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Research paper

RLS based TDOA-DV Localization in Sensor Network

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Abstract

Real-time randomly deployed sensor nodes require precise location estimates. The master nodes equipped with GPS and are aware of their locations, help the sensor nodes in estimating their locations by transmitting dual velocity beacon time stamped signals along with their location information. The sensor nodes in the collection of data, compute location using Time Difference of Arrival with Dual Velocity (TDOA-DV) technique. In this paper, Recursive Least Square (RLS) based TDOA-DV localization technique was discussed and its influence on (i) the rate at which the sample data from master nodes to be collected & (ii) the number of samples used for the regression analysis. The results show that RLS based TDOA-DV technique can achieve high precision in location estimation and also improve the number of samples required. The results are compared to TDOA technique.

Keywords: *Wireless Sensor Network (WSN), Localization, Time Difference of Arrival with Dual Velocity (TDOA-DV), Time Difference of Arrival (TDOA), Recursive Least Square (RLS).*

1. Introduction

The sensor node localization in WSN attracted most attention of researchers in this field. Localization may be defined as the process of extracting the true location information of randomly deployed sensor nodes. The true location of an unknown sensor node can be obtained from the transmitted signal properties by master nodes such as arrival times, a difference in arrival times of signals and direction of arrival.

In this paper, we focused on the TDOA-DV based localization. Due to high power consumption and cost, GPS is only provided to the master nodes and are aware of their locations with high precision. With the aid of master nodes, the sensor nodes localize using TDOA-DV technique. Applications like detection of the event/target require a precise knowledge of node locations. The fusion information from various localized nodes provides the accuracy of detection/location of an event/target. Examples of the accuracy of an event location like fire in a forest and robbery in a house are different. Similarly, locating a healthy patient and locating a petrol bunk on a highway are different. The accuracy of the event/target depends heavily on the node location information. TDOA-DV technique provides a high accuracy in estimating nodes location of the order of a few 10's of centimeters depending on its distance to master nodes.

The rest of the paper is organized as follows. Section II, work on TDOA based localization and RLS estimation algorithms are discussed. Section III elaborates on the system model along with a time difference of arrival with dual velocity based localization technique. RLS based TDOA-DV localization technique is presented in section IV. Simulation results along with discussions are given in section V and conclusions of the paper are given in section VI.

2. Related Work

Location estimation of a randomly deployed sensor node within the accuracy limits is a difficult task and much sorted work of various researchers. The accuracy limits of location estimates of a sensor node play an important role in detecting the event or target within error bounds. TDOA localization technique plays an important role in achieving the localization bounds in the order of a few 10's of centimetres.

Recursive least square estimation algorithm has been implemented [1] and provided a way to nullify the measurement error in the TDOA data set. The calculation speed of the estimated position of the solution and its accuracy is improved using the RLS algorithm.

A TOA localization technique has been implemented [2] for the selection of unknown sensor nodes using two master nodes with two distinct sensor placement scenarios. The RLS estimation algorithm has been implemented and compared with linear least squares (LLS) estimation algorithm with a TOA localization technique and the simulation results of the RLS algorithm are shown better than LLS algorithm.

Weighted least squares (WLS) estimator technique was discussed [3] for fixing the position of the multilateration problem. The curvature of the log-likelihood function used for computing the weights of WLS estimator technique.

The TDOA-DV based localization technique has been implemented [4] and provided the expression for the distance measurement. The localization error for various distribution functions like uniform, Rayleigh, racial is discussed.

3. System Model

Let N be the set of unknown sensor nodes that are randomly distributed in a 2D sensing field. The unknown positions of sensor nodes are represented as $n_i(x_i, y_i), \forall\, i = 1, \dots N$. Let M be the set of master nodes, that are placed at known locations and are represented as $m_j(x_j, y_j), \forall\, j = 1, 2, 3$.

$$\mathrm{N} = \{\mathrm{n_i}\} \quad \forall\ \mathrm{i} = 1, 2, 3 \dots\dots, \mathrm{N} \tag{1}$$

$$\mathrm{M} = \{\mathrm{m_j}\} \quad \forall\ \mathrm{j} = 1, 2, 3 \tag{2}$$

The sensor node n_i, its location is to be estimated, uses the location information of master nodes m_1, m_2 and m_3. Each of the master nodes m_j transmits beacon signals with two velocities v_1 and v_2, such that $v_1 > v_2$. Let t_1 and t_2 be the time instants of the received signals from master node m_1, t_3 and t_4 be the time instants of the received signals from master node m_2, and t_5 and t_6 be the time instants of the received signals from master node m_3, as shown in the figure 1.

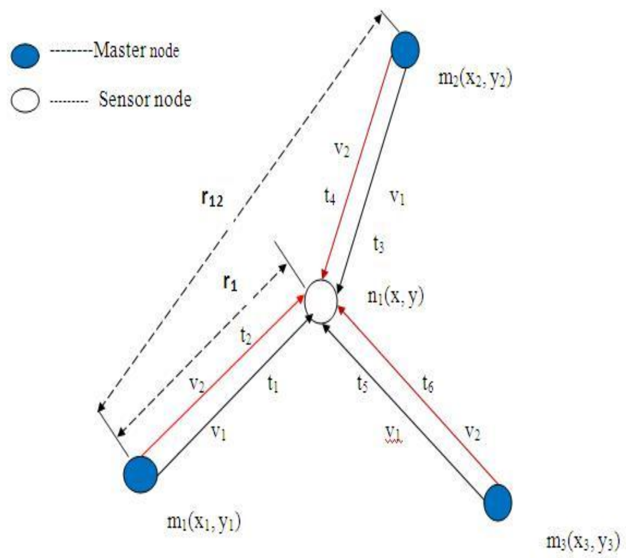

Fig. 1: Schematic of Time Difference of Arrival-Dual Velocity.

The figure 1 illustrates the localization of an unknown sensor node with respect to the three master nodes using TDOA-DV localization technique [4]. Let $\mathrm{r_1}$ be the range or distance between master node $\mathrm{m_1}$ and an unknown sensor node $\mathrm{n_1}$.

Let $\mathrm{r_{12}}$ be the range or distance between master nodes $\mathrm{m_1}$ and $\mathrm{m_2}$. Similarl $\mathrm{r_{23}}$ between master nodes $\mathrm{m_2}$ and $\mathrm{m_3}$ and $\mathrm{r_{13}}$ between master nodes $\mathrm{m_1}$ and $\mathrm{m_3}$. From the figure 1, the expression for the distance $\mathrm{r_1}$ between master node $\mathrm{m_1}$ and an unknown sensor node $\mathrm{n_1}$ is given by

$$\begin{aligned}(\mathrm{v_1} - \mathrm{v_2})(\mathrm{t_2} - \mathrm{t_1}) &= \mathrm{v_1 t_2} - \mathrm{v_1 t_1} - \mathrm{v_2 t_2} + \mathrm{v_2 t_1} \\ &= \mathrm{v_1 t_2} - 2\mathrm{r_1} + \mathrm{v_2 t_1}\end{aligned} \tag{3}$$

$$\mathrm{r_1} = \frac{\{\mathrm{v_1 t_2} + \mathrm{v_2 t_1} - (\mathrm{v_1} - \mathrm{v_2})(\mathrm{t_2} - \mathrm{t_1})\}}{2} \tag{4}$$

Similarly

$$r_2 = \frac{\{v_1 t_4 + v_2 t_3 - (v_1 - v_2)(t_4 - t_3)\}}{2} \tag{5}$$

$$r_3 = \frac{\{v_1 t_6 + v_2 t_5 - (v_1 - v_2)(t_6 - t_5)\}}{2} \tag{6}$$

The linear equations can be written in the matrix form as follow

$$\mathrm{M n_1^T} = \mathrm{h} \tag{7}$$

$$\mathrm{n_1^T} = \begin{bmatrix} \mathrm{x} \\ \mathrm{y} \end{bmatrix} \tag{8}$$

$$\mathrm{M} = \begin{bmatrix} (2\mathrm{x_2} - 2\mathrm{x_1}) & (2\mathrm{y_2} - 2\mathrm{y_1}) \\ (2\mathrm{x_3} - 2\mathrm{x_1}) & (2\mathrm{y_3} - 2\mathrm{y_1}) \end{bmatrix} \tag{9}$$

$$\mathrm{h} = \begin{bmatrix} \mathrm{r_1^2} - \mathrm{r_2^2} - \mathrm{x_1^2} - \mathrm{y_1^2} + \mathrm{x_2^2} + \mathrm{y_2^2} \\ \mathrm{r_1^2} - \mathrm{r_3^2} - \mathrm{x_1^2} - \mathrm{y_1^2} + \mathrm{x_3^2} + \mathrm{y_3^2} \end{bmatrix} \tag{10}$$

$$\hat{\mathrm{n}}_1 = (\mathrm{M^T M})^{-1}\ \mathrm{M^T}\ \mathrm{h} \tag{11}$$

In equation (11), $\hat{\mathrm{n}}_1$ is the estimated location of unknown sensor node using the least square estimation algorithm.

4. RLS Estimation Algorithm for TDOA-DV based Localization.

In the distance measurement phase of the localization process, three master nodes are employed to find the true location of a sensor node. The accuracy of the algorithm increases with increasing in master nodes. As the number of master nodes increases the cost and energy consumption also increases. The RLS estimation algorithm is applied to the position estimation of an unknown sensor node using TDOA-DV localization technique.

The equation (7) can be rewritten as.

$$\begin{bmatrix} \bar{\mathrm{M}}_\mathrm{l} \\ \mathrm{M_{l+1}} \end{bmatrix} \mathrm{n_1^T} = \begin{bmatrix} \bar{\mathrm{h}}_\mathrm{l} \\ \mathrm{h_{l+1}} \end{bmatrix} \tag{12}$$

Where ‘l’ be the number of iterations.

Computing inverse and equality

$$\hat{\mathrm{n}}_{\mathrm{l+1}} = \hat{\mathrm{n}}_\mathrm{l} + \left(\bar{\mathrm{M}}_\mathrm{l}^\mathrm{T} \bar{\mathrm{M}}_\mathrm{l} + \mathrm{M_{l+1}^T M_{l+1}}\right)^{-1} \mathrm{M_{l+1}^T}(\mathrm{h_{l+1}} - \mathrm{M_{l+1}} \hat{\mathrm{n}}_\mathrm{l}) \tag{13}$$

Equation (13) gives the solution for the true position estimation of an unknown sensor node $\hat{\mathrm{n}}_1$ using RLS estimation algorithm.

5. Results and Discussion

The performance of TDOA [1] and TDOA-DV localization techniques with the RLS algorithm are carried out using MATLAB simulations. The assumed parameters are for the simulation purpose are given in Table 1.

Table 1: Simulation Parameters

Parameter	TDOA	TDOA-DV
Number of anchor nodes	Three	Three
Location of anchor nodes at the boundary of sensing field	(0,0)m, (100, 0)m and (0, 100)m	(0,0)m, (100, 0)m and (0, 100)m
Location of unknown sensor node	(30, 30)m	(30, 30)m
Noise	Gaussian distribution with a variance of 0.1	Gaussian distribution with a variance of 0.1
Transmits packet	With single velocity	With dual velocities

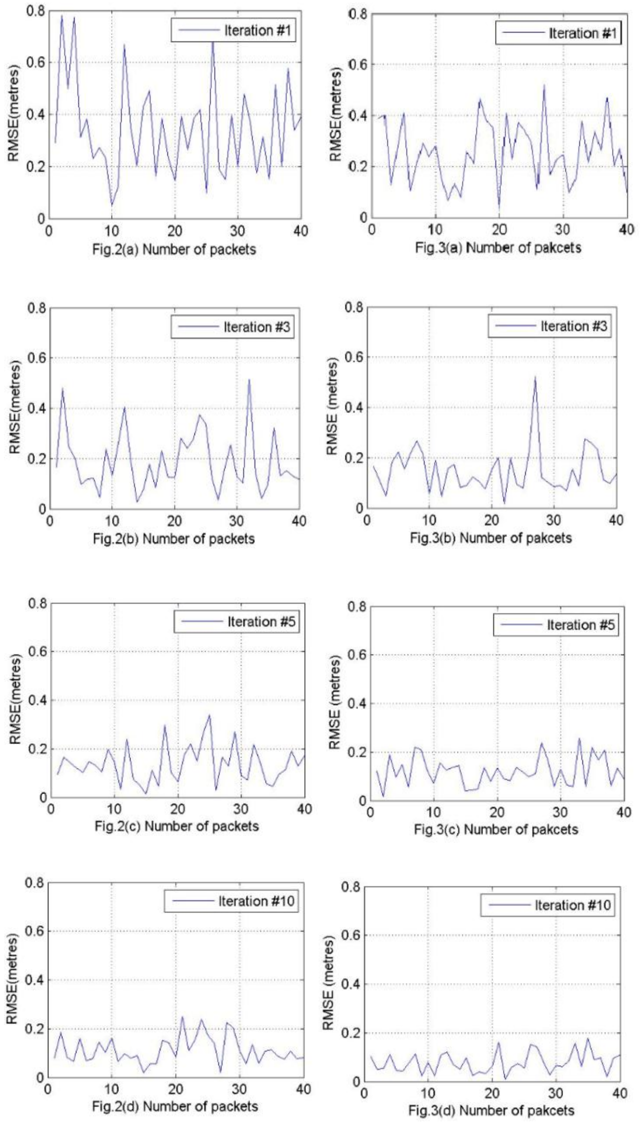

Fig. 2 & Fig. 3 : Variations in the RMSE value of TDOA localization algorithm using RLS (Left side column) and TDOA-DV localization algorithm using RLS (Right side column).

The figure 2 denotes the variations in the RMSE value of TDOA localization technique and the figure 3 denotes the variations in the RMSE value of TDOA-DV localization technique. The root mean square error (RMSE) analysis shows clearly that TDOA-DV technique outperforms the TDOA technique.

Comparing figure 2(a), figure 2(b), figure 2(c), and figure 2(d) with figure 3(a), figure 3(b), figure 3(c), and figure 3(d) respectively, it is found that the performance of TDOA-DV technique outperforms TDOA technique.

Table 2: Comparison of RMSE values in TDOA and TDOA-DV localization techniques

Iterations	RMSE value in TDOA (metres)		RMSE value in TDOA-DV (metres)
#1	Maximum	0.7800	0.5196
	Minimum	0.0497	0.0340
	Mean	0.3431	0.2556
#3	Maximum	0.5152	0.5223
	Minimum	0.0276	0.0179
	Mean	0.1878	0.1500
#5	Maximum	0.3402	0.2564
	Minimum	0.0144	0.0180
	Mean	0.1363	0.1211
#10	Maximum	0.2489	0.1776
	Minimum	0.0185	0.0093
	Mean	0.1124	0.0778

The maximum, minimum and mean of RMSE values in TDOA and TDOA-DV localization techniques for the iterations of #1, #3, #5 & #10 are shown in Table 2.

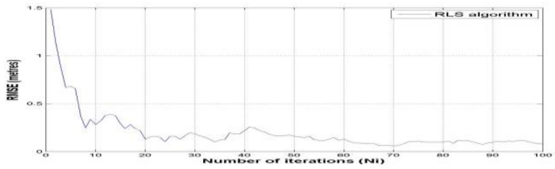

Fig. 4 : RMSE depends on as number of iterations using TDOA localization through RLS estimation algorithm.

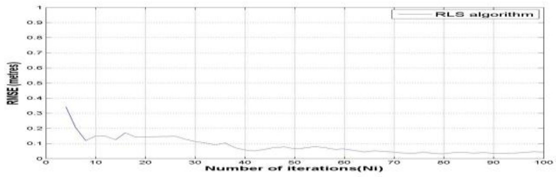

Fig. 5 : RMSE depends on as number of iterations using TDOA-DV localization through RLS estimation algorithm.

The performance of the TDOA-DV technique with an RLS estimation algorithms is analyzed with an increase in the number of iterations and compared against TDOA technique with an RLS algorithm, are shown in figure 4, and figure 5. As the number of iteration increases in the TDOA and TDOA-DV localization techniques with the RLS estimation algorithm.
The performance of both localization techniques using the RLS algorithm is similar at 60 iterations and later the performance of TDOA-DV technique is far better. It is observed that after 80 iterations, the RMSE value is almost half of the RMSE value of TDOA technique.

6. Conclusion

In this paper, TDOA-DV localization technique was discussed, and simulation results have shown that the root mean square error (RMSE) estimate is more precise. The TDOA-DV technique with RLS estimation algorithm has provided better accuracy than that of TDOA technique with the RLS algorithm.

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