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IR-UWB based Cooperative Localization for Workers in the Large Factory

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***Abstract*—Work in the large factory with racket is very dangerous because there may be large mobile machines such as transporters, gantries, etc. To prevent disasters, location based awareness and warning must be served. Before then, accurate localization of the workers and mobile machines is required. In this paper, localization of a group of workers with a node containing an impulse radio-ultra wideband (IR-UWB) chipset is considered. The well-known merit of the IR-UWB is accurate ranging. However, its coverage is short as 30m due to the restriction of the transmit power. This factor may cause a bad geometric relation among the mobile nodes (*MN*s) and anchor nodes (*AN*s) because it is difficult to make sufficient connections between nodes for wireless localization. To provide accurate location information of a group of workers in this environment, an enhanced cooperative localization method is presented. Some Monte-Carlo simulations are presented to illustrate the proposed method and demonstrate its performance.**

***Keywords*—IR-UWB; Cooperative Localization**

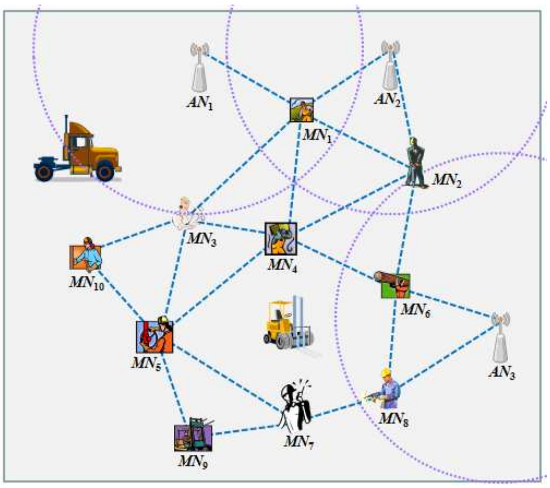

Figure 1. Environment for an example.

I. Introduction

The performance of wireless localization depends on the wireless signal characteristics, geometric relation among *AN*s and *MN*s, localization algorithm, etc. One of the PHYs containing good signal characteristics is the IR-UWB. Because of the inverse relation between the bandwidth and the duration of a signal, IR-UWB signal has very short duration waveforms. The high accuracy in ranging can be obtained due to the short duration pulse. As IR-UWB signals occupy a very large portion in the spectrum, a set of regulations are imposed on the transmitter of IR-UWB signals. Due to this regulation, the ranging coverage is short as 30m when the date rate is 850kbps. This may cause the bad geometric relation among *AN*s and *MN*s and bad localization results. To enhance the localization accuracy and availability, a cooperative localization method is used.

In this paper, the target for localization is workers in the large factory with racket. It is assumed that small number of *AN*s is installed in the factory that cannot cover the factory. Each worker possesses a *MN*. However, there may not be adequate number of *AN*s as can be seen in Figure 1. In this case, peer-to-peer (P2P) communication based localization method can be used [1]. In this ref. a cooperative localization method using the sequential algorithm was presented. This method may have several problems due to the bad geometry relation among nodes, and the insufficient measurement. In this paper, a cooperative localization method using a batch algorithm is introduced to enhance the performance of the sequential algorithm. In order to verify the performance of the proposed method, some Monte-Carlo simulations were carried out.

II. Wireless Cooperative Localization

A. Wireless Localization

Location of workers can be localized using several methods such as GPS/GNSS, sensors, wireless signals, etc. From among these, localization using wireless signals has been investigated intensively for indoor applications.

Wireless localization can be achieved using several methods: range based method, angle based method, identification based method.

- measurements for range based method: time of arrival, round trip time, received signal strength, time difference of arrival, etc.

- measurement for angle based method: angle of arrival.

- prerequisite for identification based method: database for fingerprinting.

There are several mobile communication/wireless communication infrastructures such as CDMA, GSM, WiMAX, WLAN, ZigBee, IR-UWB, chirp spread spectrum (CSS), etc. Recently, concern about IR-UWB has been increased due to its accuracy. The standardization of IEEE 802.15.4a in which IR-UWB and CSS are included as PHY was completed on the 22 March 2007. The principle interests of the standard is in providing communications ad high precision ranging/ location capability, high aggregate throughput, and ultra low power. IR-UWB radios have relative bandwidths larger than 20% or absolute bandwidths or more than 500 MHz. A large absolute bandwidth offers high resolution with improved ranging accuracy. The pulse of IR-UWB on the time-domain has several *nsec* width. This yields an excellent time resolution. Consequently, it is efficient to measure the distance using IR-UWB. However, federal communications commission (FCC) restricts the transmit power for reducing interference problem with other wireless signals. So, the coverage is short as 30m. Of course, this may restrict the range of applications [1, 2].

B. Cooperative Localization

In the range based wireless localization, several estimation methods have been used such as approximated linear estimator based on the least squares (LS) or maximum likelihood method, and closed-form solutions [3-5]. There must be more than three *AN*s connected to the *MN* to be localized. However, it is difficult to satisfy this requirement in the applications as can be seen in Figure 1. This is the main motivation for cooperative localization.

C. Cooperative Localization Method using the Sequential Algorithm

In the ref. [1], a cooperative localization method using the sequential algorithm was developed. In this method, adaptive LS method and adaptive direct solution were used. In the application of Figure 1, localization sequence is as follows using the method: $MN_1 \rightarrow MN_2 \rightarrow MN_4 \rightarrow MN_6 \rightarrow MN_3 \rightarrow MN_5 \rightarrow MN_8 \rightarrow MN_7 \rightarrow MN_9 \rightarrow MN_{10}$.

The sequential algorithm has several problems as:

- When the number of *AN*s connected to a *MN* is smaller than 2 due to the movement of the *MN*s, the *MN*s cannot be localized. If some *MN*s move, the *MN*s can be localized by using the information of the unmoved *MN*s in the coverage. In the situation that all the *MN*s move, however, the sequential algorithm cannot provide the updated location information.

- The information of the *MN*s and *AN*s that have a multi-hop connection with the *MN* to be localized in this step cannot be used.

To enhance the performance and availability of the sequential algorithm, a batch algorithm will be presented in the next section.

III. COOPERATIVE LOCALIZATION METHOD USING THE BATCH ALGORITHM

First, the following basic equation is formulated using the Euclidean distance measurement.

$$\tilde{\rho}_{i-j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} + w_{i-j} \tag{1}$$

where $\tilde{\rho}_{i-j}$ is the distance measurement, $(x_i,\ y_i)$ is the location of the MN_i, and w_{i-j} is the measurement noise.

This equation can be linearized based on the 1st order *Taylor* series expansion. In order to linearize the equation, nominal point must be set. Then the error terms with respect to the nominal point are linearize as follows:

$$\begin{aligned}\tilde{\rho}_{i-j} &= \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} + w_{i-j} \\ &= \sqrt{(\bar{x}_i + \delta x_i - \bar{x}_j - \delta x_j)^2 + (\bar{y}_i + \delta y_i - \bar{y}_j - \delta y_j)^2} + w_{i-j} \\ &\cong \sqrt{(\bar{x}_i - \bar{x}_j)^2 + (\bar{y}_i - \bar{y}_j)^2} + \frac{\bar{x}_i - \bar{x}_j}{\rho_{i-j}}\delta x_i - \frac{\bar{x}_i - \bar{x}_j}{\rho_{i-j}}\delta x_j \\ &\quad + \frac{\bar{y}_i - \bar{y}_j}{\rho_{i-j}}\delta y_i + \frac{\bar{y}_i - \bar{y}_j}{\rho_{i-j}}\delta y_j + w_{i-j} \\ &\cong \bar{\rho}_{i-j} + \bar{l}^x_{i-j}\delta x_i - \bar{l}^x_{i-j}\delta x_j + \bar{l}^y_{i-j}\delta y_i - \bar{l}^y_{i-j}\delta y_j + w_{i-j}\end{aligned} \tag{2}$$

where

$$\bar{\rho}_{i-j} = \sqrt{(\bar{x}_i - \bar{x}_j)^2 + (\bar{y}_i - \bar{y}_j)^2} \tag{3}$$

$$\bar{l}^x_{i-j} = (\bar{x}_i - \bar{x}_j)/\bar{\rho}_{i-j} \tag{4}$$

$$\bar{l}^y_{i-j} = (\bar{y}_i - \bar{y}_j)/\bar{\rho}_{i-j} \tag{5}$$

where $\bar{P}_i \equiv (\bar{x}_i,\ \bar{y}_i)$ denotes the nominal point of the $P_i \equiv (x_i,\ y_i)$ for linearization of the nonlinear equation, $\delta P_i \equiv (\delta x_i,\ \delta y_i)$ means the difference between the nominal point and the true location. In (4) and (5) $\bar{\rho}_{i-j}$ is used instead of ρ_{i-j}.

(2) can be rewritten as following matrix form.

$$\tilde{\rho}_{i-j} - \bar{\rho}_{i-j} = \begin{bmatrix}\bar{l}^x_{i-j} & \bar{l}^y_{i-j} & -\bar{l}^x_{i-j} & -\bar{l}^y_{i-j}\end{bmatrix}\begin{bmatrix}\delta x_i \\ \delta y_i \\ \delta x_j \\ \delta y_j\end{bmatrix} + w_{i-j} \tag{6}$$

If the AN_i and MN_j are connected, (6) can be changed as

$$\tilde{\rho}_{(i)-j} - \bar{\rho}_{(i)-j} = \begin{bmatrix}-\bar{l}^x_{i-j} & -\bar{l}^y_{i-j}\end{bmatrix}\begin{bmatrix}\delta x_j \\ \delta y_j\end{bmatrix} + w_{(i)-j}. \tag{7}$$

If the number of *MN*s is *n* and the number of connections is *m*, the main linear equation for the batch algorithm is presented as

$$R = H\delta P + W \tag{8}$$

where

$$\delta P = \begin{bmatrix}\delta x_1 & \delta y_1 & \vdots & \delta x_2 & \delta y_2 & \vdots & \cdots & \vdots & \delta x_n & \delta y_n\end{bmatrix}^T \tag{9}$$

$$R = \begin{bmatrix}\tilde{\rho}_{i_1-j_1} - \bar{\rho}_{i_1-j_1} \\ \vdots \\ \tilde{\rho}_{i_n-j_n} - \bar{\rho}_{i_n-j_n}\end{bmatrix} \tag{10}$$

$$W = \begin{bmatrix}w_{i_1-j_1} & \cdots & w_{i_n-j_n}\end{bmatrix}^T \tag{11}$$

and M is formulated according to the connections between MNs and ANs based on (6) and (7).

δP in (8) can be estimated using the least squares method as

$$\delta\hat{P} = \left(H^T H\right)^{-1} H^T R \tag{12}$$

The estimated error terms are added to the nominal points to estimate the locations of the MNs.

$$\begin{bmatrix} \hat{P}_1 \\ \vdots \\ \hat{P}_n \end{bmatrix} = \begin{bmatrix} \bar{P}_1 \\ \vdots \\ \bar{P}_n \end{bmatrix} + \delta\hat{P} \tag{13}$$

The estimated locations are set as new nominal points for iterating the above procedure. If (12) converges to near zero, the locations of the MNs are finally decided as (13).

IV. Simulation Results

In order to verify the performance of the presented algorithm, some Monte-Carlo simulations were performed under the environment of Figure 1. Ranging error is set as 60cm (3σ). The following figures show the performances of the batch algorithm and the sequential algorithm. As can be seen in these figures, it can be confirmed that the performance of the batch algorithm is slightly better than the sequential algorithm. The statistical estimation errors for the batch algorithm and the sequential algorithm are 37.86 cm (CEP) and 54.59 cm (CEP), respectively. Figure 4 shows the mean location error with respect to iteration that can be calculated as:

$$LocationError_t = \sqrt{\frac{1}{n+m}\sum_{j=1}^{m}\sum_{i=1}^{n}\left(\hat{P}_{MN_i,j,(t)} - P_{MN_i}\right)^2} \tag{14}$$

where m is the simulation number, n is the number of MNs, and t is the iteration step.

Figure 5 shows the mean link error with respect to iteration that can be calculated as:

$$LinkError_t = \sqrt{\frac{1}{n+m+\sum_{i=1}^{n} num_i}\sum_{k=1}^{m}\sum_{i=1}^{n}\sum_{j\in C(i)}\left(\hat{\rho}_{i-j,(t)} - \rho_{i-j}\right)^2} \tag{15}$$

where $C(i)$ is the MN ID connected to the MN_i and num_i is the number of neighbor MNs connected to the MN_i.

Figure 6 shows the mean link error with respect to estimation order. As can be seen in this figure, the location errors of two algorithms increase with estimation order due to the accumulation of the estimation error for the reference node. However, it can be concluded that the performance of the batch algorithm is better than that of the sequential algorithm.

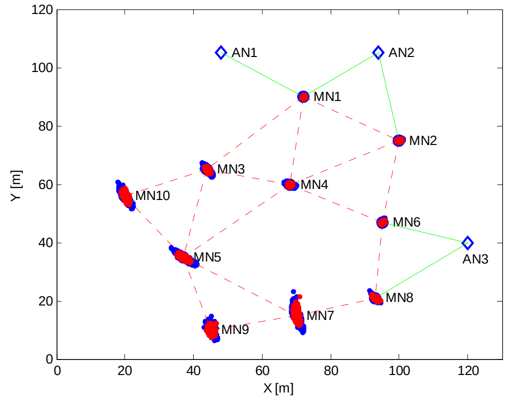

Figure 2. Estimated location of the MNs.

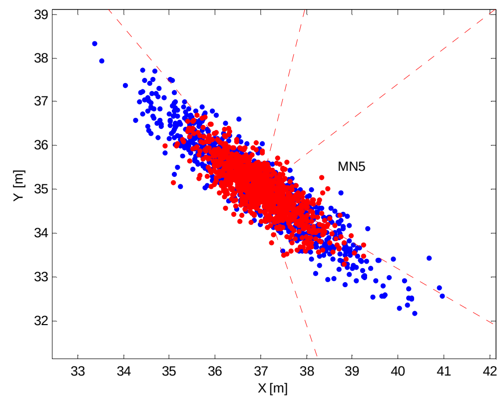

Figure 3. Estimated location of the MN_5.

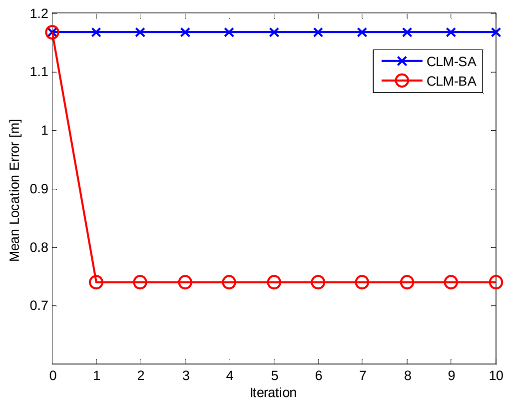

Figure 4. Mean location error with respect to iteration.

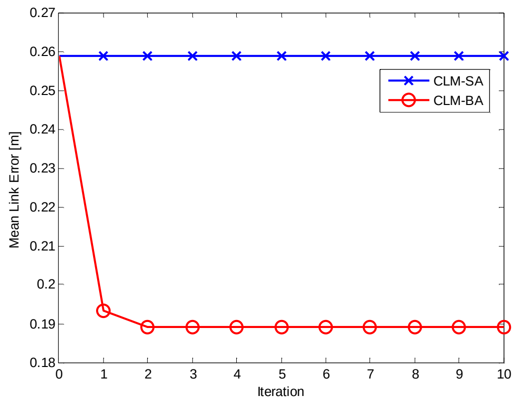

Figure 5. Mean link error with respect to iteration.

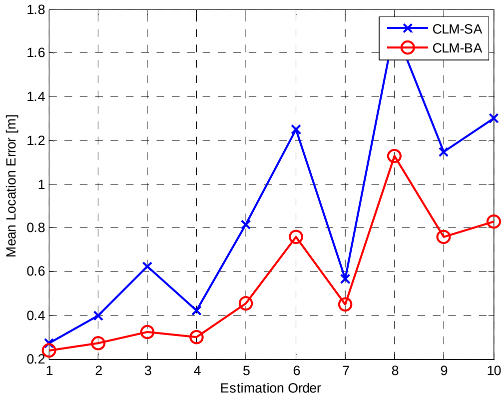

Figure 6. Mean location error with respect to estimation order.

V. Conclusions

In this paper, a cooperative localization algorithm is presented for workers in the large factory. The used wireless signal is the IR-UWB that can provide accurate ranging information. Based on this, accurate localization can be achieved. In ref. [1] a cooperative localization method using sequential algorithm was presented. In this paper another cooperative localization method is proposed using batch algorithm to enhance the performance of the sequential algorithm. The simulation results show that the performance of the batch algorithm is better than the sequential algorithm. The proposed method can be used for localization of a group of workers in the large factory with accuracy.

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