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Original Citation

Lu, Joan, Long, Hua, Xu, Qiang and Lei, Qian (2013) A New RSSI-based Centroid Localization Algorithm by Use of Virtual Reference Tags. In: The Third International Conference on Advanced Communications and Computation. INFOCOMP 2013 . IARIA, Lisbon, Portugal, pp. 122-128. ISBN 978-1-61208-310-0

A New RSSI-based Centroid Localization Algorithm by Use of Virtual Reference Tags

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***Abstract*—A good design of node location is critical for efficient and effective wireless communications. This paper presents an improved algorithm, in order to solve the low localization accuracy caused by traditional centroid algorithm. The improved algorithm combined with VIRE system and traditional centroid algorithm. The VIRE algorithm is introduced and the signal propagation model is utilized to construct virtual reference tags in the location area. Simulation shows that this further developed algorithm has further improved the accuracy of positioning up to 35.12% compared to the traditional centroid algorithm. It is concluded that this algorithm can further improve the locating accuracy in comparison with the original centroid algorithm.**

Keywords–VIRE algorithm; Virtual reference tags; RSS; Centroid algorithm.

I. INTRODUCTION

Node localization is one of the core technologies in Wireless Sensor Network (WSN) [1]. Currently, the localization algorithm of wireless sensor network can be divided into two categories: the distance-independence [2] and distance-dependence [3].

The common positioning algorithms of distance-independence are centroid algorithm and Approximate Point-In-triangulation Test (APIT) [4, 5]. Bulusu et al. [4] introduced a node positioning technology-centroid algorithm that has a lower computational complexity than that of the trilateration [5]. The positioning algorithm, such as Received Signal Strength Indicator (RSSI), of distance-dependence has better accuracy, but the survival of the network is stronger when the unknown node has not had a high positioning accuracy.

In order to improve the accuracy of centroid localization, this paper proposes a modified algorithm similar to the Virtual Reference Elimination (VIRE) algorithm [6]. This modified algorithm uses the signal propagation model [7] to construct the Received Signal Strength Indicator (RSSI) [8] information of virtual reference tags in location area and locates the object using traditional centroid algorithm. The VIRE realizes accurate position using a linear interpolation algorithm with adding a grid virtual reference tags based on the LANDMARC [9] algorithm.

To reduce the redundant calculation of VIRE algorithm, Shi et al. [10] used Subregion Selection (SRS) mechanism to reduce the interpolation area, and a nonlinear interpolation algorithm to calculate the RSSI values of virtual reference tags. Nevertheless, the location accuracy is affected by dividing areas [10].

To solve the above problem, this paper proposes an improved algorithm that combines with VIRE system and the original centroid algorithm according to the VIRE algorithm and the RSSI information of virtual reference tags that are established by signal transmission model in the location area. The simulation results show that the algorithm can further improve the locating accuracy without any additional hardware overhead in comparison with the original centroid algorithm.

The rest of the paper will be organized as follows. Section II will describe RSSI location, VIRE disposing and transmission model of wireless signal. Section III will describe the detailed research approach. Section IV will describe the experiments and error analysis. Finally, Section V will draw the conclusion and future work.

II. RELATED WORK

A. *Ranging methods*

According to the physical medium, there are four popularly ranging methods in the signal communications of sensor systems: 1) the RSSI (Received Signal Strength Indicator) [8], 2) the TOA (Time Of Arrival) [11], 3) the TDOA (Time Difference Of Arrival) [12], and 4) the AOA (Angle Of Arrival) [13]. The performance comparison of four ranging methods is shown in Table I.

TABLE I. THE COMPARISON OF RANGING METHOD BASED ON DISTANCE

Ranging method	Measuring distance	Hardware costs	Measurement Accuracy
RSSI	TOA	TDOA	AOA
>100m	>100m	10m	Short
Low	High	High	High
Low	High	High	High

Ranging method	Additional hardware	Transmission medium
RSSI	TOA	TDOA
AOA	Not need	GPS devices
Ultrasonic receiving apparatus	Antenna array	Electromagnetic
Electromagnetic	Ultrasonic wave, Electromagnetic	Ultrasonic wave, Electromagnetic

The TOA algorithm requires GPS-assisted equipment, which is not used in the indoor environment [16]. Ultrasonic transmission distance is limited, which is usually less than 10 meters, affected by angle, temperature, and obstructions [17]. The AOA is reliable only in the line of sight signal dominant circumstances [18]. It follows that these limitations of three positioning methods lead to an extreme difficulty in dealing with the complex indoor environments. The RSSI-based ranging method has the advantages of long transmission distance, lower cost, lower power consumption, easy node hardware, small size, and light weight [19]. However, the positioning accuracy of RSSI based methods is low, as it can only be used as a rough ranging method [19]. Thus, its positioning accuracy must be improved by an adjunct way.

B. Transmission model of wireless signal

The Received Signal Strength Indictor (RSSI) converts the loss during the process of transmission according to the signal intensity of transmitting and node received [14]. In the indoor location, the RSSI ranging signal propagation model can be simplified as (1) in consideration of environmental, cost, location accuracy requirements and other factors:

$$RSSI = -(10\mathrm{n}_1 \log_{10} d + k_1) \qquad (1)$$

wherein, n_1 is the signal attenuation factor that is from 2 to 4; d is the distance of reference node and object node; k_1 is the measured RSSI of one meter, with the unit of dBm.

III. RESEARCH APPROACH

The approach is designed in two phases: first, the system structure and the algorithm based on virtual tags; second, the realization of algorithm in VIRE system.

A. System structure and algorithm based on virtual tags

1) Construction of VIRE system (VIRE disposing)

'Virtual Reference Elimination' (VIRE) is introduced in [6]. In the VIRE, instead of deploying many real reference RFID tags, the concept of virtual reference tags is provided as denser reference coverage in the sensing areas.

The distribution of VIRE reader R_i and reference tags, T_a, T_b, T_c and T_d are shown in Figure 1 with relationship, a,b,c,d∈N^+. The object tags are in the range of specified area. The core of VIRE method is related to 4 reference tags as a unit grid: N1xN1, shown in Figure 2.

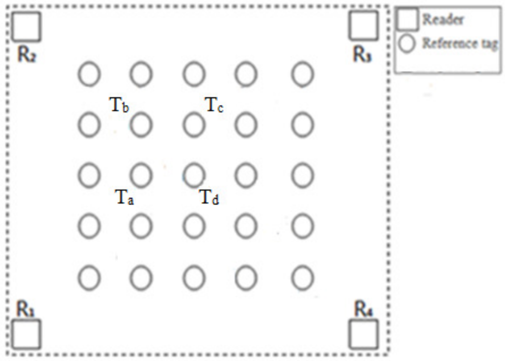

Figure 1. The distribution of VIRE readers and tags

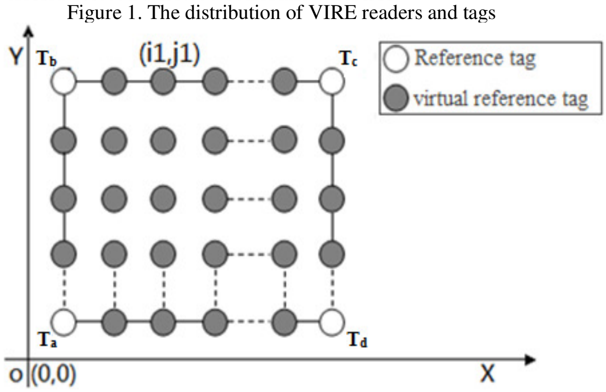

Figure 2. The distribution of virtual reference tags

Under the condition of known values of reference tags' position and density, the field strength of virtual reference tags in both horizontal and vertical directions is calculated by (2) and (3):

$$E_{\mathrm{Ri}}(t,b) = E_{\mathrm{Ri}}(a,b) + t \times \frac{E_{\mathrm{Ri}}(a+N1,b) - E_{\mathrm{Ri}}(a,b)}{N_1} \qquad (2)$$

$$E_{Ri}(u,y) = E_{\mathrm{Ri}}(a,y) + u \times \frac{E_{Ri}(a,b+N1) - E_{\mathrm{Ri}}(a,b)}{N_1} \qquad (3)$$

wherein, E_{Ri} is RSSI value of reference tag located at the coordinate (i, j) for the R_i reader. The values of parameters are $a = \lfloor i/N1 \rfloor$, $b = \lfloor j/N1 \rfloor$, t is known and located at *x* axis as the interval of object virtual reference tag, and u is known and located at *y* axis as the interval of object virtual reference tag.

Under the conditions of known values of the field intensity of reference tags and virtual reference tags, LANDMARC algorithm is normally used to select a certain threshold for solving the nearest reference tag weights, in order to obtain positioning results [10].

According to the VIRE system, this paper gives a further development of the positioning method.

ISBN: 978-1-61208-310-0

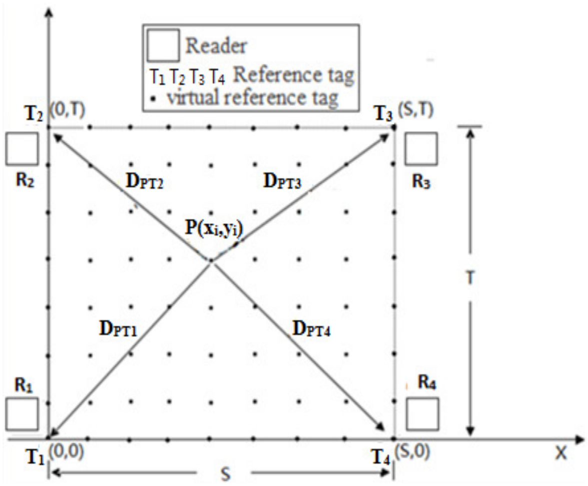

Figure 3. The definition of virtual reference tags area

The positioning system is for a two-dimensional plane. The location area has a size of S×T, where reference tags are the four vertices of the region, and the coordinates are $T_1(0,0)$, $T_2(0,T)$, $T_3(S,T)$, $T_4(0,S)$. Four readers are placed on those vertices, as shown in Figure 3.

Assuming the Coordinate of virtual reference tag D is (x_i, y_j), the Euclidean distance between D and reference tags T_i are:

$$\begin{aligned} D_{PT_1} &= \sqrt{x_i^2 + y_i^2} \\ D_{PT_2} &= \sqrt{x_i^2 + (y_i - T)^2} \\ D_{PT_3} &= \sqrt{(x_i - S)^2 + (y_i - T)^2} \qquad (4) \\ D_{PT_4} &= \sqrt{(x_i - S)^2 + y_i^2} \end{aligned}$$

According to above (4), the tables are established for the four reference tags shown in Table II below.

TABLE II. VIRTUAL REFERENCE TAGS RSSI FOR REFERENCE TAGS

Distance of virtual reference Tags to the reference tags	RSSI value of virtual reference Tags relative to the reference tags
D_{PT_1}	$RSSI_{PT_1}$
D_{PT_2}	$RSSI_{PT_2}$
D_{PT_3}	$RSSI_{PT_3}$
D_{PT_4}	$RSSI_{PT_4}$

There are $(N1+1)^2 - 4$ data in the table.

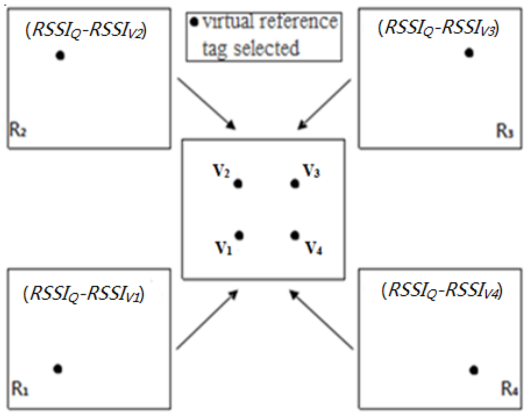

Figure 4. Process of selection of virtual reference tags

2) The selection of virtual tags

An object node is located at $Q(x_q, y_q)$, the RSSI values will be read by readers at four corners. A comparison was carried out with the virtual reference tags'RSSI from readers. The virtual reference tags that are nearest distance between $Q(x_q, y_q)$ are selected according to the following algorism.

IF $RSSI_Q$ *>0*
  THEN
    for i=1 to $(N1+1)^2$ *-4*
      do $Value_i = \left| RSSI_Q - RSSI_{V_i} \right|$
        ELSE
          Return (min Value$_i$)
          Return i
          end
    End

The four virtual reference tags are selected in Figure 4 as below.

$$V_1(x_{v_1}, y_{v_1}), V_2(x_{v_2}, y_{v_2}), V_3(x_{v_3}, y_{v_3}), V_4(x_{v_4}, y_{v_4})$$

B. The realization of algorithm in VIRE system

1) Traditional centroid algorithm

According to the traditional centroid algorithm, the four virtual reference tags are selected to form an enclosed area that is the estimated area of the object node [12]. By (5), the estimate coordinates of object node can be calculated.

$$\begin{cases} x_q = \frac{1}{4}(x_{v_1} + x_{v_2} + x_{v_3} + x_{v_4}) \\ y_q = \frac{1}{4}(y_{v_1} + y_{v_2} + y_{v_3} + y_{v_4}) \end{cases} \qquad (5)$$

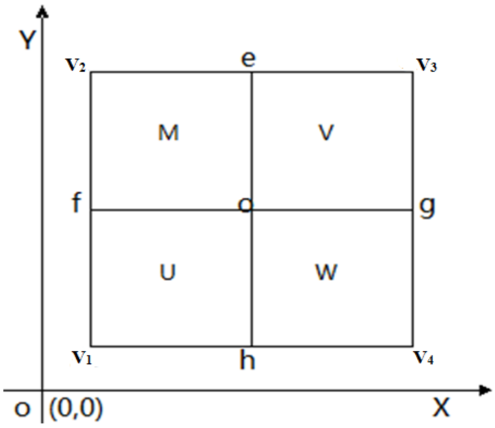

Figure 5. The schematic diagram of the renewed centroid algorithm

2) Renewed centroid algorithm

Through narrowing down the testing area, a key improvement of centroid algorithm in positioning accuracy is described as follows.

According to the geometric relationship, in Figure 5, the coordinates: e, f, g, h, and o, are defined in the following relationships of (6), (7), (8), (9) and (10):

$$x_e = \frac{1}{2}(x_{v_2} + x_{v_3}) \qquad y_e = \frac{1}{2}(y_{v_2} + y_{v_3}) \tag{6}$$

$$x_f = \frac{1}{2}(x_{v_1} + x_{v_2}) \qquad y_f = \frac{1}{2}(y_{v_1} + y_{v_2}) \tag{7}$$

$$x_g = \frac{1}{2}(x_{v3} + x_{v_4}) \qquad y_e = \frac{1}{2}(y_{v_3} + y_{v_4}) \tag{8}$$

$$x_h = \frac{1}{2}(x_{v_1} + x_{v_4}) \qquad y_h = \frac{1}{2}(y_{v_1} + y_{v_4}) \tag{9}$$

$$x_o = \frac{1}{4}(x_{v_1} + x_{v_2} + x_{v_3} + x_{v_4}) \qquad y_o = \frac{1}{4}(y_{v_1} + y_{v_2} + y_{v_3} + y_{v_4}) \tag{10}$$

The process of the renewed algorithm is as shown in Table III.

TABLE III. PROCESS OF THE RENEWED ALGORITHM

Conditions of judgment	Estimation region	Estimation of the object node's coordinate (x_{test}, y_{test})
When Δ_1 is Less than $\Delta_2\,\Delta_3\,\Delta_4$	In the region of U	The centroid of U: $\frac{1}{4}(V_1 + f + o + h)$
When Δ_2 is Less than $\Delta_1\,\Delta_3\,\Delta_4$	In the region of M	The centroid of M: $\frac{1}{4}(V_2 + f + o + e)$
When Δ_3 is Less than $\Delta_1\,\Delta_2\,\Delta_4$	In the region of V	The centroid of V: $\frac{1}{4}(V_3 + e + o + g)$
When Δ_4 is Less than $\Delta_1\,\Delta_2\,\Delta_3$	In the region of W	The centroid of W: $\frac{1}{4}(V_4 + g + o + h)$
When $\Delta_1 = \Delta_2$ and is Less than $\Delta_3\,\Delta_4$	In the segment of fo	The midpoint of fo: $\frac{1}{2}(f + o)$
When $\Delta_3 = \Delta_4$ and is Less than $\Delta_1\,\Delta_2$	In the segment of go	The midpoint of go: $\frac{1}{2}(g + o)$
When $\Delta_2 = \Delta_3$ and is Less than $\Delta_1\,\Delta_4$	In the segment of eo	The midpoint of eo: $\frac{1}{2}(e + o)$
When $\Delta_1 = \Delta_4$ and is Less than $\Delta_2\,\Delta_3$	In the segment of ho	The midpoint of ho: $\frac{1}{2}(h + o)$

IV. THE SIMULATION AND ERROR ANALYSIS

In the simulation experiment, Matlab7.6.0 software is used. There are two indicators of size set up and the positioning accuracy is set as the evaluation criteria, when the positioning precision, scale, network coverage rate, and power consumption are often used as the evaluation index in the WSN. In the simulation experiment, the WSN area is set that the S and T are equal to 90. The reference tags are located at the four vertices of this area and uniformly distributed. The positioning error of the object nodes is defined in (11):

$$AverageError = \frac{\sqrt{(x_q - x_{real})^2 + (y_q - y_{real})^2}}{s_1} \quad (11)$$

Wherein, s_1 is the times of the Simulation.

A. Searching the optimum number of the virtual reference tags

As shown in Table IV, ten object nodes' RSSI are from the reader R_i, where i is shown as 1, 2, 3, 4.

TABLE IV OBJECT NODES'S RSSI

unit(dBm)	Object node1	Object node2	Object node3	Object node4	Object node5	Object node6	Object node7	Object node8	Object node9	Object node10
Reader R_1	-72.5	-72.9	-70.6	-68.2	-72.4	-74.2	-76	-75.7	-78.9	-83.5
Reader R_2	-72.3	-72.2	-72.8	-71.4	-71.8	-72.4	-76.7	-68	-73.2	-68.6
Reader R_3	-73.2	-71.1	-75.8	-73.2	-65.1	-66.2	-60.8	-67.2	-66	-50.5
Reader R_4	-72.4	-72.4	-71.5	-72.2	-70.9	-72.2	-72.6	-67.8	-66.2	-68.1

When the number of the virtual reference tags increases, the error in comparison with the two algorithms are illustrated in Figures 6 and 7.

Figure 6 shows that there is no obvious change between the two algorithms, if the number of the virtual reference tags is above 121 and the 90/N2 is greater than 10. The best performance shows that the number of the virtual reference tags is 49 when 90/N2 is equal to 6. It follows that the renewed centroid algorithm could further improve the accuracy compared with the traditional centroid algorithm.

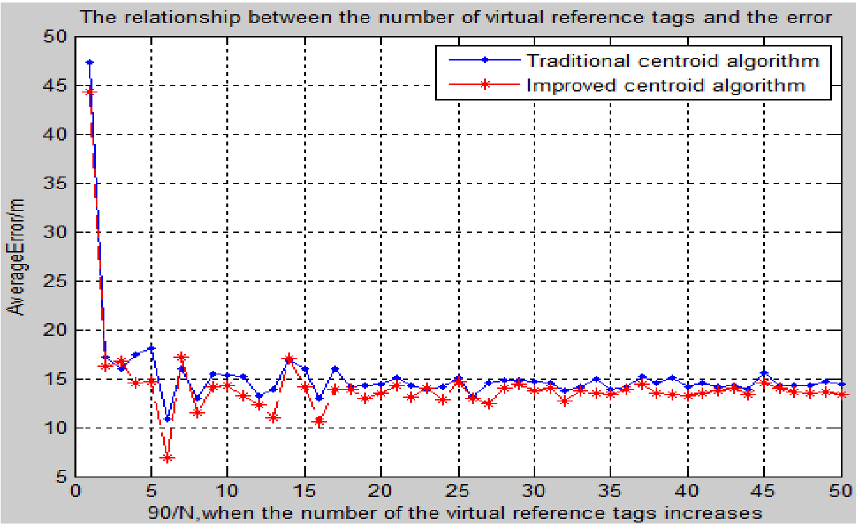

Figure 6. The difference between two algorithms

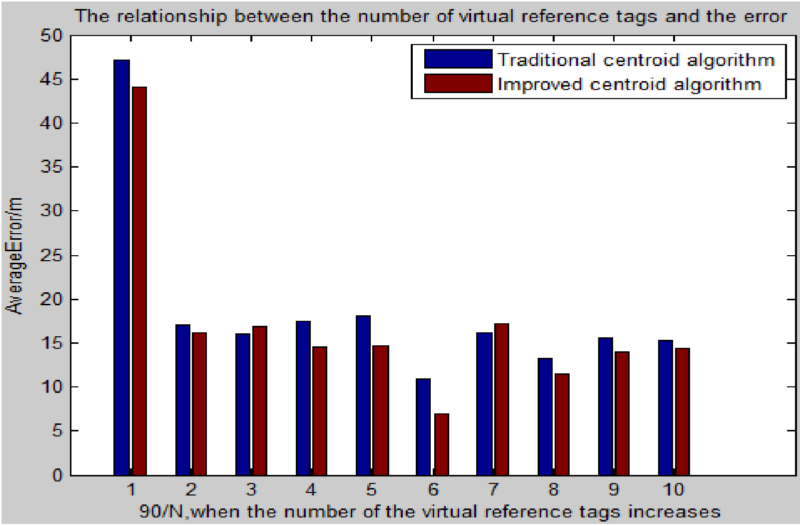

Figure 7. The error comparison of two algorithms when the number of the virtual reference tags increases

B. Comparison of the two algorithms when the number of virtual reference tags is 49

Figure 8 shows that the results are obtained by (5) from the test for 100 times. It is clear that the renewed centroid algorithm gets a further improved localization accuracy compared with the traditional one.

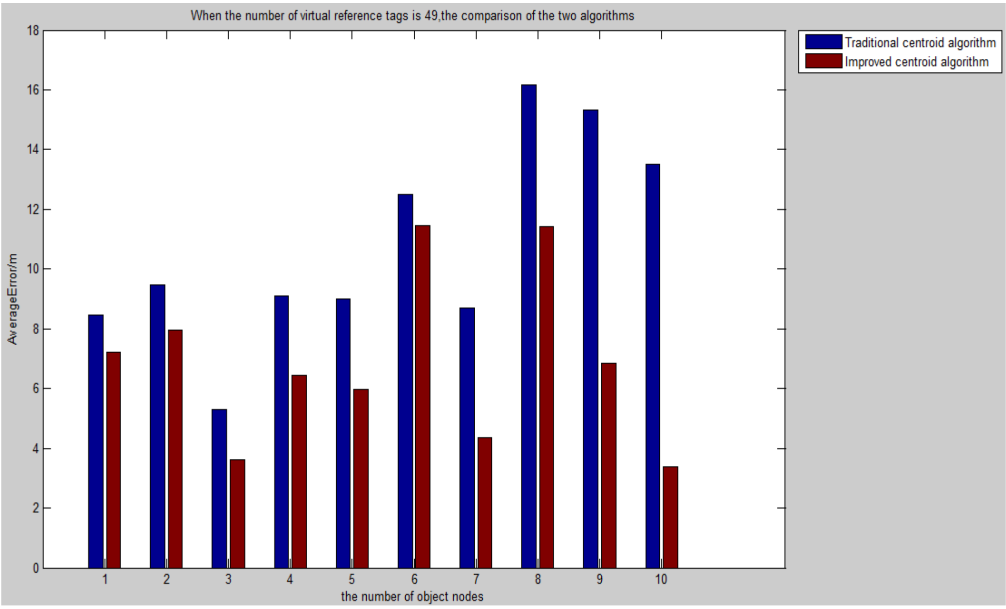

Figure 8. The comparison of the two algorithms

C. Error analysis

For the virtual reference tags, they may not be able to choose four ones near the object node, or four virtual reference tags are repeatedly chosen, as it may lead to excessive error(s). In the radio propagation model, the signal is disturbed by the external environment instead of being transmitted in free space. Through repeated measurements and the statistical average value, some error can be reduced, although the further improvement is still needed.

V. CONCLUSION AND FUTURE WORK

A. Achievements

One of the hot topics in WSN is localization of the object node. The paper proposes an improved centroid algorithm combined with the VIRE system. The algorithm is simple. The positioning accuracy of the object nodes has been improved significantly in comparison with the traditional centroid algorithm. This new algorithm can be used to solve the problem of the low localization accuracy of the traditional centroid algorithm.

B. Future work

However, there are still some shortcomings existing in the positioning methods. On one hand, the signal propagation model applicable to non-free-space conditions needs further research. On the other hand, the selection methods of the virtual reference tags need further optimization so as to further improve the positioning accuracy.

Acknowledgement: authors thank Dr Sawsaa's feedback and proof reading for the final version of the paper.

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