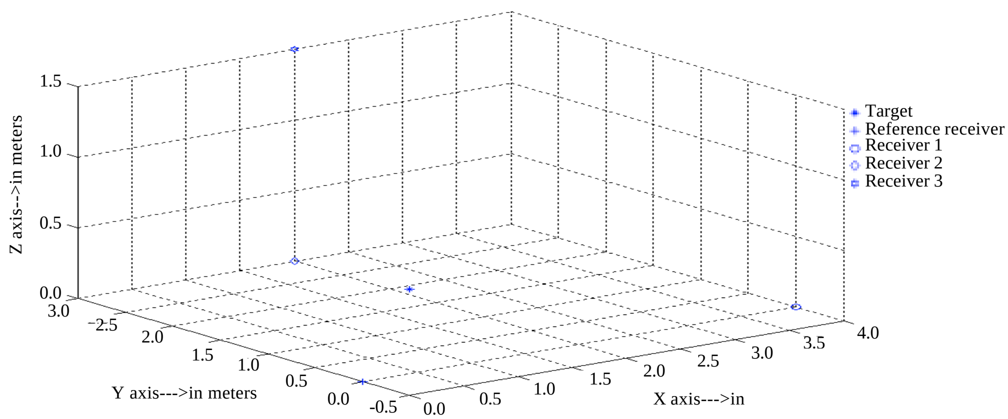

Fig. 11: Position estimation using fang without noise, X axis, Y axis and Z axis-----distance in meters

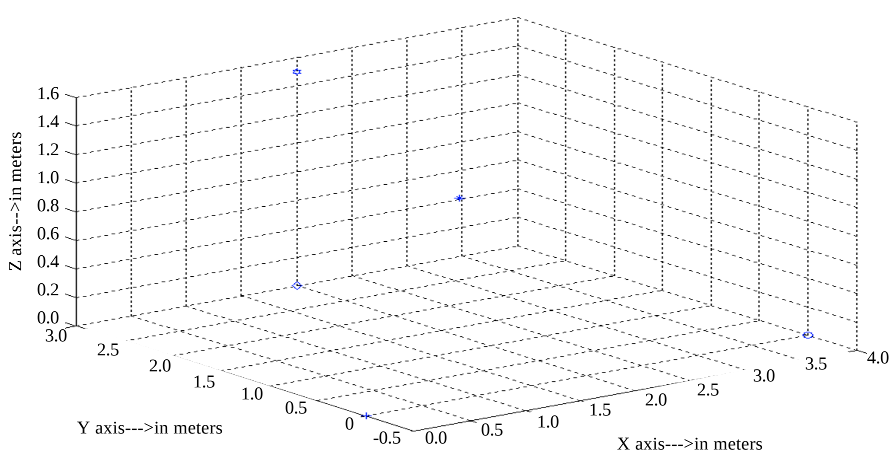

Fig.12: Position estimation using fang with noise, X axis, Y axis and Z axis-----distance in meters

From the Fig. 11 and 12 it is clear that the determination of unknown position of the target is accurate in the case of TDOA based PL system using GCC method which forms the main theme of this article.

CONCLUSION

This study investigates, the performance of the three different PL systems namely RSSI, TOA and TDOA using general hyperbolic algorithm, Fang algorithm and GCC method. The simulated results show that the accuracy of TDOA with GCC based PL system is better than the rest of the PL systems discussed. But one of the receivers (reference receiver) is to be placed close to the target. PL systems make use of UWB technology, since it determines the position of the unknown target with high resolution in time based technique. Kalman filter is used to find the future position of the moving target under noisy environment. It can also predict the future position of the target accurately with smaller value of step interval. The term context is used wherever the user's context is changing rapidly. In future it is proposed to use the Multidimensional Scaling (MDS) technique to locate the moving target with increasing coordinate dimensions of the mobile source.

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