Enhancement of weighted centroid algorithm for indoor mobile non-cooperative localization system

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Abstract. Nowadays, indoor wireless localization is being challenged research by providing high accuracy of location information. However lower processing time, resistant to environmental condition, simple network topology are also become main concern. Non-cooperative localization based on RSSI allow the anchor nodes as the reference nodes communicate directly to the target node by exchanging the location data. High sensitivity of RSSI to the indoor environment, make difficulties in modelling propagation characteristic called as PLE. Incompatibility the PLE value can influence to the estimated position result. Weighted centroid localization (WCL) is feasible solution for RSSI-based that can obtain the target node location just by RSSI and anchor nodes coordinate without PLE value and estimated distance. While, the centroid determination of WCL give better estimation only to the centralized position of target node between all anchor nodes position. Therefore, we propose enhancement of WCL (eWCL) by replacing the weight based on RSSI with different estimated distance from WCL calculation. The simulation result show that using eWCL can reduce the error estimation around 60.42% compared to the WCL algorithm with 1.85 meters MSE value. Then, compared to the cooperative localization based on trilateration algorithm achieve 12.15% error estimation larger than eWCL at non-cooperative scheme.

1. Introduction

Location information about the sensor nodes is crucial requirement in enabling several applications of mobile wireless sensor networks, such as enviromental monitoring, disaster relief, site security, battlefield surveillance, home automation, assisted living, forest fire detection, and so on. According to its different applications, sensor nodes are deployed in indoor or outdoor environment. Sensor nodes could be equipped with a global positioning system (GPS) for determining its location, but indoor environment is inaccessible by GPS service. Thus, in the recent years, many researchers develop alternative technologies, and systems including schemes, algorithms for indoor localization with higher accuracy performance [1,2].

The commonly adopted technology in indoor localization are radio frequency (RF) spesifically WiFi, Zigbee, Bluetooth and cellular, while the non-RF system including cameras, inertial measurements, ultrasound signal. Among all available tecnologies, Received Strength Signal Indicator (RSSI) based on RF technology can be easily implemented to support indoor localization system due to some wireless communication modules are embedded in sensor nodes [3,4]. However indoor localization using RSSI are also easily affected by many factors such as multipath fading, interference, and attenuation from the environment condition [5]. Therefore, it is required suitable localization algorithm which should be resistant to environment influences and also fast calculated the estimated position related to the low computational system [6].

Basicly, the localization algorithm have been categorized into Range-based localization algorithm using distance approximation measurement to determine node position. The other one is range-free algorithm, which utilized the nodes connectivity and regardless the inter nodes distance to obtain the sensor nodes location. Some of range-based localization algorithm are trilateration, multilateration, while the example of range-free localization algorithm are centroid, multidimensional scaling (MDS), DV-Hop [7,8]. On other hand, according the communication mechanism inter nodes at localization system have been divided into non-cooperative refers that target node can communicate only with the connected anchor nodes which is suitable to the range-free algorithm. Then at cooperative scenario, all nodes can comunicate with each other in order to exchange some location information. Range-based localization within cooperative scenario show accurate location result than range-free algorithm at non-cooperative scenario, but it have non efficent realization in calculating estimated distance from RSSI [9]. RSSI measurement data have fluctuative value based on propagation characteristic which is called as pathloss exponent (PLE). PLE value have some indications especially at indoor environment which have inconsistence condition according to the building material and interior design. Incompatibility of PLE value can be influenced to the estimated distance calculation which is directly affected to the estimated position [10].

In order to overcome such problems, the enhancement weighted centroid localization (eWCL) as the part of range-free localization to improve the conventional WCL algorithm accuracy is presented in this paper. WCL uses a static degree factor which is the main parameter for determining the node location. Using estimated distance as static degree have been proposed at [3][11-14]. Due to the estimated distance degree is depend on the spesific PLE value, some researchers try to replace the static degree of WCL using the RSSI measurement data [6,15]. However the highest accurate estimated position of WCL algorithm when the target nodes position are only at the center of all connected anchor nodes. This condition will be difficult for randomic position of target nodes. Therefore we add the enhancement scheme based on different estimated distance (DED) which is adopted from [3]. To apply eWCL scheme, there are 18 anchor nodes (ANs) sending RSSI via Xbee S2 PRO module to the unknown node (UN) as the target. The WCL static degree is calculated only from three strongest RSSI measurement which have stable RSSI data replacing the static degree at[3]. The output from WCL will be improved using DED algorithm as the final estimation result of eWCL. Using non-cooperative scenarios, this proposed system will also compare with previous work that used trilateration algorithm at cooperative localization system [16]. To evaluate the performance of eWCL, this mobile non-cooperative localization system will be simulated using RSSI data measurement in a realistic condition.

2. Methodology

The adopted algorithms of this paper are WCL algorithm which is calculated the target location by using static degree from RSSI measurement data, and DED algorithm for improving the accuracy position from WCL algorithm that have better result only at centre position of target node to the ANs. Combining WCL and DED algorithm become an eWCL algorithm based on non-cooperative scenario will be repaired two main aspect problems at indoor RSSI based localization, minimizing propagation effect and reducing the estimated position error.

2.1. Weighted Centroid Localization (WCL) Algorithm

WCL algorithm is developed from centroid localization (CL) for improving its low accuracy. CL algorithm is only utilize RSSI from ANs (*i=1,2,3,...n*) whether the UNs (*j=1,2,3,..n*) is in the centre of ANs group. For example, if two UNs with different position received RSSI from the same group of ANs, the estimated position of UNs is almost same. Obviously this condition maybe not appropriate for the randomic UNs position. CL improvement is presented by using weight factor which is called as WCL algorithm. There are two approaches for calculating the weight factors of WCL algorithm. At the first, weight w_{ij} is defined as inverse of estimated distance d_{ij} based on g multiplier factor as shown in this following formula [3]:

$$w_{ij} = \frac{1}{(d_{ij})^g} \quad (1)$$

In this approach, the value of g should be at optimal value for getting the best estimated position result. The disadvantage of this weight calculation is using estimated distance as the main parameter. Estimated distance is determining from RSSI and PLE as the propagation characterictic value. The PLE value (n) should be in spesific for having better estimated distance result [16].

$$d_{ij} = 10^{\frac{RSSI_0 - RSSI_{ij}}{10\,n}} \tag{2}$$

$RSSI_0$ is the RSSI in 1 meters distance as the reference value of initial measurement, then the RSSI based its movement position is written as $RSSI_{ij.}$ The difficulties for determining the compatible PLE value which is always different based its environment condition is the main problem in this approach. Then the second approach of weight calculation is only using RSSI value of target node. The weight factor based on RSSI is derivative formula from formulas (1,2) that can be expressed as [6,15]:

$$w_{ij} = \frac{\sqrt{\left(10^{RSSI_{ij}/10}\right)^{g}}}{\sum_{i,j=1}^{n}\sqrt{\left(10^{RSSI_{ij}/10}\right)^{g}}} \tag{3}$$

The estimated position of UNs (x_i , y_i) based on WCL algorithm can be calculated using this following formula [2,3,6,15] :

$$P_{wcl(x_i,y_i)} = \frac{\sum_{j=1}^{n}(w_{ij}\ x\ (x_j\ , y_j))}{\sum_{i,j=1}^{n} w_{ij}} \tag{4}$$

Weight value implies the influence in calculating the UNs estimated position. Therefore previous research suggested the improved weight which can increased the accuracy when the UN position getting closer to the ANs [15]:

$$w'_{ij} = w_{ij}\ x\ N_{AN}{}^{2w_{ij}} \tag{5}$$

Its improvement performance based on the number of AN (N_{AN}) as the multiplier factor proposed solution as the enhancement of WCL algorithm. According to the formula (3-5), it can be seen that in obtaining the UN estimated position by just knowing the RSSI value and ANs coordinate, without PLE value parameters as shown previously at formula (1,2).

2.2. Difference of Estimated Distance (DED) Algorithm

The high accuracy result that have been proposed before by [15] still distribute at center area of UNs with ANs group communication. Weighted factor just reduce the error estimation without adjust the displacement position of UNs. So we adopted previous work in [3] by adding difference of estimated distance (DED) to denote the distribution of accuracy evently all each UNs position.

At the early step of DED is calculate the estimated distance between ANs to the UN. The estimated distance is obtained from WCL estimation to the each ANs ($d_{m=1,2,\ldots N}$) . Then for adapting the weighted factors of WCL, DED algorithm use β as degree factors derived as this following formula.

$$\begin{aligned} f(x_k, y_k) &= (x_j, y_j)\ x \left((d_{m+1} - d_m)^{\beta} + (d_{m+1} - d_m)^{\beta} + \frac{1}{d_m} + \frac{1}{d_{m+1}} \right) \\ f(x_{k+1}, y_{k+1}) &= (x_{j+1}, y_{j+1})\ x \left((d_{m+1} - d_m)^{\beta} + (d_{m+2} - d_{m+1})^{\beta} + \frac{1}{d_{m+2}} + \frac{1}{d_{m+1}} \right) \\ f(x_{k+2}, y_{k+2}) &= (x_{j+2}, y_{j+2})\ x \left((d_{m+2} - d_m)^{\beta} + (d_{m+2} - d_m)^{\beta} + \frac{1}{d_{m+2}} + \frac{1}{d_m} \right) \end{aligned} \tag{6}$$

The estimated position of DED algorithm (x_{ded},y_{ded}) can be calculated as:

$$x_{ded}, y_{ded} = \frac{f(x_k, y_k) + f(x_{k+1}, y_{k+1}) + f(x_{k+2}, y_{k+2})}{2\ x\ \left((d_{m+1} - d_m)^{\beta} + (d_{m+1} - d_m)^{\beta} + (d_{m+2} - d_{m+1})^{\beta} + \frac{1}{d_m} + \frac{1}{d_{m+1}} + \frac{1}{d_{m+2}} \right)} \tag{7}$$

In this DED scenario, there are three ANs as the reference for calculating each estimated distance. It can be added more ANs number to DED calculation depends on WCL modelling system. The connected AN numbers should be same with the number of estimated distance calculation which is influenced to the DED formulas (6-7).

2.3. Proposed Enhancement WCL Algorithm

In this system, we propose mobile non-cooperative localization using eWCL and DED as refinement algorithm for minimizing several problems in RSSI based localization. UN as the target node will move followed by RSSI data reception from the ANs group. Each group contain three nearest ANs to the UN which can be determined from strongest RSSI reception. Those RSSI data will be averaged for calculating the weighted factor of WCL algorithm.

According to the previous research in [6][15], weighted value based on RSSI is calculated by formula (3), while in this proposed system WCL algorithm will be calculated using β degree factor that adjust to DED algorithm parameters. The acceptable value of β in this system is 1 that have been observed before based on simulation process. This proposed WCL algorithm isn't increase the weight factor, but choose the highest weight value. Due to increase weight isn't significantly improve the accuracy performance. The weighted factor at formula (3) can be modified into this function as follows:

$$w_{ij} = max\left(\frac{\sqrt{\left(10^{RSSI_{ij}/10}\right)^{\beta=1}}}{\sum_{i,j=1}^{n}\sqrt{\left(10^{RSSI_{ij}/10}\right)^{\beta=1}}}, 3\right) \tag{8}$$

After getting the highest weight value from three strongest RSSI data, the UN estimated calculation based on WCL algorithm can be written using this following formula:

$$(x_{wcl}, y_{wcl}) = \sum_{j=1}^{N=3}(x_{j=1,2,3}\ , y_{j=1,2,3}) * \max(w_{ij}, 3) \tag{9}$$

WCL result as the initial estimated position will be processed again for having estimated distance calculation at formula (10) and also estimated position by DED algorithm (x_{ded}, y_{ded}) as shown at formula (6-7).

$$\left(d_{m(wcl\rightarrow AN_j)}\right) = \sqrt{\left(x_j - x_{wcl}\right)^2 + \left(y_j - y_{wcl}\right)^2} \tag{10}$$

Using simulation process based on data measurement and realistic scenario of indoor environment at third floor post graduated PENS building, this eWCL is achieved the accuracy improvement due to two parts involve weighted based RSSI measurement and its estimated location have been repaired using DED algorithm.

3. Results and Discussion

In this section will be presented the design system of mobile non-cooperative localization system and the RSSI measurement procedure. There are two main parameters for analyzing this eWCL algorithm performance, those are error estimation and the processing time requirement.

RSSI measurement phase was taken from signal transmission of Xbee S2 Pro module at 3rd floor of applied postgraduate PENS building as the observation environment. There are 18 ANs (anchor node) as the reference node at 2.4 meters height was sending RSSI to the UN (unknown node) as the target node at 0.9 meters height. The main concept of mobile non-cooperative localization is allow UN will be served by all deployed ANs when it move continously. For minimizing the variative RSSI data measurement and fluctuative weight calculation, the number of RSSI data which will be processed only three strongest RSSI data. RSSI Measurement is taken by UN displacement position every 2 meters based on each 53 positions assumption as shown at figure 1. In sending RSSI data to the UN is also followed by AN coordinate. The weighted calculation and estimated position determination including WCL and DED algorithm are conducted at UN. After the location estimation obtained, UN send the final estimation result to the server for monitoring the target location.

The success level of the proposed eWCL algorithm for improving accuracy performance in estimated position is presented by comparing the MSE (mean square error) result of WCL algorithm, existing enhanced WCL algorithm, and also cooperative localization based on trilateration algorithm. MSE result as the error estimation of this system can be analyzed in overall data using cummulative distribution function (CDF), as well, as illustrated at figure 4.

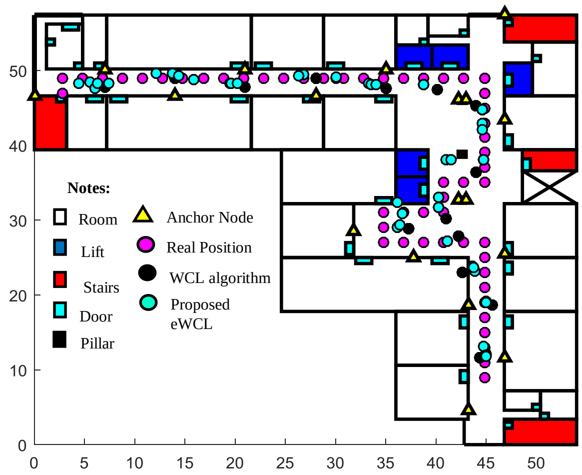

Figure 1. Estimated Position of WCL and proposed eWCL comparison.

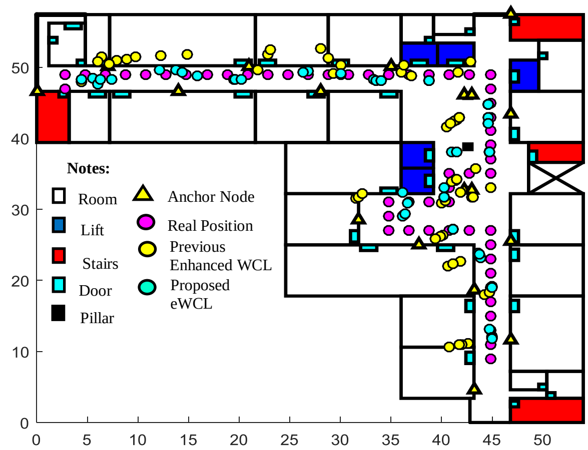

Figure 2. Estimated Position of previous enhanced WCL and proposed eWCL comparison.

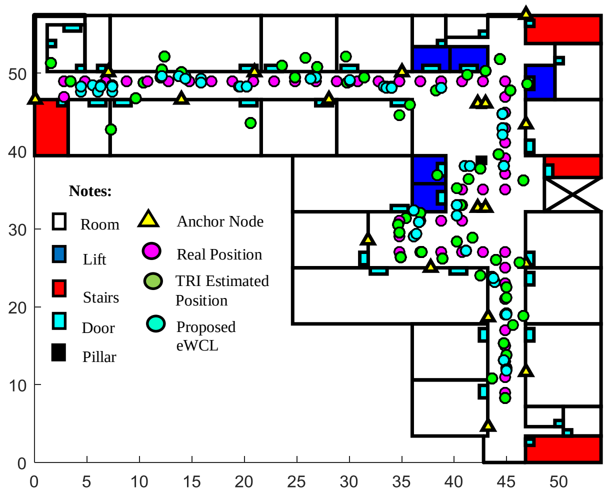

Figure 3. Estimated position of trilateration and proposed eWCL comparison.

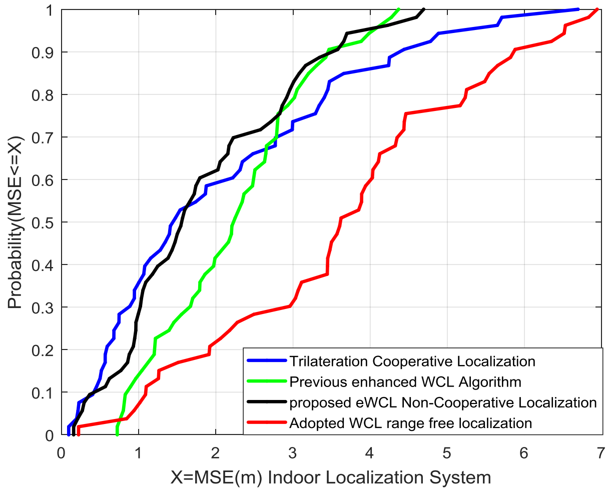

Figure 4. Error CDF graph comparison at applying eWCL algorithm.

Table 1. Performance comparison of several algorithms at cooperative and non-cooperative localization.

Localization Scheme	MSE Average (m)	Processing Time (s)
Trilateration Cooperative Localization	2.08	0.014
Adopted WCL range free localization	3.64	0.042
Proposed eWCL Non-Cooperative	1.85	0.059
Previous enhanced WCL Algorithm	2.26	0.044

The MSE comparison at figure 4, shows that proposed eWCL algorithm is the best scheme which has lowest error estimation at range of 0.15 meters up to 4.7 meters. Whereas the previous enhanced WCL algorithm is achieved MSE at 0.72 meters up to 4.37 meters which is higher at CDF 0 until 0.9 but lower MSE result at above 0.9 CDF value. Although at the range of MSE comparison between proposed eWCL and previous enhanced WCL have small difference in MSE average value calculation, our proposed eWCL algorithm still achieve the smallest error at 1.85 meters as listed at table 1. Compared with the cooperative scheme based trilateration algorithm, its cooperative scheme has higher range error estimation up to 6.67 meters. It prove that range free algorithm with non-cooperative scenario can be choiced scheme for indoor localization if using the appropriate method as well as eWCL algorithm. This is because the original WCL algorithm still have higher error range up to 6.95 meters.

The processing time performance of this system was measured by Matlab type R2016a simulator tools at Toshiba satelite core i7 M840 laptop spesification. According to the simulation result show that proposed eWCL algorithm was took up around 4 times longer than using trilateration algorithm. The difference processing time was not significantly influence when this algorithm apply at small device of node, due to the processing time still under 1 seconds and the sensor device technology development today have been quite good processor and capacity. Therefore in indoor localization, the accuracy performance still main priority at design system.

4. Conclusion

In this paper, we propose range free algorithm for mobile non-cooperative localization using eWCL algorithm. There are two estimated location process in this system. WCL algorithm as the initial calculation is obtaining the position based on weighting the connected anchor nodes coordinate. Using only RSSI parameter and anchor node coordinates at weighted value calculation can be minimized the unstability estimated distance calculation by spesified propagation index. The output of WCL estimation which is only accurate at centroid position, is effectively improved by DED algorithm. The comparative analysis show that our proposed eWCL could decrease around 1.12 times better than cooperative localization based trilateration algorithm. Although it was required 0.047 seconds additional time for computation.

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