A Multi-scale Indoor Localization Method for Shipboard Environment

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***Abstract*-Shipping information-based management is rapidly developing, which results in increasingly research on location-sensing technologies for shipboard environment. However, these technologies have not been extensively applied on shipboard environment for two fatal limitations. Firstly, they waste resources of node when sometimes fewer nodes are asking for the positioning requirements. Secondly, they ignore the privacy protection while improving the positioning accuracy. In this paper, a new method called Multi-scale Localization Method is proposed, which is based on RSS information. A multi-precision location model is constructed from step level to room level to meet different requirements and protect privacy of people. Meanwhile, a Filtering algorithm is utilized to reduce the localization error by decreasing RSSI noise. Computer simulations and real experiments have been conducted to evaluate the method on shipboard environment, the result shows that it performs well with better scalability, lower cost, and customized privacy protection.**

Keywords-shipboard environment; Indoor Localization; localization requirement; Filtering algorithm; privacy protection

I. Introduction

With the development of electronic information technology, wireless sensor networks get more and more applications in pervasive environment monitoring[1-2]. Meanwhile, Owing to the importance of node location information on monitoring, more related location technologies are gradually being introduced to the shipping industry. And positioning system is an important scene in the application of wireless sensor network in the maritime field. It locates and tracks objects by wireless sensor nodes, which can track and manage goods in real time, further efficient response to emergency. Thus, the application of shipboard positioning is of great significance.

Shipboard positioning system is similar to the general indoor positioning system, both of which are provide location information to users to meet specific needs. However, due to the more complex multi-path effects in shipboard environment, the general positioning technology performed not as good as ordinary indoor environment positioning. As so far, the research of shipboard positioning technology mainly appeared in the South Korea's SAN project and the EU's (European Union) MONALISA project. ETRI (Electronics and Telecommunications Research Institute) and Modern Heavy Industries jointly developed the ship communication technology - Ship Area Network (SAN) project, which firstly use WiBro wireless communications and RFID technology in shipyards, and it's currently a representative study of the "smart boat". The EU proposed the MONALISA 2.0 project in 2013, applied the RFID technology to the ship environment, and realized real-time monitoring of people. Thus, there exist shortages of the shipboard positioning system research. That is the high cost of RFID, meanwhile ignoring the importance of realizing personnel location requirements of different precisions by localization algorithm.

In this paper, we firstly present a Multi-scale Indoor Location Method (MILM) for the problem of marine environment location research. MILM use different positioning accuracy to meets the positioning requirements and the privacy of objects. It can not only satisfy the regional monitoring but also realize the location information acquisition of personnel goods. The reminder of the paper is organized as follows. Section 2 gives a comparative overview of the current positioning technologies and positioning algorithms, simultaneously, gives a classification and definition of location requirements. Section 3 discusses the MILM. Section 4 gives the tests and results.

II. Related Work

Many technologies are utilized in indoor positioning such as ZIGBEE[3], Wi-Fi[4], RFID[5], but only RFID currently is utilized in ship environment, in spite of the localization algorithms are the same. In this section, we make a discussion on the advantages and disadvantages of them to the shipboard positioning in what follows.

A. Indoor Positioning Technology

The purpose of locating people on board of a ship could be fulfilled, in principle, by means of many locating technologies available on the market and successfully utilized in other field[6]. ZIGBEE、Wi-Fi and RFID currently are performed well in indoor positioning. Due to the mapping relationship between the RSSI(Received Signal Strength Information) value and the distance，both ZIGBEE、Wi-Fi、RFID can locate position by RSSI. However, the cost of ZIGBEE is the lowest, and Wi-Fi is higher since on the ship environment it not as accessible as on common indoor environment, and the RFID with the highest cost but can cover much wider area. Thus, the ZIGBEE technology is utilized in this paper, and related hardware equipment shown in figure 1.

Figure 1 Hardware Equipment

Moreover, different from general indoor environments, there are more complex multipath effects on ship environments[7], which results in the multipath fading and the RSSI-based positioning systems' accuracy stay at lower level. As in figure 2 shows, the RSSI changes at different environment even when the anchor node is the same, and the relationship between RSSI and distance no longer conforms to the traditional path loss model in a relatively narrow environment. But there have been many researches on it, most of which by improving the parameter of path loss model or ignoring the mapping relationship and comparing the high-low relationship of RSS directly. Furthermore, many researches that based on high-low relationship of RSS have been utilized in different field and proved work well.

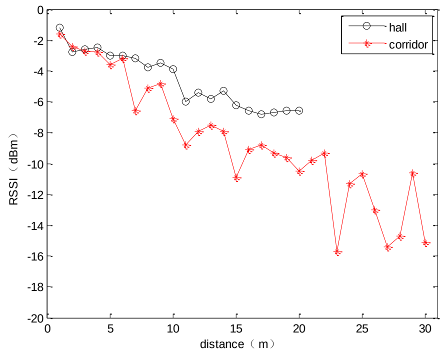


Figure 2 Relationship of RSSI and Distance at Different Environment

B. Indoor Positioning Algorithm

Traditional indoor localization algorithm is divided into range-based and range-free two categories. TOA[8-9], AOA[10], RSSI-based are range-based localization algorithms. Range-free algorithm contains the centroid algorithm[11], DV-HOP[12], and fingerprint location algorithm[13-14]. The use of TOA and AOA is relatively less for high synchronization requirements, while the DV-HOP algorithm utilized more in isotropic network. The location accuracy of centroid algorithm is very limited for its high correlation with the distribution of anchor nodes. Although the fingerprint location method can suffer from complex environment effect than many other positioning algorithms, it requires larger workload to get fingerprint acquisition.

With the development of traditional indoor localization algorithm, reference [15] proposed a sequence-based positioning method, devising the location area into subareas by vertical line of anchor nodes, and the centroid of subarea is the location result. Reference [16] Proposed a similar positioning method with [15], but the vertical line segmentation is improved by the arc segmentation with higher location accuracy. In this paper, we propose the new method called MILM by improving the traditional area-division method with less computation complexity as well more robust to the complex shipboard environment.

C. Location Requirements

The EU MONALISA project defines the requirements of positioning, including precision, speed, reliability, cost, privacy protection, etc[17]. A people tracking system does basically just one thing: tracking movements of people inside certain generally complex environment, like for example cruise vessels, ferries, military and offshore vessels. Despite of that, data generated can be analyzed and then utilized in a very large amount of way. Depending on the very purpose of each installation, i.e. depending on the application the system is used for, the relative importance of each previously described requirement, might vary a lot.

There are areas with more than one application on the ship, which results in described requirements vary a lot in the same area. For example, the positioning system in the hall of a ship should meet the low-precision positioning requirements to protect the privacy of the guests, and have to meet the high-precision positioning requirements of the child's care at the same time. To realize different application requirements and improve the service quality, MILM would be an effective way utilized in the shipboard environment.

III. Description of MILM

This section will first describe the network architecture, and give an overview of MILM. Then show how MILM works in details using field division method in shipboard environments.

A. The architecture of MILM

As analysis in section 2, MILM is a scalable localization scheme to meet different requirements of localization accuracy on ship environment. And we have the architecture of MILM as figure 3.

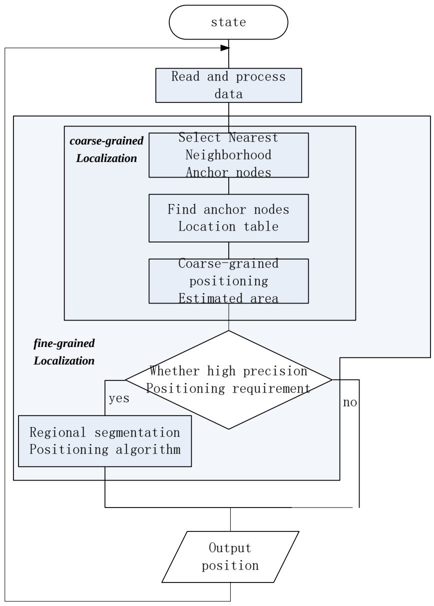


Figure 3 Architecture of MILM

The MILM consists of two parts, one is the coarse-gained localization algorithm and it is to meet the requirements of low-precision positioning; another one is fine-gained localization algorithm which meet the requirements of high-precision positioning. The two algorithms will be described in detail later.

B. Anchor Deployment Strategies

As the anchor deployment scheme has a great influence on the positioning effect, it is the basis of the research on the two positioning algorithms mentioned before. Therefore, we first study how the distance between nodes affects the communication quality. The relationship between RSSI and distance reflects the effect of distance between nodes on the communication quality. As shown in figure 2, the RSSI trend is basically consistent with the path loss model when the distance between nodes is less than 20 meters; the RSSI fluctuation amplitude increases no longer meet the path loss model when the distance is greater than 20 meters. It can be concluded that on the ship environment, the distance between nodes within 20 meters can basically guarantee the quality of communication.

Then, we study how the number of anchor nodes affects the positioning quality. As shown in figure 4, the positioning error is gradually reduced with the increase of the number of anchor nodes, that is, the positioning accuracy is obviously improved, and the reliability of positioning is gradually enhanced by the trend of variance. Specifically, when the number of anchor nodes changes from 4 to 6, the positioning error reduces more quickly, equivalent to the positioning accuracy is improved obviously; when the anchor nodes increases to more than 6, the change trend of positioning error gradually smooth. Therefore, for the ship positioning system, the deployment strategy of the anchor node should follow the principle of receiving the signal of 4-6 anchor nodes in a position, which can reduce the positioning hardware cost when the positioning accuracy is constant, and achieve the optimization of positioning efficiency.

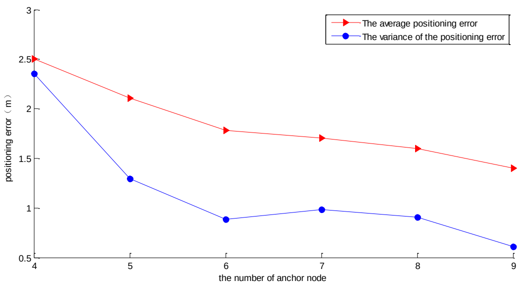
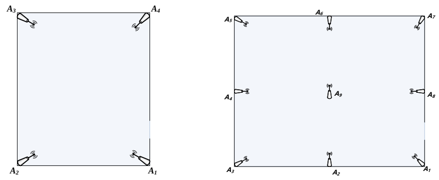


Figure 4 The Relationship Between

Localization Error and Number of Anchor Nodes

Moreover, generally the node deployment would be regular placement or irregular placement, and the regular placement can lower down the complexity and improve the stability of the positioning algorithms[18]. Thus, we have two regular anchor deployment strategies, both are satisfied the communication quality requirements and the number of receiving anchor nodes, in spite of one of which is coverage-preferred deployment strategy and another is performance-preferred deployment strategy.

The coverage-preferred deployment strategy is utilized in areas with low-accuracy requirement. On shipboard environment, like for cruise vessels and ferries, the area such as guest room ask for coarse-gained localization to guarantee people privacy, and the danger zone need coarse-gained localization to minimize cost and reduce computation. In these areas, the anchors positions forma rectangle-like quadrilateral, as the example in figure 5(a) shows.



(a) Coverage-preferred Deployment Strategy

(b) Performance -preferred Deployment Strategy

Figure 5 Deployment Strategy

The performance-preferred deployment strategy is utilized in areas with high-accuracy requirement. On shipboard environment, like for cruise vessels and ferries, the area such as hall and restaurant ask for coarse-gained localization to guarantee people privacy, and need fine-gained localization to provide timely high-quality services at the same time. In these areas, the anchors positions forma rectangle-like figure 5(b) shows. The anchors are no longer at the corners of a room but the distance of which are adapted to the communication and localization quality.

C. Coarse-gained localization

For areas with low accuracy requirements, the objects can only be recognized whether they are in the area, but do not need to or cannot be recognized the specific location in the area. We employ the radio signal strength (RSS) justification scheme. In RSS justification scheme, the positions of the anchors in each room should meet the following conditions: (a) setting anchors according to the whole area or divided sections of the room; normally four anchors for one room; (b) within communication radius, the node is placed as far as possible. With the deployment scheme, the RSS values of a user-tag to each anchor can be compared to decide which room the tag belongs to.

Table 1 Pseudo Code of Coarse-gained localization

Algorithm 1 A coarse-gained localization algorithm

Input: the real coordinate of anchor nodes (x_i, y_i);
the received signal strength of user-tag $\mathbf{S_i}$:

(1) make $\mathbf{S_i}$ into orderly vector

(2) select the max number of $\mathbf{S_i}$ to determine the nearest anchor node A

(3) determine the neighbor anchor nodes $\mathbf{N_j}$ of A

(4) for j=1:n;

(5) compare the RSS value of $\mathbf{N_j}$ and make $\mathbf{N_j}$ into orderly vector

(6) end for

(7) the user-tag is in the area consist of (N1,N2,A)

Output: the room number of the area the user-tag is in

Assume there are N anchors, and the signal strength vector of a user-tag A_i ($i\in[1,N]$) recorded as

$$\boldsymbol{S}_i = (S_{i1}, S_{i2}, \cdots; S_{in}), \qquad (1)$$

Where S_i denotes the signal strength of the user-tag Ai received from anchors 1to N. According to the coarse-gained localization algorithm, the nearest anchor node would be determined with S_i, and then find out the neighbor nodes of the nearest anchor node, some of which with bigger RSS values consist of the area the user-tag in. The computational complexity of the coarse-gained localization algorithm is O(n).

D. Fine-gained localization

In scenarios which require high localization accuracy, the positioning system of this paper just employs a fine-gained localization algorithm, which is based on the field division algorithm and was verified in the tests of this paper. Field division algorithm works with the idea that the unknown positions of the active user-tags could be calculated with the already-known fixed positions of anchor nodes. In this paper, the anchor deployment strategy is performance-preferred deployment strategy, the positions of the anchors in each room should meet the following conditions: (a) setting anchors according to the whole area or divided sections of the room; (b) the distance between the nodes is no bigger than the distance while the node communication effect is great, which is effected by the environment; (c) the anchors positions forma rectangle-like quadrilateral.

Assume we have N anchor nodes, and we get the signal strength vector of a user-tag S_i, $i \in [1,N]$ as formula (5), where S_i denotes the signal strength of the user-tag received by anchor 1 to N. According to the fine-gained localization algorithm, the nearest anchor node would be determined with S_i. Then there will be three kinds of situations: 1) the nearest node is on the corner; 2) the nearest node is on the side; 3) the nearest node is on the center. Take N is 9 for example, as figure 5(b).

1)the nearest node is on the corner(A_1、A_3、A_5、A_7):take A_1 is the nearest node for example, the user-tag must in the triangle $A_1A_2A_8$, and triangle $A_1A_2A_8$ is divided into ① to ④ parts by perpendicular bisector of A_1 、A_2 、A_8, as figure 6, the user-tag must in the area ② or ③.Then compare RSS values the user-tag get from anchor A_2 and A_8, if A_8 bigger than A_2, the method thinks the user-tag in the area ②,and the centroid of ② will be calculated as the location of the user-tag. Otherwise, the centroid of ③ will be calculated as the location of the user-tag.

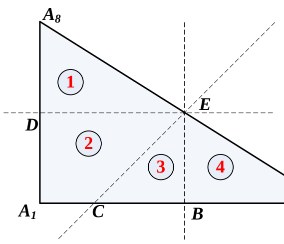


Figure 6 The Field Division With The Nearest Node is A_1

Assume that the edges of the rectangles are parallel to the X and Y axes, and the position of anchor A_1 is represented by (x_1, y_1), A_2 is (x_2, y_2), A_8 is (x_8, y_8) , B is (x_B, y_B) , C is (x_C, y_C) , D is (x_D, y_D), and E is (x_E, y_E). Therefore, y_1 is equal to y_2 and x_1 is equal to x_8. As the midpoint of A_1A_2, x_B and y_B can be recorded as:

$$x_B = \frac{x_1 + x_2}{2}, y_B = \frac{y_1 + y_2}{2} \tag{2}$$

As the same,

$$x_D = \frac{x_1 + x_8}{2}, y_D = \frac{y_1 + y_8}{2} \tag{3}$$

$$x_E = \frac{x_2 + x_8}{2}, y_E = \frac{y_2 + y_8}{2} \tag{4}$$

Then x_C, y_C can be calculated and be recorded as:

$$x_C = \frac{2 \times y_1 \times (y_2 - y_8) - (y_2^2 - y_8^2) - (x_2^2 - x_8^2)}{2(x_8 - x_2)}, y_C = y_1 \tag{5}$$

The centroid of ① is:

$$C_{1x} = \frac{x_D + x_E + x_8}{3}, C_{1y} = \frac{y_D + y_E + y_8}{3} \tag{6}$$

The centroid of ② is:

$$C_{2x} = \frac{x_1 + x_D + x_E + x_C}{4}, C_{2y} = \frac{y_1 + y_D + y_E + y_C}{4} \tag{7}$$

The centroid of ③ is:

$$C_{3x} = \frac{x_C + x_B + x_E}{3}, C_{3y} = \frac{y_C + y_B + y_E}{3} \tag{8}$$

The centroid of ④ is:

$$C_{4x} = \frac{x_2 + x_B + x_E}{3}, C_{4y} = \frac{y_2 + y_B + y_E}{3} \tag{9}$$

2)the nearest node is on the side(A_2、A_4、A_6、A_8): take A_2 is the nearest node for example, the method will then compare RSS values the user-tag get from anchor A_1 and A_3, if A_1 bigger than A_3, the method thinks the user-tag in the triangle $A_1A_2A_9$,otherwise, the user-tag is in triangle $A_2A_3A_9$. Both in triangle $A_1A_2A_9$ and triangle $A_2A_3A_9$, the method of computing the location of the user-tag is the same as before computing the location of the user-tag in triangle $A_1A_2A_8$.

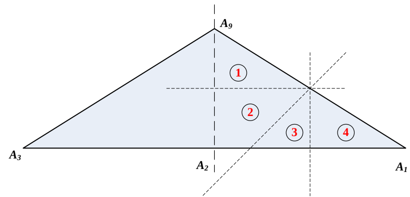


Figure 7 The Field Division With The Nearest Node is A_2

3)the nearest node is on the center(A_9): compare RSS values the user-tag get from anchor A_2、A_4、A_6、A_8, determine which triangle the user-tag is inside, triangle $A_2A_8A_9$, triangle $A_2A_4A_9$, triangle $A_4A_6A_9$, or triangle $A_6A_8A_9$. Then the method of computing the location of the user-tag is the same as before computing the location of the user-tag in triangle $A_1A_2A_8$.

IV. Implementation and Results

We implemented an experiment for the ship environment scenario, as a validation for our MILM method. In this section we (1) describe the experimental parameters and (2) present the data and results from the system we used.

A. Parameters Setting

We implemented the experiment on M.S.Yangtze II cruise vessel, which contains six decks, 139.05 meters long, and 19.6 meters wide, as figure 8. We select the theater of M.S.Yangtze II cruise vessel as the experiment scenario. Anchor nodes are deployed as figure 9, the red marker represents anchor node, black marker represents the real location of unknow node. There are 9 anchor nodes, and the coverage area is about 7.4×8.4 square meters. In the low-accuracy algorithm verification experiment, each unknow node receives RSSI from 4 anchor nodes that can form rectangle, while all of the 9 anchor nodes would be utilized in high-accuracy algorithm verification experiment. In order to save experiment time, we collected RSSI from 9 anchor nodes at the same time, and select the corresponding RSSI of desired anchor nodes as different algorithm verification experimental result.

Figure 8 M.S.Yangtze II Cruise Vessel

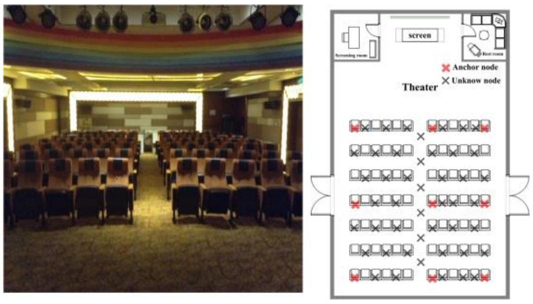


Figure 9 The Theater and Its Layout

B. Experiments and Results

As mentioned in section 2, there will be more complex effect on RSSI in shipboard environment. Thus, before positioning with RSSI, we deal with RSSI by the method combine average filtering and sliding window filtering.

In order to illustrate the advantages of MILM. Firstly, the experiments with 4 anchor nodes in different size of area inside the theater were done. Assume there are β unknow nodes in an experiment area, α represents the number of unknow nodes exactly calculated in the area, we make a definition of accuracy as:

$$accuracy = \frac{\alpha}{\beta} \times 100\% \qquad (10)$$

The localization result as table 2. According to the result, the accuracy of coarse-gained localization algorithm is increase with the increase of the location area size, and the accuracy is 100% with only 4 anchor nodes covered in the whole theater. The results shows that coarse-grained localization can guarantee the reliability requirements with fewer anchor nodes.

Table 2 Coarse-gained localization Result

case	**Size of area(m^2)**	**α**	**β**	**accuracy**
1	12.60	9	12	75%
2	18.48	11	13	85%
3	31.08	23	26	88%
4	62.16	46	46	100%

Then, the experiments with 4-9 anchor nodes inside the theater were done，and we use both fine-gained localization algorithm and weight centroid localization algorithm to figure out the position of unknow nodes. The precision is evaluated as the relative error to the real coordinates in the room:

$$precision = \sqrt{(x_i - x_{i0})^2 + (y_i - y_{i0})^2} \qquad (11)$$

Where (x_{i0},y_{i0}) represent the real coordinate of unknow node, (x_i,y_i) represent the calculated coordinate.

1)comparison of positioning accuracy results

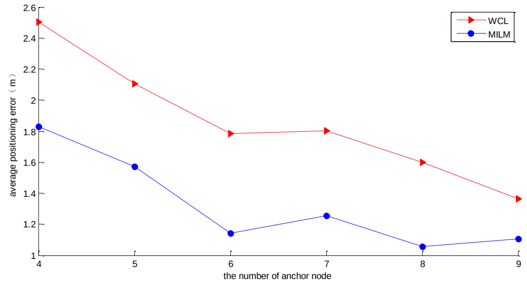


Figure 10 positioning accuracy compare of WCL and MILM

As shown in figure 10, when the number of anchor nodes changes from 4 to 9, the positioning error of the fine-grained localization algorithm is always smaller than that of the weighted centroid localization algorithm. Therefore, the fine-grained localization algorithm in the ship environment can basically guarantee a high positioning accuracy.

2) comparison of variance of positioning error

The variance of the localization error is used as the reliability evaluation index. The higher the mean square error is, the lower the positioning reliability. In this paper, the localization experiment was carried out respectively at ship berthing state and ship move state. The experiment was done at ship berthing state at first, and the result shown in figure 11.

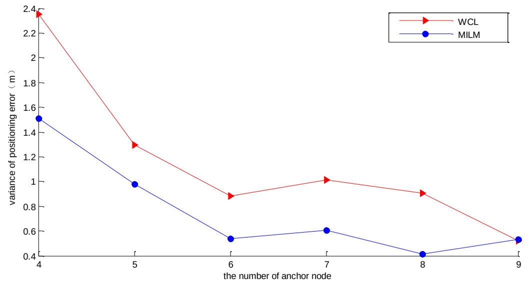


Figure 11 variance of positioning accuracy compare of WCL and MILM

As shown in figure 11, when the number of anchor nodes changes from 4 to 9, the variance of positioning accuracy of the fine-grained localization algorithm is always smaller than that of the weighted centroid localization algorithm. Therefore, the fine-grained localization algorithm in the ship environment can basically guarantee a high positioning reliability.

Then, the same experiment was carried out at move state, and the result shown in figure 12. When the number of anchor nodes changes from 4 to 9, the variance of positioning accuracy of the fine-grained localization algorithm is still smaller than that of the weighted centroid localization algorithm. Therefore, the fine-grained localization algorithm in the ship environment can guarantee a high positioning reliability even at the movement state.

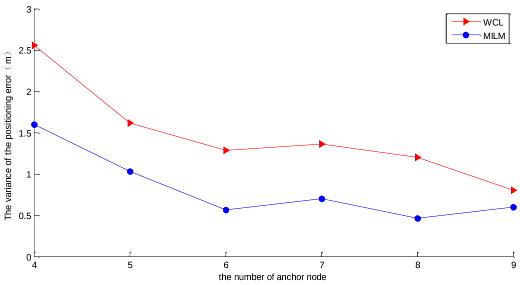


Figure 11 variance of positioning accuracy compare of WCL and MILM when the ship is move

The MILM includes both coarse-gained localization and fine-gained localization, it means that MILM can guarantee high accuracy to 100% and appropriate localization precision within 3 meters at the same time. It should be noticed that the precision of fine-gained localization may not as better as some state-of-the-art localization algorithms, while the main focus of this paper is the entire method rather than the specific fine-gained localization algorithm. Though, the positioning accuracy of high-accuracy algorithm may be further improved in case of necessity.

V. Conclusions

This paper presents a multi-scale indoor localization method, which consists of fine-gained localization algorithm and coarse-gained localization algorithm. The method can realize lower precision to decrease cost and provide privacy protection, and provide higher precision for special applications, which can meet the requirements of usability, scalability, privacy for a position system and could be more practical in shipboard environment. We verified the method with experiments on M.S.Yangtze II cruise vessel, the analysis of the data and the localization result show that the method with lower cost performance well. However, the positioning accuracy should also be further improved to meet more challenging requirements and the entire method should be tested in more scenarios in the future work.

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