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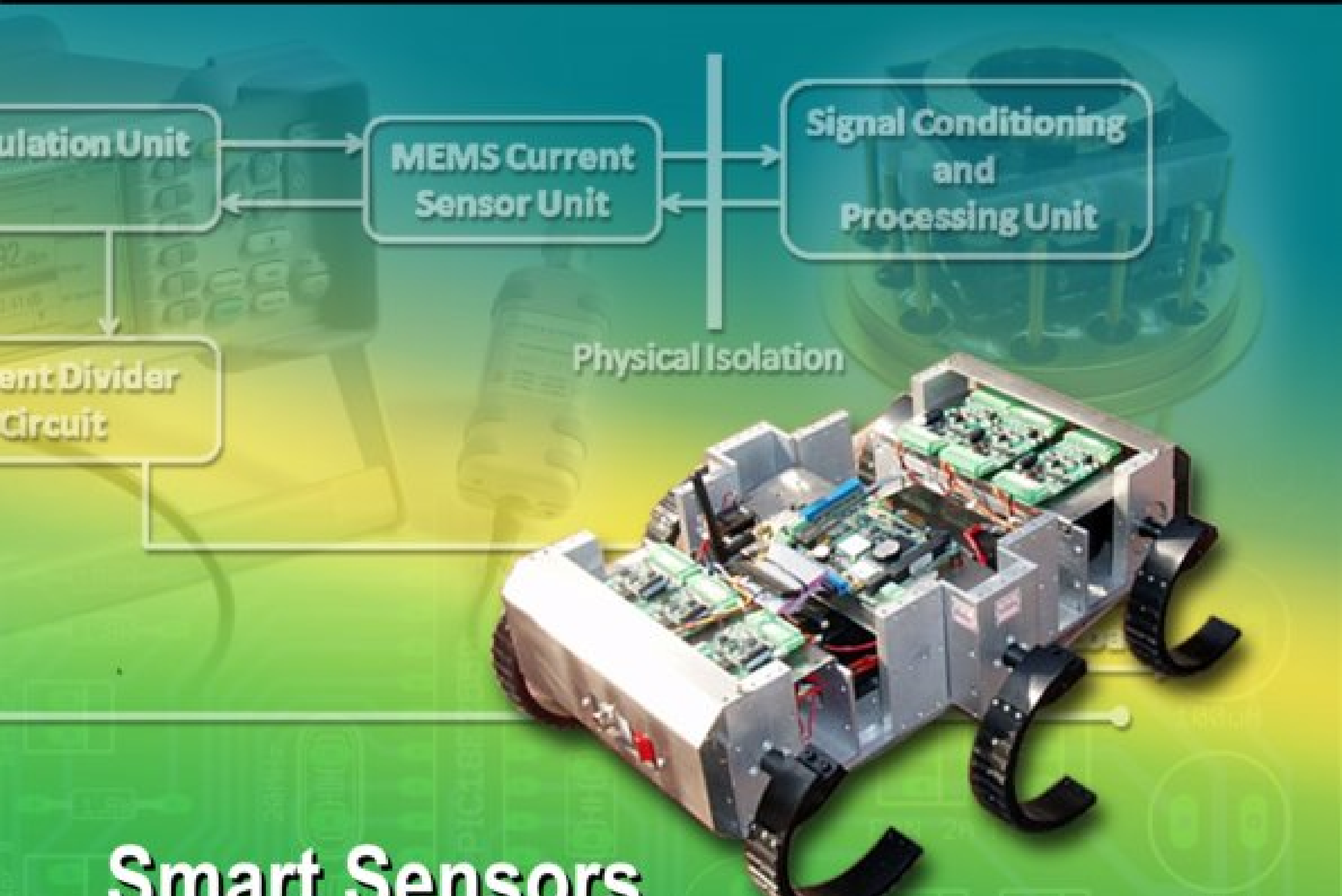

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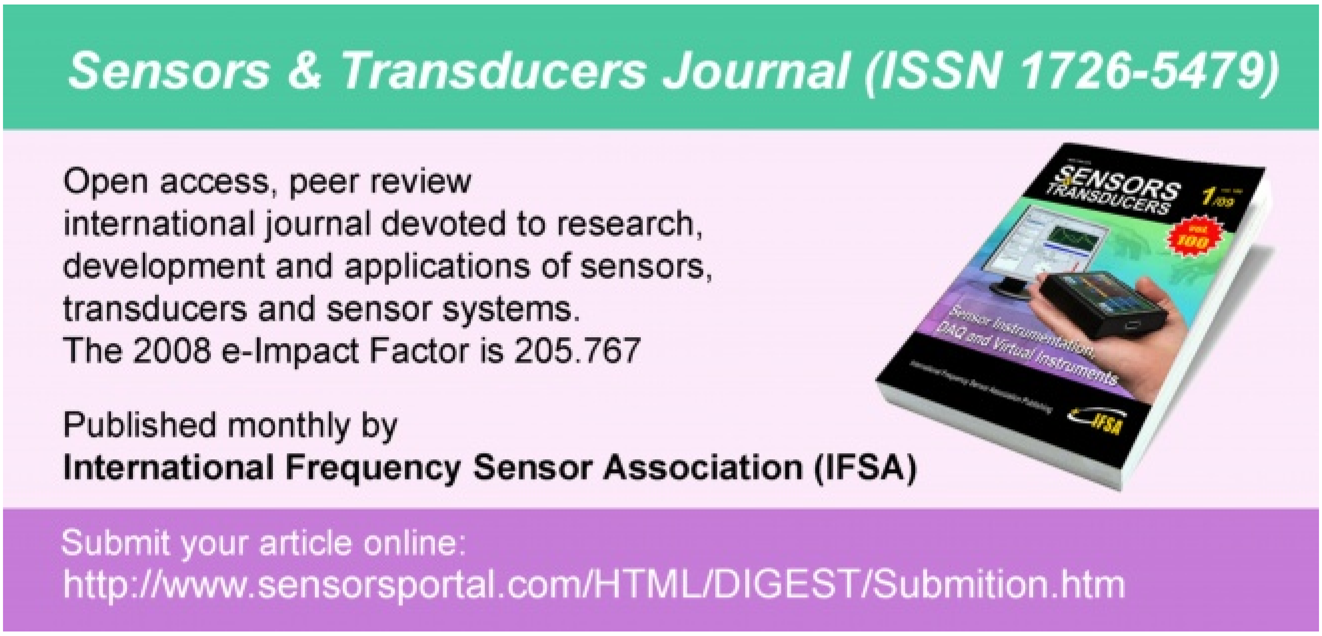

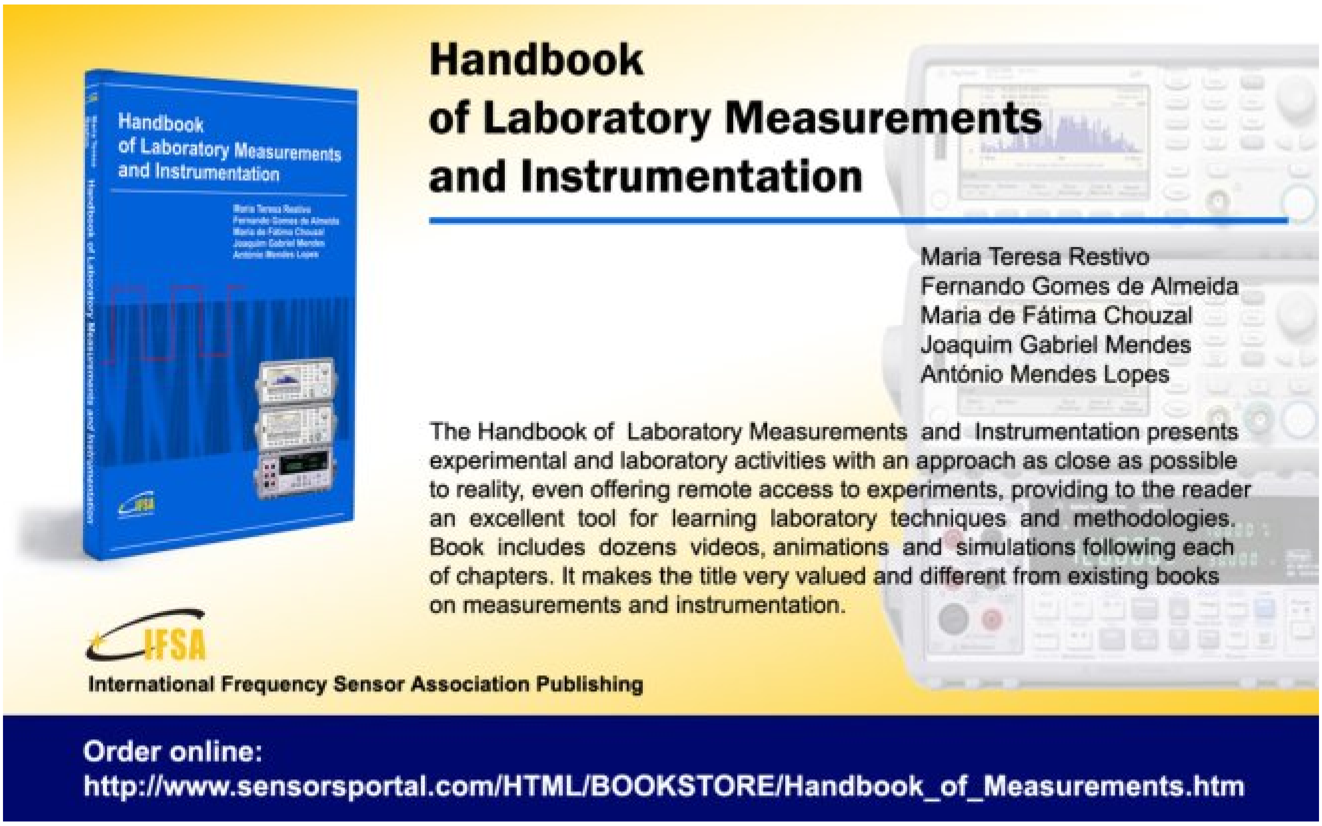

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Data Acquisition Latency in Dynamic Localization: A Weighted Least Squares Approach

Mohammad Amin RAHIMIAN, Shinji OHYAMA
Department of Mechanical and Control Engineering,
Graduate School of Science and Engineering
Tokyo Institute of Technology, 2-12-1, O-okayama, Meguro-ku, Tokyo, Japan
Tel.: +81-3-5734-2543
E-mail: sohyama@ctrl.titech.ac.jp

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Abstract: The problem of latency in data acquisition, which is specific to the case of mobile wireless sensor networks, has been introduced and investigated. In this regard, the properties of the so-called Data Acquisition Latency error, and the way it affects the performance of the respective localization schemes in a mobile network are discussed through both theoretical analysis and simulations. Moreover, a weighted version of lateration scheme is introduced and shown to outperform the traditional one, while tracking a mobile node. This work is to the best of the authors' knowledge the first to have addressed the aforementioned problem for localization in mobile wireless sensor networks, and to have offered a solution for its alleviation. *Copyright © 2012 IFSA.*

Keywords: Localization, Mobility, Best linear unbiased estimator, Weighted least squares, Lateration.

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1. Introduction

Despite the extensive body of research on localization in wireless sensor networks (WSN), the amount of research that has been devoted to the study of localization in mobile WSN, is slim. The majority of the existing literature have been focusing on localization in static sensor networks, where localization is basically a one time or low-frequency activity [1-3].In a static case the sensor nodes are either essentially constant or otherwise move in a manner that can be tolerated by the localization method, i.e. are much slower compared to the time taken by the localization and its frequency.

In the mobile case, on the other hand, due to the constant changes in the position of the nodes, the localization process should be repeatedly invoked. The authors in [4] have suggested a set of protocols that will monitor and adjust the frequency, with which localization is performed. Reference [5] considers the problem of designing the optimum length of the averaging window for Received Signal Strength Indication (RSSI) measurements in a mobile network, where fading and motion account for two opposite behaviors from an averaging point of view, giving rise to an interesting trade-off. To be more specific, although the longer window widths will help mitigate the fading effects, they would also translate into a larger change in the position of the node, as the node is mobile. The Monte-Carlo Localization (MCL) technique in [6] leverages the changes in network connectivity, caused by the node's movements, to update the samples of probability distribution function for the position of a target node. Reference [7] introduces an enhanced version of MCL, called MSL, which can work with both mobile and static networks. The authors in [8] have proposed a two layer structure for their network, with the anchor nodes put in a separate layer from that of the normal sensor nodes (which they call buoy nodes, suggested by their application in the Chinese coastlines).Their work further shows that through adoption of an event-driven and two-layer network topology they are able to cut on the network's main traffic and the power consumption caused by localization, thus increasing the network lifetime [8]. Moreover, their deployment also focuses on a dynamic case, considering issues such as localization and beaconing frequency as well as the mean message latency and their mutual effects.

None of the above, however, have addressed the time-shift between data acquisition and localization, which is inherent immobile WSN and can cause the tracking scheme to fail, no matter how precise the distance data are, at the point of measurement. In other words, as a node moves across the field, the range, angle, or connectivity data measured by the node at some point in time may no longer be valid at a later time, when it is used to derive the node's unknown position. The rest of this paper is organized as follows. This introduction is followed by Section 2, which defines the Data Acquisition Latency (DAL) error and presents a theoretical analysis of its properties. Section 3 describes how the distance data are used to estimate the unknown coordinates of a target node using a traditional lateration scheme, which is then improved by use of a weighted least squares technique in Section 4. The method proposed in Section 4 helps alleviate the effects of data acquisition latency in the localization for mobile WSN. The simulations in Section 5 supplement the discussions of the previous three sections, and Section 6 concludes this paper.

2. The Latency in Data Acquisition for Mobile Wireless Sensor Networks

In the localization for mobile wireless sensor nodes, the inherent latency of data acquisition and data shift caused by the difference between the time of data measurement and the time of localization can seriously disrupt the operation of the existing localization methods, even if the range or distance data are precisely known. Fig. 1 demonstrates how the so-called Data Acquisition Latency error can degrade the performance of a traditional lateration-based localization scheme, even if the measured distance data are error free at each instance of measurement. In this paper, the distance measurements are assumed to be between a single mobile target node whose location is the desired unknown, and N arbitrarily located anchor nodes with known and constant positions. The measured distances are then used in a lateration-based framework to determine the location of the target node, as described in Section 3.

For $i \in N$, let d_i denote the distance between the target node and the $i-$th anchor node A_i. Fig. 2 exhibits how the distance data measured at some point of time is used to determine the node's position at a later point. This phenomenon, which is referred to as Latency in Data Acquisition, is the source of DAL error that is the focus of this section. According to Fig. 2, the distance d_1 to the first anchor node A_1, which is measured at the beginning of the beaconing period, suffers the most from the Data Acquisition Latency error, as it faces the maximum delay between the time d_1 is measured T_i^1, and the time d_1 is used to localize the position of the target node, i.e. at the end of the $i-$th localization attempt, T_i^N.

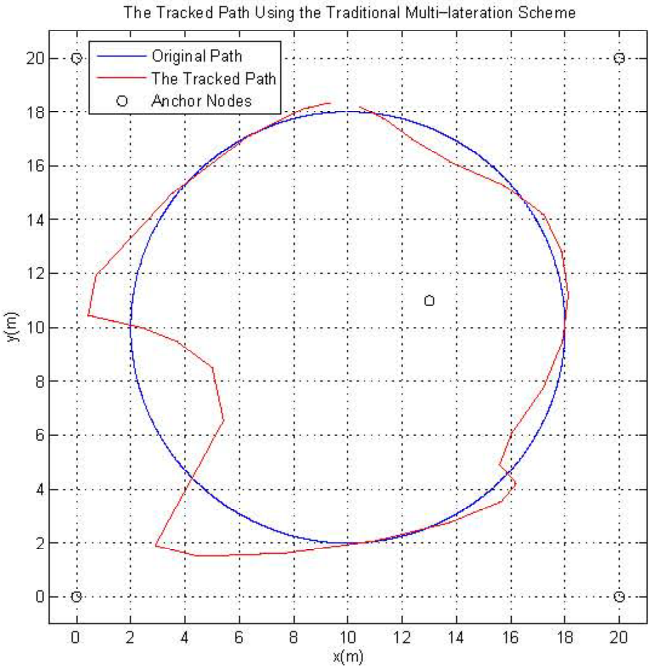


Fig. 1. The degradation in the localization performance caused by the latency in distance data acquisition for a mobile target node is demonstrated. The distance measurements at each instance of time are error-free; however, the delay between the time at which the distance is measured, and when it is used to localize the position of the target node causes the overall localization performance to suffer from a new kind of error, which is referred to as the Data Acquisition Latency error. The target node is moving on a circular path with an angular speed equal to 2πrad/s. The localization period is set at T = 0.0318s and the sampling time is t = 0.003s (See Fig. 2 for their definitions).

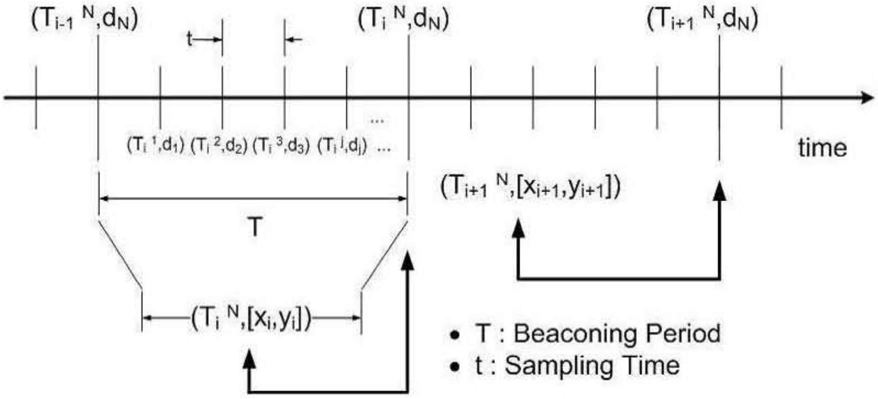


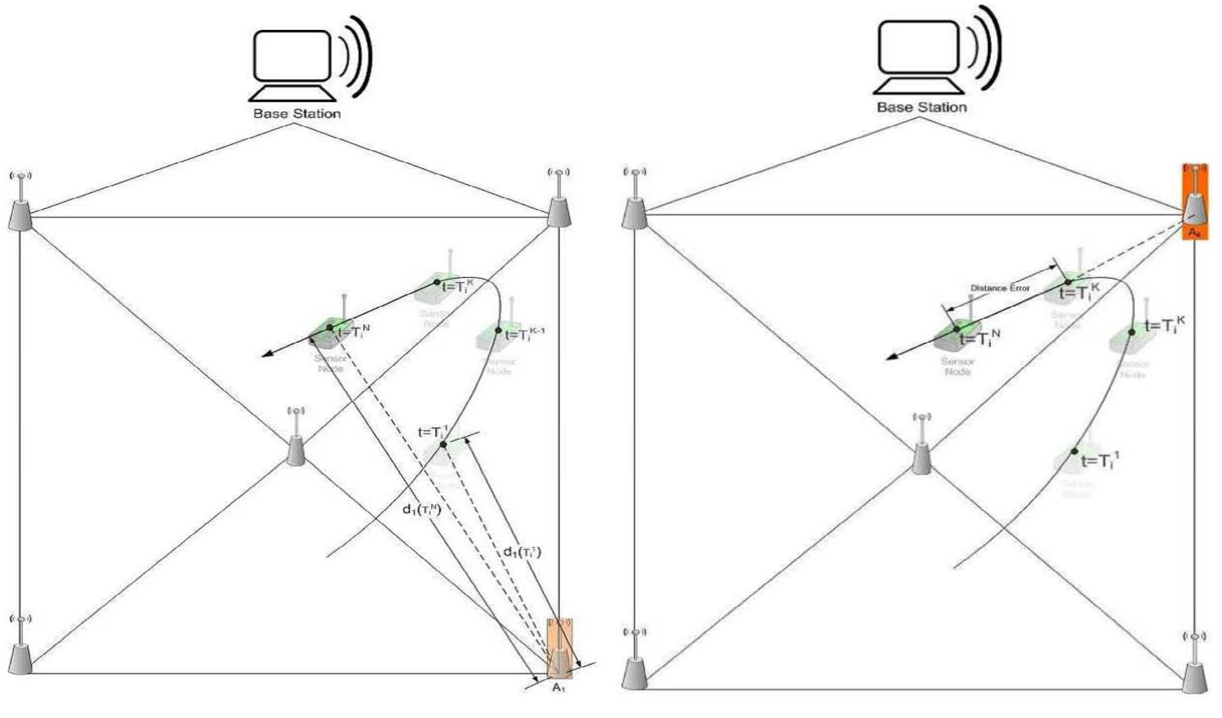
Fig. 2. The latency in data acquisition, which is intrinsic to mobile WSN, can be a new source of error for the localization processes. This figure shows how various data measured at different points throughout the $i-$th beaconing period ($d_1, d_2, \dots, d_N$ measured at $T_i^1, T_i^2, \dots, T_i^N$, respectively) are used to locate the position of the node at the end of the $i-$th beaconing period T_i^N. The localization period or beaconing period T in the figure refers to the time interval between two localization attempts, during which the distance data are measured. The sampling time t refers to the time difference between two consecutive points at which individual distance data are sampled. It principally symbolizes the time that it takes for one distance sample to be measured.

For $i \in N$ and $t \in R^+$, let $d_i(t)$ denote the distance between the target node and the $i-$th anchor node A_i at time t. Fig. 3(a) illustrates the variations in the measured distance between the target node and the first anchor node A_1, from the beginning to the end of the $i-$th localization period, as well as the overall difference $|d_1(T_i^1) - d_1(T_i^N)|$. The maximum error in the measured distance from the $k-$th anchor node d_k, caused by the Data Acquisition Latency, can be formulated as follows (assuming that the magnitude of node's maximum speed $|V_{max}|$ is known):

$$|d_k(T_i{}^N) - d_k(T_i{}^k)|_{\max} = |V_{\max}|(T_i{}^N - T_i{}^k) = |V_{\max}|(N-k)t. \tag{1}$$

This corresponds to the case, when throughout the rest of the localization period, i.e. from T_i^K to T_i^N, the target node moves in the direction of the line connecting its position at T_i^K to the $k-$th anchor node, and at a speed equal to $V = |V_{max}|$,as depicted in Fig. 3(b). To find the maximum overall error in one Beaconing Period, set k in (1) equal to 1, so that:

$$\text{Maximum Distance Error} = |V_{\max}|(N-1)t. \tag{2}$$



(a) (b)

Fig. 3. (a) The latency in data acquisition is maximum for the node, the distance to which is measured first, i.e. at the beginning of the beaconing periodT_i^1. (b) The maximum Data Acquisition Latency error in the measured distance to the $k-$th anchor node A_k occurs when the target node moves straightaway from or toward A_k, throughout the rest of the beaconing period, i.e. from T_i^K to T_i^N. In this case, the target node will move on a straight line that connects the location of the static anchor A_k to the target node position at the time its distance to A_k was measured $(X_T(T_i^K), Y_T(T_i^K))$. The case corresponding to the maximum Data Acquisition Latency error for the distance to anchor node A_k is depicted in this figure.

Equation (2) offers a valuable insight into the nature of DAL error and the factors affecting it. In particular, it is clear that:

- The error increases with the increasing number of Anchor Nodes N;
- Increasing the sampling time t will degrade the operation of the localization scheme in a mobile WSN;

- Changing the Beaconing Period T does not affect the Data Acquisition Latency error;
- The increase in the mobility of the target nodes (increasing $|V_{max}|$) exacerbates the error;
- Lastly, according to the relation derived in (1), the value of the error is the largest at the first time-slot, $k = 1$, and decreases to zero as one approaches the end of a Beaconing Period, $k = N$.

The above effects are simulated in Section 5-B. The relationship between localization error and distance measurement error is explored in the next section.

3. Relation between Localization Error and Distance Measurement Error

Suppose that the following set of inter-nodal distances have been measured:

$$(d_1, d_2, \ldots, d_N)^T, \tag{3}$$

where, d_i, $i \in \overline{N} := \{1, 2, \ldots, N\}$, represents the measured distance between the target node and the i^{th} anchor, at the time when the measurement is performed. To emphasize the error in distance measurements one may use "~". Such distance data may be acquired through a variety of measurement techniques, such as RSSI, time-of-arrival (ToA), time-difference-of-arrival (TDoA), angle-of-arrival (AoA) and so on. The measured data are then combined and processed, using methods such as tri-lateration, triangulation, multi-lateration and maximum-likelihood estimation, to yield the desired target locations [9]. In general, each measured distance d_i in (3) corresponds to a nonlinear equation in terms of the unknown coordinates of the target node (X_T, Y_T) and the known coordinates of the $i-$th anchor node (X_{Ai}, Y_{Ai}). This equation in the two-dimensional case takes the form:

$$(X_T - X_{Ai})^2 + (Y_T - Y_{Ai})^2 = {d_i}^2, \; i \in \overline{\mathrm{N}}, \tag{4}$$

thus resulting in a set of N nonlinear (quadratic) equations. It can be shown that the set of N nonlinear equations given by (4) can be transformed into the following linear system of $N-1$ equations in terms of the target node's unknown coordinates (X_T, Y_T) [2]:

$$\begin{pmatrix} 2(X_{A_N} - X_{A_1}) & 2(Y_{A_N} - Y_{A_1}) \\ . & . \\ . & . \\ . & . \\ 2(X_{A_N} - X_{A_{N-1}}) & 2(Y_{A_N} - Y_{A_{N-1}}) \end{pmatrix} \begin{pmatrix} X_T \\ Y_T \end{pmatrix} =$$
$$\begin{pmatrix} {d_1}^2 - {d_N}^2 \\ . \\ . \\ . \\ {d_{N-1}}^2 - {d_N}^2 \end{pmatrix} + \begin{pmatrix} {X_{A_N}}^2 - {X_{A_1}}^2 \\ . \\ . \\ . \\ {X_{A_N}}^2 - {X_{A_{N-1}}}^2 \end{pmatrix} + \begin{pmatrix} {Y_{A_N}}^2 - {Y_{A_1}}^2 \\ . \\ . \\ . \\ {Y_{A_N}}^2 - {Y_{A_{N-1}}}^2 \end{pmatrix}. \tag{5}$$

Denoting the left-hand-side coefficients matrix in (5) by *A*, the unknown coordinates by **x**, and the right-hand-side by **b**, (5) can be rewritten as[1]:

$$A\mathbf{x} = \mathbf{b}, \tag{6}$$

where for $N = 3$ non-collinear anchors, *A* is a non-singular 2×2 matrix, for which (6) has a unique solution given by $A^{-1}\mathbf{b}$.However, so as to reduce the influence of errors in the observations (distance measurement errors), one would like to use a greater number of measurements than the number of unknown parameters in the model [10]. The resulting problem is to solve an over-determined linear system of equations. The optimum solution ˆ,**x**, should minimize the Euclidean error vector (residual vector) norm, $||A\mathbf{x} - \mathbf{b}||_2^{\,2}$, and is given by:

$$A^T A\hat{\mathbf{x}} = A^T \mathbf{b}, \tag{7}$$

which upon solving for ˆ,**x** yields:

$$\hat{\mathbf{x}} = (A^T A)^{-1} A^T \mathbf{b}. \tag{8}$$

The relations (5) and (8) can be utilized to show how the distance measurement errors are mapped into the localization error, following the lateration process:

$$e^2 = \begin{pmatrix} \tilde{d}_1^2 - {d_1}^2 + {d_N}^2 - \tilde{d}_N^2 \\ . \\ . \\ . \\ \tilde{d}_{N-1}^2 - {d_{N-1}}^2 + {d_N}^2 - \tilde{d}_N^2 \end{pmatrix}^T (B^{-1})^T B^{-1} \begin{pmatrix} \tilde{d_1}^2 - {d_1}^2 + {d_N}^2 - \tilde{d}_N^2 \\ . \\ . \\ . \\ \tilde{d}_{N-1}^2 - {d_{N-1}}^2 + {d_N}^2 - \tilde{d}_N^2 \end{pmatrix}, \tag{9}$$

where $B = (A^T A)^{-1} A^T$. It should be noted that the localization error *e* is defined as the Euclidean distance between the detected location and the real position of the target node at the end of the beaconing period *T*. In the next section, a modification to the above procedure is proposed to enhance its performance for localization of a mobile target node in the face of DAL.

4. Weighted Least Squares

In the previous section, the least squares method was utilized to derive the unknown coordinates of the target nodes from the measured distances. Gauss-Markov theorem ensures that when the measurement errors in the observation vector **b** have zero expectations, are uncorrelated, and have equal variances, the solution, given by (8), will be the best linear unbiased estimator (BLUE) [10].Now consider the case of the least squares coordinate estimation scheme described in Section 3, with the measured distances given as in (3) and assume that DAL is the only source of error in the measurements. From (1) it follows that:

$$|\tilde{d}_1 - d_1|_{\max} > |\tilde{d}_2 - d_2|_{\max} > \cdots > |\tilde{d}_{N-1} - d_{N-1}|_{\max} > |\tilde{d}_N - d_N|_{\max} = 0, \tag{10}$$

---

[1] [1]Vectors are expressed by bold face lower case letters, superscript “T” denotes the matrix transpose, and ε[.] indicates the mathematical expectation.

where " ˜ " denotes the measured values. Obviously, (10) implies that the assumption of equal variances cannot be applied to the observations anymore, i.e. the elements of the observation vector **b** in (6) are not known with the same accuracy and the errors do not have equal variances. Hence, the application of (7) to estimate the unknown coordinates of the target node will not result in the BLUE of the target node's position anymore. Aitken (1935), introduced a well-known extension to the Gauss-Markov Theorem that provides a BLUE, for the case where the covariance matrix of the measurement errors in the observation vector **b** is non-scalar and is given by:

$$\mathrm{COV}[\mathbf{b}] = \sigma^2 W. \tag{11}$$

It is further assumed that the measurement errors have zero means and matrix W is symmetric, positive-definite. Accordingly, with the error covariance matrix given as in (11), the BLUE of **x** in (6) would be the least squares solution $min_{\mathbf{x}}(A\mathbf{x}-\mathbf{b})^T W^{-1}(A\mathbf{x}-\mathbf{b})$, and is given by the following set of normal equations [10]:

$$A^T W^{-1} A\hat{\mathbf{x}} = A^T W^{-1}\mathbf{b}, \tag{12}$$

or equivalently:

$$\hat{\mathbf{x}} = (A^T W^{-1} A)^{-1} A^T W^{-1}\mathbf{b}, \tag{13}$$

where **b** is the observation vector and is given by the right-hand-side of (5) as:

$$\mathbf{b} = \begin{pmatrix} {d_1}^2 - {d_N}^2 \\ . \\ . \\ . \\ {d_{N-1}}^2 - {d_N}^2 \end{pmatrix} + \begin{pmatrix} {X_{A_N}}^2 - {X_{A_1}}^2 \\ . \\ . \\ . \\ {X_{A_N}}^2 - {X_{A_{N-1}}}^2 \end{pmatrix} + \begin{pmatrix} {Y_{A_N}}^2 - {Y_{A_1}}^2 \\ . \\ . \\ . \\ {Y_{A_N}}^2 - {Y_{A_{N-1}}}^2 \end{pmatrix}. \tag{14}$$

The case $W = I$ (identity matrix) corresponds to the linear model already discussed in Section 3. Now, in order to be able to apply the result of (13) to the over determined system in (5), the knowledge of the covariance matrix W for the elements of the observation vector **b**, given by (14), is necessary. On the other hand, peering into (14), it is clear that the only part of (14) that is prone to the DAL error is the vector:

$$\mathbf{d} = \left({d_1}^2, \ldots, {d_{N-1}}^2\right)^T. \tag{15}$$

Accordingly, the covariance matrix of **b** will be given by the covariance matrix of vector **d** in (15), i.e.

$$\mathrm{COV}[\mathbf{b}]_{ij} \;=\; \varepsilon[(b_i - \varepsilon[b_i])(b_j - \varepsilon[b_j])] = \varepsilon[({d_i}^2 - \varepsilon[{d_i}^2])({d_j}^2 - \varepsilon[{d_j}^2])],\ i, j \in \overline{\mathrm{N}-1}. \tag{16}$$

In order to go ahead with the calculation of the above covariance matrix, one needs to know about the random properties of the DAL error, including its average and probability distribution function. Based on the simulation results in Section 5-A, for relatively random movements of the target node it would be fair to assume that, for $i \in \overline{N-1}$ the DAL errors in measuring d_i have zero-mean, are uncorrelated, and are uniformly distributed between $\pm|V_{max}|(N-i)t$. Using these assumptions for $i \in \overline{N-1}$,the measured distance $\tilde{d}_i$ is a uniformly distributed random variable between $\varepsilon[d_i]-|V_{max}|(N-i)t$ and $\varepsilon[d_i]+|V_{max}|(N-i)t$. Therefore, the probability distribution function f_{Di} ($\tilde{d}_i$) is given by:

$$f_{D_i}(\tilde{d}_i) = \begin{cases} \frac{1}{2|V_{\max}|(N-i)t}, & \varepsilon[d_i] - |V_{\max}|(N-i)t \leq \tilde{d}_i \leq \varepsilon[d_i] + |V_{\max}|(N-i)t \\ 0, & \text{otherwise} \end{cases}, i \in \overline{\mathrm{N}-1}. \tag{17}$$

Next, the probability distribution function of d_i^2 in (15) can be found using the concept of functions of random variables [11]. Accordingly, if X is a random variable, whose probability distribution function is given by $f_X(x)$, then the probability distribution function of $Y = X^2$ will be given by:

$$f_Y(y) = \frac{f_X(-\sqrt{y})}{2\sqrt{y}} + \frac{f_X(\sqrt{y})}{2\sqrt{y}}. \tag{18}$$

Hence, to calculate the probability distribution function for the elements of the vector **d** in (15), one can substitute the result of (17) in (18) to obtain:

$$f_{D_i^2}(\tilde{d}_i^{\,2}) = \begin{cases} \frac{1}{4\tilde{d}_i|V_{\max}|(N-i)t}, & (\varepsilon[d_i] - |V_{\max}|(N-i)t)^2 \leq \tilde{d}_i^{\,2} \leq (\varepsilon[d_i] + |V_{\max}|(N-i)t)^2 \\ 0, & \text{otherwise} \end{cases}, i \in \overline{\mathrm{N}-1}. \tag{19}$$

Finally, with the probability distribution function given in (19), the variance of d_i^2 can be computed as:

$$\begin{aligned} \varepsilon[(\tilde{d}_i^{\,2} - \varepsilon[\tilde{d}_i^{\,2}])^2] &= \varepsilon[\tilde{d}_i^{\,4} - 2\tilde{d}_i^{\,2}(\varepsilon[\tilde{d}_i^{\,2}]) + (\varepsilon[\tilde{d}_i^{\,2}])^2] = \varepsilon[\tilde{d}_i^{\,4}] - (\varepsilon[\tilde{d}_i^{\,2}])^2 \\ &= \left(\overline{d_i}^4 + 2\overline{d_i}^2(|V_{\max}|(N-i)t)^2 + \frac{(|V_{\max}|(N-i)t)^4}{5}\right) - \left(\overline{d_i}^2 + \frac{(|V_{\max}|(N-i)t)^2}{3}\right)^2 \\ &= \frac{4}{3}\left(\overline{d_i}^2(|V_{\max}|(N-i)t)^2 - \frac{(|V_{\max}|(N-i)t)^4}{15}\right), i \in \overline{\mathrm{N}-1}. \end{aligned} \tag{20}$$

Following the measurements in (3), each of the average distances $\overline{d_i} = \varepsilon[d_i]$ in (20) may be approximated by the actual measured values $\tilde{d}_i$. Accordingly, the matrix $W = (W_{ij})_{(N-1)\times(N-1)}$ in (13) can be estimated as:

$$W_{ij} = \begin{cases} 0, & i \neq j \\ \frac{4}{3}(\tilde{d}_i^2(|V_{\max}|(N-i)t)^2 - \frac{(|V_{\max}|(N-i)t)^4}{15}), & i = j \end{cases}, i, j \in \overline{\mathrm{N}-1}. \tag{21}$$

Using the diagonal matrix introduced by (21) in the context of the linear system of equations given in (13) will yield a weighted version of the system of equations given by (8), in which the more recent measurements are regarded as more valuable and are assigned a larger weight, as they represent the real value of the measured distances at the point of localization with a greater accuracy. To derive the equivalent of (9) for the case where the unknown coordinates are given by (13) and DAL is the only source of error in the distance measurements, let $B' = (A^T W^{-1} A)^{-1} A^T W^{-1}$ and knowing that $d_N{}^2 - \tilde{d}_N{}^2 \equiv 0$, one can rewrite (9) as:

$$e'^2 = \begin{pmatrix} \tilde{d}_1^2 - d_1{}^2 \\ . \\ . \\ . \\ \tilde{d}_{N-1}^2 - d_{N-1}{}^2 \end{pmatrix}^T (B'^{-1})^T B'^{-1} \begin{pmatrix} \tilde{d}_1{}^2 - d_1{}^2 \\ . \\ . \\ . \\ \tilde{d}_{N-1}^2 - d_{N-1}{}^2 \end{pmatrix}. \tag{22}$$

which shows how the DAL error in distance measurement is mapped into the localization error e' (The Euclidean distance between the estimated and actual target sensor positions).As a concluding remark, it is worth noting that since the proposed weighting can be implemented as a modification within the framework of the traditional lateration, it does not impose any additional hardware costs. The results of simulations in Section 5-B confirm the superiority of the proposed approach in the mobile case.

5. Simulation Results and Discussion

In the preceding sections, a theoretical analysis of the properties of DAL error was presented. In this section, simulation studies are performed to validate and clarify on the theoretical results. A combination of the random Waypoint and Gauss-Markov mobility models were exploited to simulate the random movement of the target node across the localization field [12].In random waypoint, a mobile node moves towards a random destination location with a randomly chosen speed, pauses for a specific period of time when it reaches this destination (pause-time), and then chooses a random destination again. In the Gauss-Markov model, initially each node is assigned a current speed and direction. At fixed intervals, the speed and direction are updated. Specifically, the speed s_n(m/s) and direction d_n(rad) at the $n-$th instance is calculated based on the value of speed and direction at the $(n-1)-$th instance, according to the following equations:

$$\begin{aligned} s_n &= \alpha s_{n-1} + (1-\alpha)\bar{s} + \sqrt{1-\alpha^2}\, s_{xn-1}, \\ d_n &= \alpha d_{n-1} + (1-\alpha)\bar{d} + \sqrt{1-\alpha^2}\, d_{xn-1}, \end{aligned} \tag{23}$$

where s_n and d_n are the updated speed and direction of the mobile node at the $n-$th time interval. The tuning parameter α is used to vary the randomness; $\overline{s}$ and $\overline{d}$ are constants representing the mean value of speed and direction as $n \to \infty$; ands_{xn-1} and d_{xn-1} are random variables from a Gaussian distribution. By setting $\alpha = 0$, one gets a very random motion, while $\alpha=1$ gives a completely linear motion. Intermediate levels of randomness are obtained by varying the value of α between 0 and 1. In order to realize a realistic mobility model, a combination of both models is utilized. The random pauses in the random waypoint model are set to zero and a total of 10000 uniformly distributed random locations, corresponding to the path taken in one time-unit (1s), are considered and the speed and direction of the movement are updated according to (23) every 30 samples (0.003 s). The Gaussian random variables in (23) are assumed to be normally distributed and the randomness factor α is set at 0.2. The initial speed and direction are set at 5 m/s and 34 rad, respectively, and their initial average values, $\overline{s}$ and $\overline{d}$, are set at 50 m/s and 4 rad, respectively. The averages $\overline{s}$ and $\overline{d}$ are updated every 90 samples (0.009 s), according to the random waypoint model. The mean values are assumed to be uniformly distributed, with the maximum value of speed set at $|V_{max}|$ = 100m/s and the direction taking any value between 0 and 2π. The aforementioned parameters are kept the same throughout the simulations of this section. Furthermore, the target node starts its movement from the initial position (10 m, 10 m) and a total of N = 5 static anchor nodes are used, which are located at A_1 = (2,11), A_2 = (11,0),A_3 = (11,11), A_4= (5,6), and A_5 = (0,0). Moreover, the beaconing period T and the sampling time t are set at T = 100 samples = 0.01 s and t = 20 samples = 0.002 bs, respectively. Fig. 4 depicts the original path and the localized positions, which are obtained using the lateration scheme, described in Section 3.

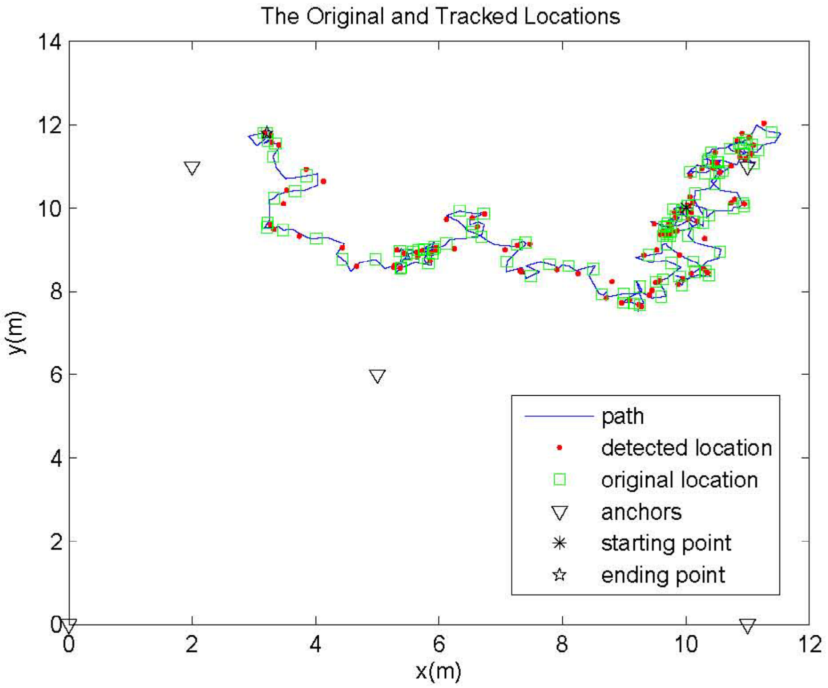


Fig. 4. The original path and the tracked locations are depicted. A total of N = 5 anchor nodes were used and their locations are marked in the figure. The localization period is set at T = 0.01s and the sampling time is t = 0.002 s. The movement of the node is simulated for one second (time-unit).

5.1. Properties of the Data Acquisition Latency Error

Fig. 5 shows the errors e_i in the measured distances to each of the anchors A_i, $i \in \overline{4}$, note that $e_5 \equiv 0$. Accordingly, despite the random fluctuations of the error values, caused by the various directions that the target node takes with respect to different anchor nodes, e_1 tends to take larger magnitudes and e_4 smaller ones. Sharp autocorrelation peaks for e_1 to e_4 in Fig. 8, as well as the approximately zero averages, and the random distribution of the magnitudes, observed in Fig. 7, suggest that it would be reasonable to assume a random behavior for the errors subjected to the conditions imposed by (1). Moreover, the sharp overall autocorrelation peak in Fig. 6 and the relatively low magnitude of the mutual cross-correlation functions in Fig. 9 suggest that the error sequences e_1 to e_4 are reasonably uncorrelated. In lack of any further information and with the apparent distribution of the error magnitudes between the $\pm|V_{max}|(5-i)t$ bounds provided by (1), one can assume that, for $i \in \overline{4}$ the error sequence e_i is a random process, with uniform probability distribution between $\pm|V_{max}|(5-i)t$. Finally, it should be highlighted that the above results are correct only when the movement of the target node within the localization field is relatively random.

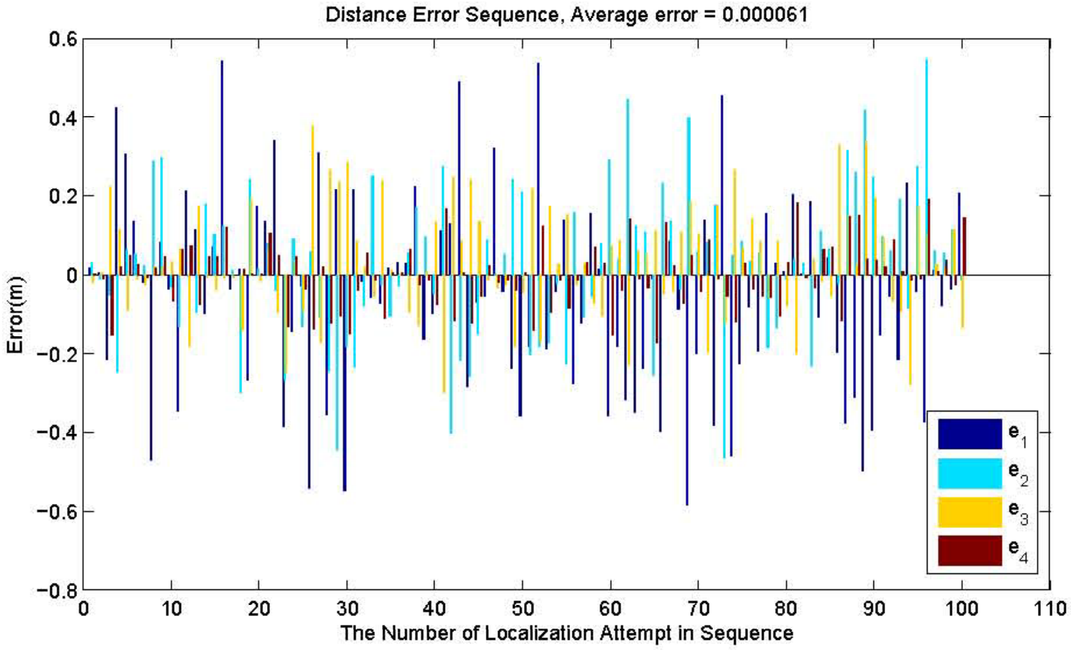


Fig. 5. Distance Errors, e_1, e_2, e_3, e_4, and e_5 denote the errors in the measured distances to the first, second, third, fourth, and fifth anchor nodes, respectively. The distance measurements at each instance of time are error free so DAL is the only source of error. According to equation (1), one has: $e_5 \equiv 0$.

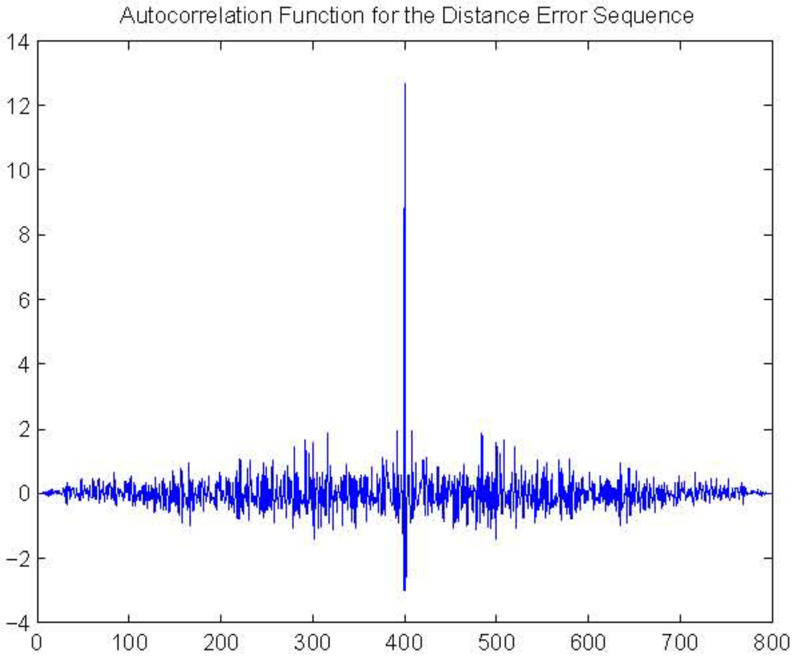


Fig. 6. Autocorrelation function for Distance Error Sequence of Fig. 5.

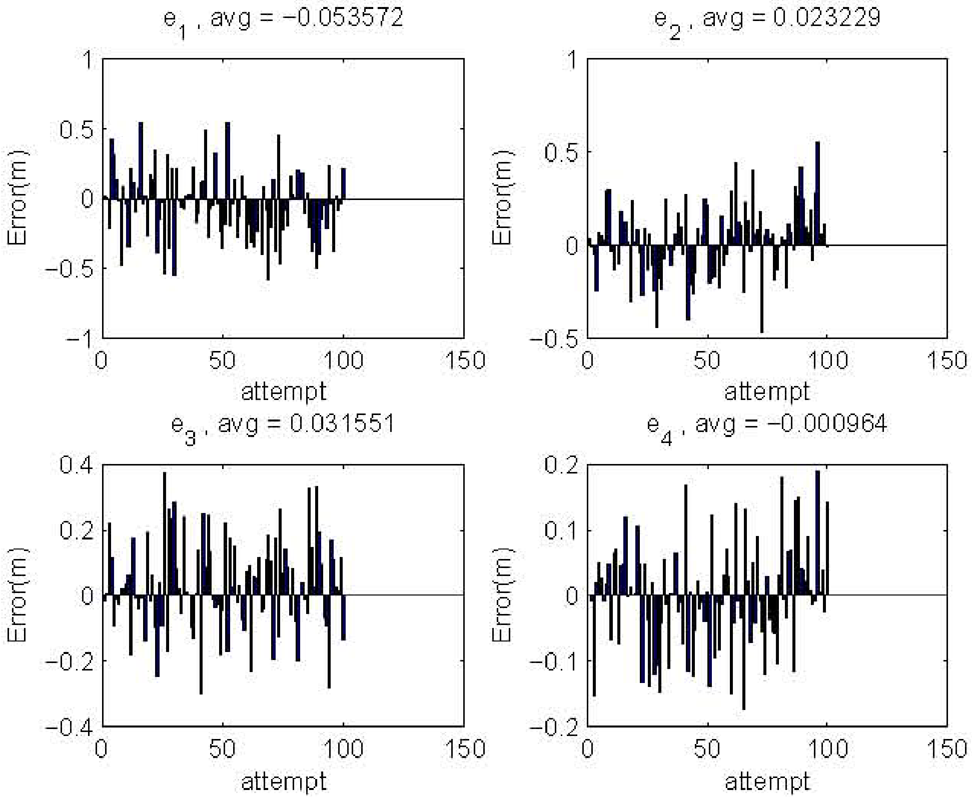


Fig. 7. Errors in distances to each of the anchor nodes.

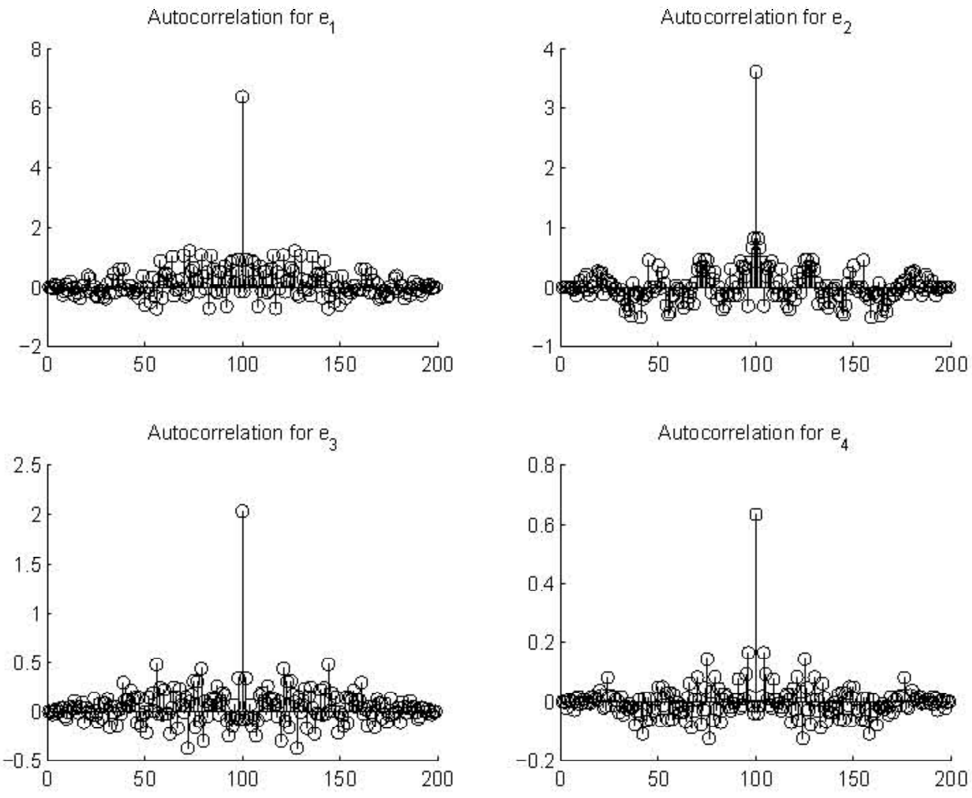


Fig. 8. Autocorrelation for errors in distances to each of the anchor nodes.

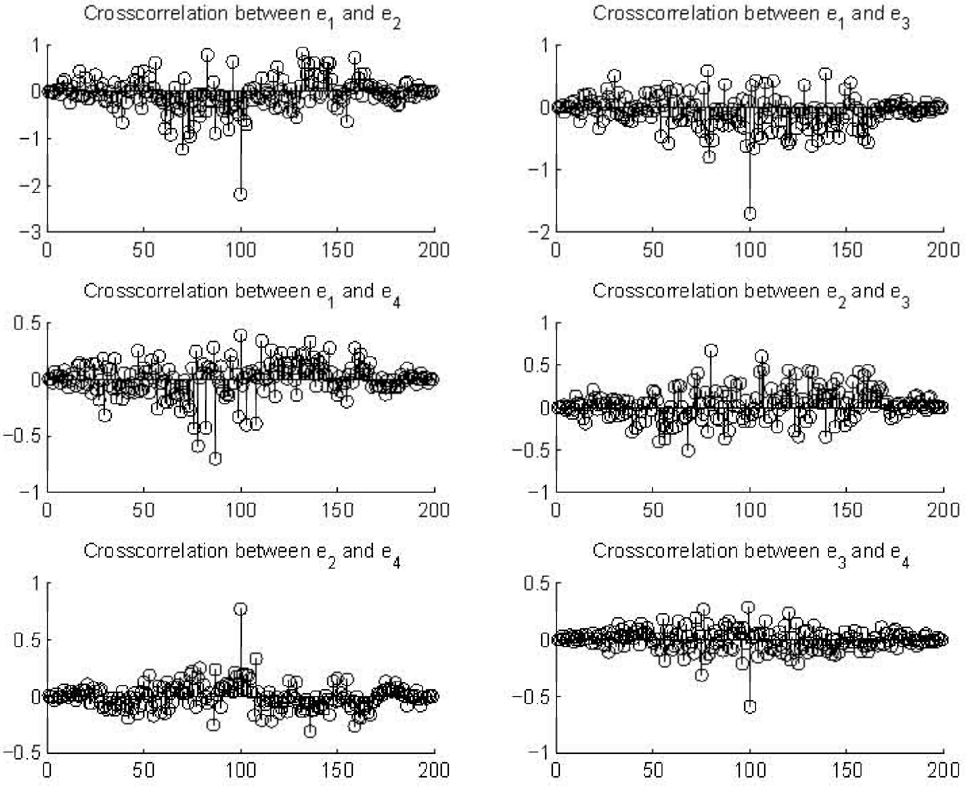


Fig. 9. Mutual cross-correlations between distance errors.

5.2. Localization Error Due to the Data Acquisition Latency

Equation (2) happens to be an effective tool when it comes to the prediction of the effects of *t*, and *N* on the Distance and localization errors. Figs. 10-12 depict the effects of localization period *T*, sampling time *t*, and number of anchor nodes *N*, respectively. Except for the one under investigation the rest of the parameters for the following simulations are kept constant at the values reported earlier. Moreover, the simulations are performed on a common path generated by using the previously described mobility models. It is evident from Figs. 10-12 that the proposed weighted least squares approach outperforms the lateration scheme under all circumstances.

1) Effect of Beaconing Period: According to Fig. 10 and equation (2) the average DAL error does not depend on the beaconing period *T*; but rather the variations that are observed in the graph are due to the random nature of the error. Moreover, the way the localization error plots and the distance error plot follow one another, can be illuminative to the relations in (9) and (22).

2) Effect of Sampling time: Fig. 11 illustrates the effect of Sampling time *t* on the error performance of the localization scheme for a mobile case. As already pointed out, the distance error caused by DAL increases, with increasing sampling time *t*. Nonetheless, a longer sampling time, corresponding to a longer averaging window, is often necessary to improve the accuracy of equations, relating the average path-loss to the transmitter-receiver separation [13]. Therefore, the proper choice of sampling time *t* poses a fundamental trade-off in the design of the localization schemes for mobile WSN. On the one hand, the increment of sampling time *t* increases the reliability of the measured distance data by improving their correlation with the measured RSSI values; and on the other hand, it exacerbates the DAL error. Since the latter factor becomes less dominant with the decreasing speed and mobility of the sensor nodes, it is reasonable to assume that an optimum solution will take into account the effect of the target node's speed, hence favoring longer sampling times at lower speeds.

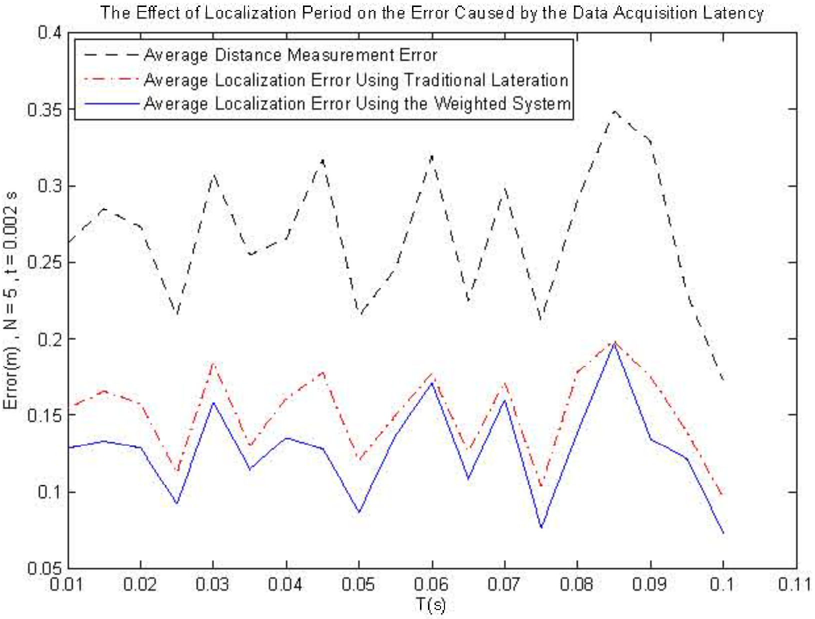


Fig. 10. Effect of Beaconing Period *T*.

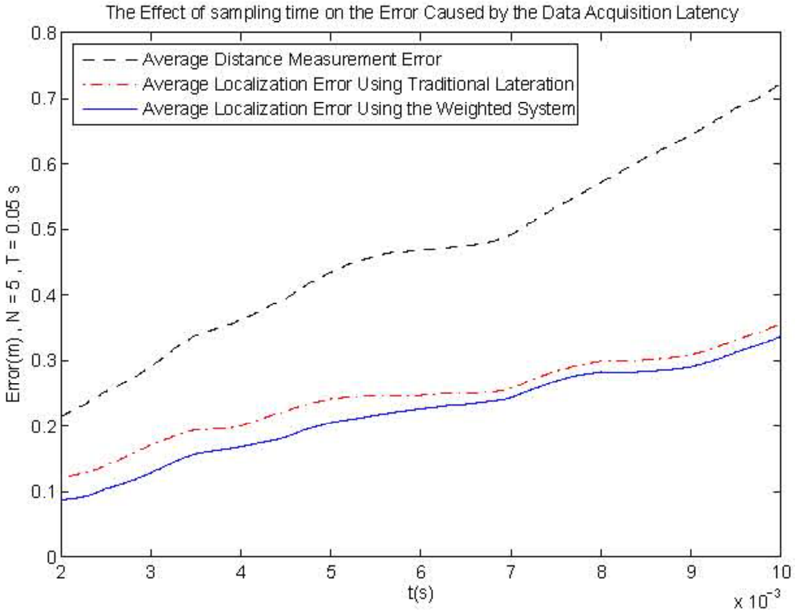


Fig. 11. Effect of Sampling Time *t*.

3) Effect of the Number of Anchor Nodes: Fig. 12 demonstrates the simulation results for the localization of a mobile target node with different number of anchor nodes *N* put randomly across the localization field. As predicted by (2), the localization performance degrades with increasing *N*. However, the relation between the number of anchor nodes and the localization error is made complex due to the fact that an increase in the number of anchor nodes will not only increase the absolute value of the elements of the distance error vector in (22), as suggested by (2), but also increases the dimension of the aforementioned vector. The latter has the additional effect of alleviating the overall error, by increasing the number of observations in the least squares method, thus preventing the localization error from increasing in a smooth linear manner as was the case with Fig. 11for sampling time. This again points to a trade-off this time in the optimum choice of *N*, the increase of which, will on the one hand, increase the

DAL error, and on the other hand, lessen the overall effect of the measurement errors by adding more observations to the equation-set in (6). What is most interesting is the effect of the proposed weighting on this parameter. According to Fig. 12, with the weighting introduced in Section 4, one can annul the effect of increasing *N* on the Data Acquisition Latency, and thus freely exploit the former to cancel out the random measurement noises. This will in turn enhance the robustness of the proposed scheme against distance measurement errors.

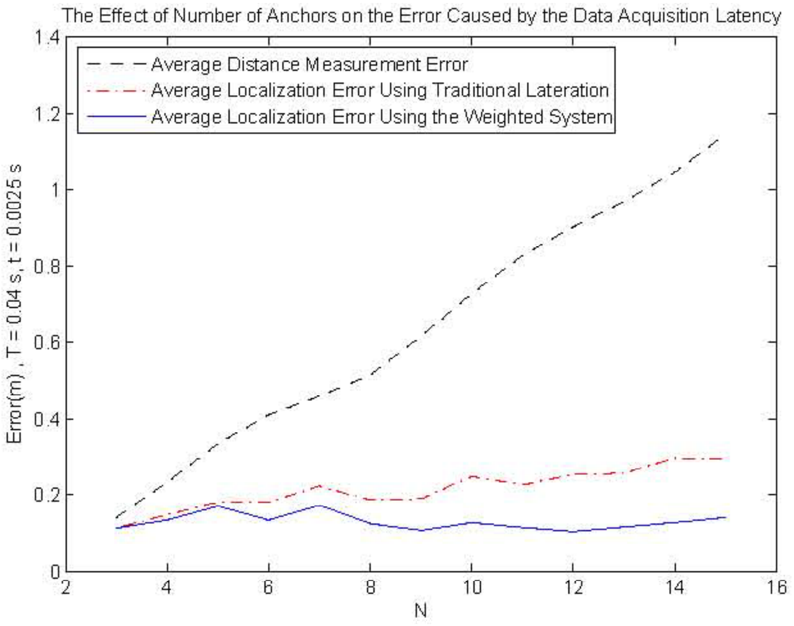


Fig. 12. Effect of the Number of Anchor Nodes *N*.

6. Conclusion

It was shown that the time-difference between the data acquisition and localization which is intrinsic to mobile WSN, can prove to be an impediment to the operation of the traditional distance estimation and position computation techniques. Accordingly, a new kind of error, called Data Acquisition Latency error, was introduced and its properties were investigated. Moreover, a weighted linear system of equations was suggested that can help mitigate the effect of DAL error on the lateration process. The simulation results confirmed the superior performance of the proposed method. It was further indicated that, while traditionally increasing the number of anchor nodes or widening the averaging window during RSSI sampling, is thought to help alleviate the effect of measurement errors, these two factors will exacerbate the DAL error, thus posing a new trade-off in the design of localization schemes for mobile sensors.

References

[1]. D. Munoz, F. B. Lara, C. Vargas, and R. Enriquez-Caldera, Position Location Techniques and Applications, *Academic Press,* 2009.

[2]. H. Karl and A. Willig, Protocols and Architectures for Wireless Sensor Networks, *John Wiley & Sons*, 2005.

[3]. N. P. Mahalik, Sensor Networks and Configuration: Fundamentals, Standards, Platforms, and Applications, *Springer-Verlag New York, Inc.,* Secaucus, NJ, USA, 2006.

[4]. S. Tilak, V. Kolar, N. B. Abu-Ghazaleh, and K.-D. Kang, Dynamic localization protocols for mobile sensor networks, Aug 2004. [Online]. Available:http://arxiv.org/abs/cs.NI/0408042

[5]. P. Bergamo and G. Mazzini, Localization in sensor networks with fading and mobility*, in Proc. of the 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications,* 2002., Vol. 2, 2002, pp. 750–754.

[6]. L. Hu and D. Evans, Localization for mobile sensor networks*, in Proceedings of the 10th Annual International Conference on Mobile Computing and Networking MobiCom '04*, New York, NY, USA, 2004, pp. 5–57.

[7]. M. Rudafshani and S. Datta, Localization in wireless sensor networks*, in Proceedings of the 6th International Conference on Information Processing in Sensor Networks IPSN '07,* New York, NY, USA, 2007, pp. 51–60.

[8]. X. Chen, P. Han, Q. He, and S. Tu, A viable localization scheme for dynamic wireless sensor networks, *in Proc. of the 1st International Multi-Symposiums on Computer and Computational Sciences IMSCCS '06*, Vol. 2, 2006, pp. 587–593.

[9]. A. Savvides, C.-C. Han, and M. B. Strivastava, Dynamic fine-grained localization in ad-hoc networks of sensors, *in Proceedings of the7th Annual International Conference on Mobile Computing and Networking MobiCom '01*, New York, NY, USA, 2001, pp. 166–179.

[10]. Å. Björck, Numerical Methods for Least Squares Problems, *SIAM,* Philadelphia, Penn, 1996.

[11]. T. T. Soong, Fundamentals of Probability and Statistics for Engineers, *John Wiley & Sons*, 2004.

[12]. J. Ariyakhajorn, P. Wannawilai, and C. Sathitwiriyawong, A comparative study of random waypoint and Gauss-Markov mobility models in the performance evaluation of MANET*, in International Symposium on Communications and Information Technologies ISCIT '06* , 2006, pp.894–899.

[13]. J. B. Andersen, T. S. Rappaport, and S. Yoshida, Propagation measurements and models for wireless communications channels, *Communications Magazine, IEEE*, Vol. 33, No. 1, 1995, pp. 42–49.

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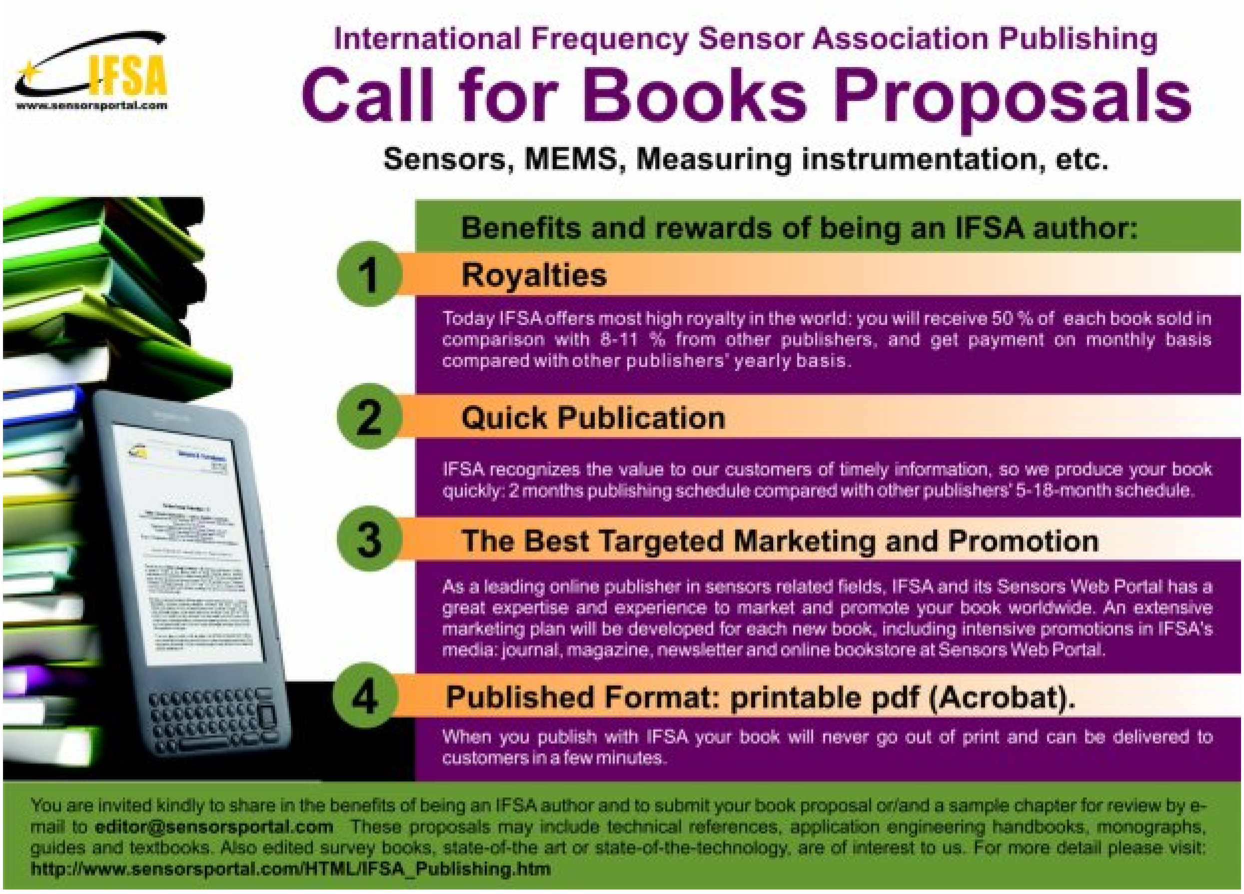

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