

Hybrid TOA/DOA based indoor localization with real time tracking for UWB systems

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Abstract

Background: Localization is one of the most important tasks of the future wireless sensor networks (WSNs). Wireless positioning for indoor environment with higher accuracy is essential for the future of context aware systems. Since one positioning method cannot function accurately in different environments, a hybrid can be used to increase the accuracy and robustness of the system. Tracking can be performed by combining the system measurements with statistical procedures to produce optimal solutions.

Materials and Methods: In this paper, a hybrid TOA/DOA method is used for indoor localization of a mobile system using UWB radio. The joint usage of distance based and direction based measurements provides accurate localization. The hybrid is obtained through geometric method. UWB system provides high resolution with low power in short range and hence is the one of the most promising technologies for indoor localization. Real time tracking is performed in linear environment using Kalman filter and non-linear environment using Extended Kalman filter.

Result & Discussion: It is observed that mean square for the set of samples using hybrid method gives lower Mean Square Error (MSE of 0.1298m) than the conventional methods (MSE for conventional TOA method = 1.2243m and conventional DOA method = 0.7127m). Average MSE for tracking the moving target through a path can be reduced by using the Kalman filter and it is further reduced by EKF. For the same Mobile Station (MS) co-ordinates, the MSE of conventional and hybrid methods are compared for various SNR values.

Conclusion: Simulation was performed using MATLAB with several configurations and the proposed algorithm has outperformed the conventional methods under various noise conditions

Key words: Indoor Localization, TOA, AOA using MUSIC, UWB, Tracking, Kalman filter, Extended Kalman Filter.

INTRODUCTION

In current complex environment, people and resources are spread throughout the premises. It is essential for various context based applications that their locations be determined efficiently. In outdoor environment, GPS is used in most cases as the standard method. But in indoor environment, the signals from the satellites are attenuated by various obstacles like roof, walls, furniture and other things. And with the recent developments in the context aware technologies, the necessity for a standard Indoor Positioning System (IPS) has increased exponentially [1].

IPS use sensory data from various nodes to locate the user. This data can be anything like magnetic fields, wireless signals, auditory waves or optical information. In this paper, we made use of wireless signals to accurately determine the position of the mobile system.

Among the current technologies, UWB is the best option for IPS since it has low power, no interference issues, better security and most importantly, superior penetration capability. In indoor environment, there are many obstacles and line of sight communication might not be possible in all cases but since, UWB pulses can penetrate through obstacles the path loss is minimized [2 and 3].

Many localization techniques have been proposed based on the wireless positioning methods like TOA, TDOA, RSSI and DOA. RSSI method is accurate only in LOS conditions and for smaller range. Both the time based techniques i.e., TOA and TDOA need at least three non-collinear base stations to obtain a 2-D fix on the mobile station while the DOA scheme requires only two base stations [4]. But the time based methodologies have higher accuracy than the direction based schemes. DOA is highly range-dependent [5]. When the mobile station is far away from the base stations, a small angle measurement error will cause a large positioning error. Therefore, a hybrid method has been proposed by combining the advantages of the TOA and DOA methods and as they are complementary, their limitations have been minimized [6-9].

Tracking the target through a series of points while the user travels through the premises is affected by erratic measurements and due to constant movements. Also, most of the context aware systems require more data than just the position of the user like orientation, route and mapping. It is not possible to determine the direction of user movements using just the IPS, hence recursive algorithms like Kalman and Extended Kalman Filter (EKF) have been used to perform real time tracking of the user [3 and 10].

GEOMETRIC HYBRID ALGORITHM

Two base stations are considered at two known points say BS1 and BS2. Hence the distance between the two base stations is known. The base stations can be positioned in such a way that the range of the two antennas covers the entire indoor environment. Range can be obtained by using time of arrival [11] of pulse from transmitter to receiver as

$$RTOA = c \Delta tTOA \quad (1)$$

where, c =speed of electromagnetic wave or the speed of light

$RTOA$ = range measurement

$\Delta tTOA$ = time of arrival

If receiver coordinates are (x_i, y_i) and unidentified coordinates of the user are (X, Y) , then the actual distance between the receiver and the target can be represented as,

$$rTOA = \sqrt{(X - x_i)^2 + (Y - y_i)^2} \quad (2)$$

where, $rTOA$ = true distance between target and receiver.

Considering the co-ordinates of base stations as the centers and the obtained range values as radii respectively two circles $C1$ and $C2$ are obtained [12].

DOA method is performed like in the conventional method using the MUSIC algorithm [12]. In MUSIC algorithm, the angle at which the power peaks is considered the direction of arrival.

Since the steering vector A is perpendicular to noise eigen values U , the angle at which the signal arrives produces the peak power. Hence, the final angles at which the power is maximum for each of the base stations are obtained as θ_1 and θ_2 . Hence the DOA for BS1 is θ_1 and DOA for BS2 is θ_2 .

Two lines are obtained based on the DOA measurements for BS1 and BS2 as y_1 and y_2 .

The intersection points of $C1$ (circle equation of BS1) and y_1 (line equation of BS1) and $C2$ (circle equation of BS2) and y_2 (line equation of BS2) are obtained respectively as shown in Fig.1. In this paper, we have used the in-built function `lincirc` to obtain the intersection points.

Now we have four points (P,Q,S and T). The distance between a set of points is calculated by the formula,

$$Distance = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (3)$$

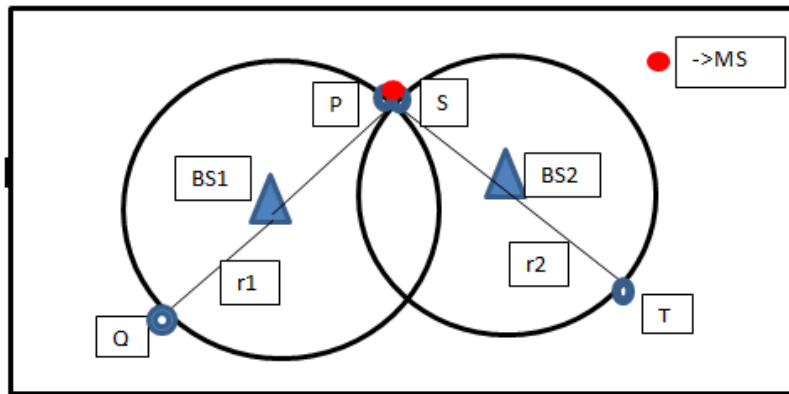


Fig. 1: MS localization by hybrid method

The pair of points that are separated by the minimum distance are taken. Average of the abscissae and ordinates of the pair of points gives the respective abscissa and ordinate of the MS position.

TRACKING

Kalman filter works on the principle of feedback control of the measured values based on predicted values and Kalman gain. It is optimal for systems defined linear stochastic state equations. But Kalman filter cannot function in non-linear environment. So, EKF is used. EKF linearizes the non-linear state and measurement equations by obtaining the partial derivatives using the Jacobian matrices. In this paper, the constant velocity EKF is considered.

Kalman filter

Predictor equations:

$$x_{k+1} = A_k x_k + B u_k + w_k \quad (4)$$

$$z_k = H_k x_k + v_k \quad (5)$$

where x_{k+1} is the present value

A_k is the state function that is applied to the past value. It gives relation between past and present values if there is no driving function or process noise.

x_k is the past value

B_k is the control-input model which is applied to the control vector u_k .

H_k is the measurement function

z_k is the measured value

w_k and v_k are process and measurement noise respectively. They are assumed to be white with normal probability distribution.

Corrector equations:

$$K = P_k' H_k^T (H_k P_k' H_k^T + R_k)^{-1} \quad (6)$$

$$\hat{x} = \hat{x}' + K(z_k - H_k \hat{x}') \quad (7)$$

$$P = (1 - KH_k)P' \quad (8)$$

where noise covariance is obtained as $P = p(w)$ and $R = p(v)$ and K is the Kalman gain.

Extended Kalman filter

Predictor equations:

$$\hat{x}_{k+1} = f(\hat{x}_k) + w_k \quad (9)$$

$$z_k = h(\hat{x}_k) + v_k \quad (10)$$

$$P_{k+1} = A_k P_k A_k^T + W_k Q_k W_k^T \quad (11)$$

where w is Gaussian noise with covariance Q

v is Gaussian noise with covariance R

f : non-linear function in this case the distance as time for sampling is taken as constant so distance is directly proportional to velocity

$\hat{x}$: a priori state estimate

P : a priori estimated state covariance

z : current measurement

Q : process noise covariance

R : measurement noise covariance

Corrector equations:

$$\hat{x}'_k = \hat{x}_{k-1} + K(z_k - \hat{x}_{k-1}) \quad (12)$$

$$K = P_k' H_k^T (H_k P_k' H_k^T + V_k R_k V_k^T)^{-1} \quad (13)$$

$$P_k = (1 - KH_k)P_k'$$

(14)

K is kalman gain.

Simulation and Results

Conventional TOA method requires three non-collinear base stations (BS) to locate a mobile station (MS) in 2-D environment. Conventional DOA requires only two BS's but when the MS is located far away from the BS, a small error in angle measurement leads to a large error in the position result. Hence, TOA and DOA are combined so their limitations can be minimized while the advantages are exploited. It is shown that the hybrid method gives lower mean square error (MSE) than the conventional methods and that average MSE for tracking the MS through a path can be reduced by using the Kalman filter and it is further reduced by EKF. The simulation is performed using MATLAB.

We have considered two receivers at [65 30] and [10 70]. The ideal co-ordinates for mobile station is given by the matrix

MS=[0 0

10 15

20 30

30 45

40 59

51 76

62 92
 69 104
 81 121
 90 134
 100 150]

As it can be observed, the velocity is approximately constant. Hence, extended kalman filter with constant velocity can be used. The SNR for this case is considered to be 1.

Figures 2 ,3 and 4 represents target positions for above set of samples using Hybrid TOA/DOA, Hybrid TOA/DOA with Kalman filtering and Hybrid TOA/DOA with Extended Kalman filtering.

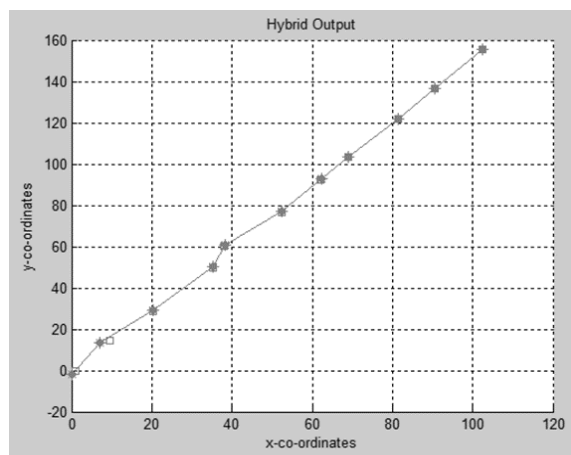


Fig. 2: Tracking using Hybrid TOA/DOA

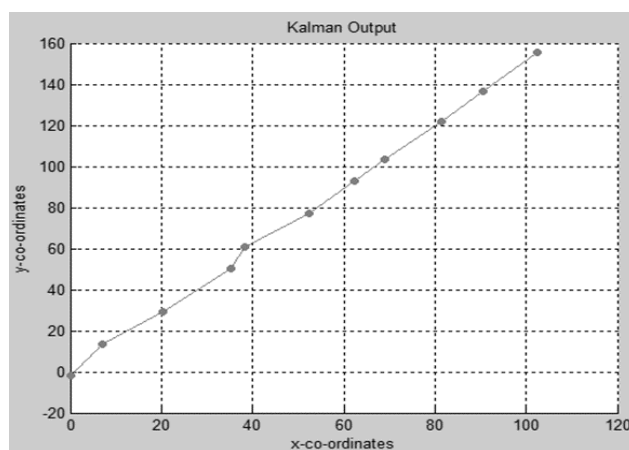


Fig. 3: Tracking using Hybrid TOA/DOA and Kalman filter

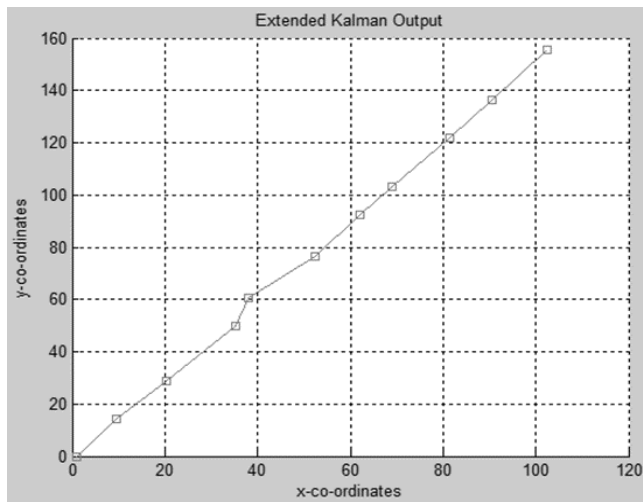


Fig. 4: Tracking using Hybrid TOA/DOA and EKF

It is observed that mean square for the set of samples using hybrid method gives lower mean square error (MSE of 0.1298m) than the conventional methods (MSE for conventional TOA method = 1.2243m and conventional DOA method = 0.7127m)

Average MSE for tracking the MS through a path can be reduced by using the Kalman filter and it is further reduced by EKF.

Average mean square error for the set of samples considered using Hybrid TOA/DOA = 2.7158m

Average mean square error for the set of samples considered using Hybrid TOA/DOA with Kalman filter = 2.1469m

Average mean square error for the set of samples considered using Hybrid TOA/DOA with extended Kalman filter = 1.7530m

It can be observed that the average mean square error has decreased considerably from hybrid TOA/DOA method to Kalman filter and to extended Kalman filter.

For the same MS co-ordinates, the MSE of conventional and hybrid methods are compared for various SNR values as shown in the table below.

Table 1: Comparison of error values for conventional and proposed methods for different SNR values

The average for all the mean square error values for all the different SNR values was obtained as,

For TOA, the overall average MS = 4.5507m

For DOA, the overall average MSE= 8.2997m

SNR	TOA MSE	DOA MSE	Hybrid TOA/DOA MSE	MSE after applying Kalman filter	MSE after applying Extended Kalman filter
0.1	4.0869	0.4398	3.0262	2.6749	2.6558
0.5	3.9806	3.4461	2.2155	1.8224	1.8439
1	4.4388	20.5244	5.9272	5.9020	5.6767
8	4.6688	7.6579	6.0314	5.8559	4.8777
10	5.5784	9.4303	4.5914	1.6598	1.4363

For Hybrid TOA/DOA, the overall average MSE= 4.3583m

For Hybrid with Kalman filter, the overall average MSE= 3.5830m

For Hybrid with Extended kalman filter, the overall average MSE= 3.2981m

It can be observed that the overall MSE is higher for conventional TOA and DOA compared to the hybrid method. The error is further decreased after using the Kalman filter and the least MSE is obtained by using Extended Kalman filter.

CONCLUSION

This project proposes a simple geometric algorithm to combine direction-based and distance-based localization techniques to mitigate the limitations of both and to improve the accuracy over the conventional non-hybrid methods.

Noise smoothening is performed by two filters namely Kalman and Extended Kalman. Kalman filter is more

accurate for linear environment and Extended Kalman filter is useful in non-linear environment. In this project, the EKF is considered for uniform velocity case.

Simulation was performed using MATLAB with several configurations and the proposed algorithm has outperformed the conventional methods under various noise conditions.

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