Location Estimation using Extended Kalman Filter in CSS WPAN

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Abstract. The location estimation of mobile nodes in low rate WPAN is specified as optional function and devices based on CSS specification have been used widely. The performance of location estimation using CSS devices are reported in many researches. We have studied post processing algorithm using extended Kalman filter for TOA and TDOA. We consider frequency offsets of mobile nodes in our algorithm and the algorithm show better performance. In this paper, we describe our algorithm and its performance.

Keywords: Location Estimation, Chirp Spread Spectrum, Extended Kalman filter, TOA, TDOA

1 Introduction

In many sensor network applications, location based services are frequently required. IEEE 802.15.4 has defined a low data rate, low power consumption, low cost medium access control (MAC) and a PHY(physical layer) specification for wireless personal area networks (WPANs). Also alternate PHYs employing CSS(chirp spread spectrum) or UWB( ultra-wide band) signaling have been defined in IEEE802.15.4a[1]. The UWB[1][2] and CSS signals can also be used for data communication and ranging. For the UWB, the ranging function and algorithms are defined in detail. And enhancements of location estimation have been studied in two-way ranging(TWR) [3][4] and one-way ranging[5] by using frequency offset. For the CSS, simple location estimation with distance measurements gives an accuracy of 1~2 meters in (10m x 10m). Post processing[6][7] such as Kalman filter may be used to improve the accuracy. The biased ranging algorithm[7] can reduce biased ranging error. In this paper, we describe our location estimation algorithm using extended Kalman filter with frequency offsets of nodes.

2 Proposed Algorithm

Non-linear state equations are as follow.

\[ x_{t+1} = f(x_t, w_t) = x_t + w_t \]
\[ y_i = h_i(x_i, v_j) \]

Here, \( x_i \), \( y_i \), \( w_j \) and \( v_i \) is state vector, measurements vector, process noise vector, and measurement noise vector respectively.

We assume that there are 4 anchor nodes preinstalled at fixed locations in 2 dimensional coordinate. To reduce ranging error, frequency offset compensation should be considered. If the frequency offsets of anchor nodes are added as states, the system can’t make sure controllable or observable. In our Kalman filter model, the frequency offsets of anchor nodes are divided into a common variable one and a constant one with respect to each anchor node. As a result, the state vector includes the coordinate of a mobile node and a common frequency offset as states in a proposed model. The state vector \( x_i \) at time \( i \) and the coordinate of \( k_a \) anchor node \( a_k \) are shown.

\[
\begin{bmatrix}
  x_1(i) \\
  x_2(i) \\
  r(i)
\end{bmatrix}
= \begin{bmatrix}
  a_{i1} \\
  a_{i2}
\end{bmatrix}
\]

Here, \([x(i)_1, x(i)_2]^T\) describes a location of mobile node and \( r(i) \) represents a common frequency offset of anchor nodes.

In TOA(Time of Arrival) measurement, the distance between the mobile node and \( k_a \) anchor node, \( d_k(i) \), and measurement vector \( y_i \) at time \( i \), is shown.

\[
d_k(i) = (1 + r(i) + f_k) \sqrt{(x(i)_1 - a_{i1})^2 + (x(i)_2 - a_{i2})^2}
\]

Here, \( f_k \) represents the constant frequency offset of \( k_a \) anchor node.

Therefore, the measurement vector can be described as follows.

\[
y_i = \begin{bmatrix}
  y_1(i) \\
  y_2(i) \\
  y_3(i) \\
  y_4(i)
\end{bmatrix} = h_i(x_i, v_i) = d_k(i) + v_i
\]

The distance \( d_k(i) \) includes constant frequency offset \( f_k \) which represents the frequency offset of \( k_a \) anchor node with the state of common frequency offset variable \( r(i) \). The constant frequency offset of each anchor node can be obtained on the way of ranging and communication. As a result, this proposed model apply individual frequency offset of each anchor node to the state of EKF while the biased ranging model[7] apply a common frequency offset of anchor nodes to the state of EKF.

Jacobian matrixes of the measurement vector equation and the process vector equation are as follow.

\[
F_j = \frac{\partial f(x_i, w_j)}{\partial x_i}
\]
In this way, our algorithm can be applied to TDOA (Time Difference of Arrival) measurement.

3 Experiment and Simulation

Distance measurement using CSS nodes has been experienced with 5 anchor nodes and a mobile node in (10m x 10m x 2.5m) space. And we evaluate our proposed Kalman filter model with measured distance data in computer simulation. We simulated algorithms of normal EKF, a biased ranging model with a common frequency offset variable, and our proposed model and compared the performances of 2 dimension EKF (2D only), 2D with a common frequency offset (2D biased), 3D only, 3D with a common frequency offset (3D biased), and proposed one (3D foc). Figure 1 shows one of results at (2.5m x 2.5m x 1.8m). The errors of x axis, y axis and location are compared with algorithms. In the figure, the normal EKF gives the location error about 30cm, biased ranging EKF gives about 20cm, and our proposed EKF gives less 5 cm. Proposed model shows better performance which points almost exact location of the mobile node. The states, which represent a biased ranging and a common frequency offset, show very similar changes.
4 Conclusions

In this paper, we have studied to enhance the accuracy of location estimation using CSS devices. The post processing with frequency offset compensation using adaptive digital filter such as extended Kalman filter shows improved performance. This result shows that CSS devices may be used for accurate location estimation. The algorithm may be applied to an actual positioning system.

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References

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