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실내 위치 정확도 최적화를 위한 자동 거리 교정을 사용한 가중 사각형 위치 알고리즘

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A Weighted Quadrangle Positioning Algorithm Using Automatic Distance Correction for Optimizing Indoor Positioning Accuracy

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요 약

본 논문은 FM 라디오 신호와 LTE-MTC 기술을 활용하여 실내 환경에서 저비용으로 고정밀의 안정적인 데이터 전송을 달성하기 위해 가중치 사각 측위 알고리즘을 채택한다. 중심점에서 각 실내 스테이션까지의 가중치 값은 실험적 선형 프로그램 모델 알고리즘을 사용하여 업데이트되며, 목표물과 수신 스테이션 사이의 거리는 가중치 값을 동적으로 수정해 나간다. 목표물의 위치는 삼각 위치 알고리즘과 중심 알고리즘을 결합하여 계산한다. 이 알고리즘은 거리의 자동 교정과 선형 프로그램 모델을 통해서 일반 측위 알고리즘에 비해 더 정확하고 간섭이 적다. 실험 결과는 베이스 기초 삼각 측위 접근 방식과 FM 기반 가중치 삼각 측위 접근 방식에 비해 정확도가 각각 6.207 배, 4.1 배 향상된 것으로 나타났다. 실내 측위의 정확도를 향상시킬 뿐만 아니라 LTE-MTC 기술을 결합해 활용하여 데이터의 전송 지연과 에너지 소비를 크게 줄일 수 있다. 이 기술은 스마트 공장에서 로봇의 측위 문제를 해결하고 로봇 간의 협력 능력을 향상시킬 수 있다.

Key Words : LTE-MTC, FM Radio Signal, Indoor Positioning, Triangulation Method, Quadrangle-weighted Method

ABSTRACT

This paper adopts a weighted quadrangle positioning algorithm to achieve low cost, high accuracy and stable data transmission in indoor environment by utilizing FM radio signal and LTE-MTC technology. The weights from the center point to each indoor station are updated using the experimental linear program mode algorithm, and the distance between the target and the receiving station is corrected by dynamic weight values. The location of target position is calculated by combining the trigonometric positioning algorithm and the centroid algorithm. Compared with traditional positioning algorithms, this algorithm is more accurate and less interfered by combining distance automatic correction method and linear programming model. The experimental results show that the accuracy is improved by 6.207 and 4.1 times, respectively, compared with the FM-based triangulation positioning approach and FM-based weight triangulation approach. It not only improves the accuracy of indoor positioning, but also greatly reduces data transmission delay and energy consumption by the utilization of LTE-MTC technology. This technology can solve the localization problem of robots in intelligent factory and improve the cooperation ability between robots.

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Ⅰ. Introduction

With the rise of 5G networks and intelligent factories, indoor accuracy positioning for robots has gradually become an open issue and raise new challenge such as low latency, high bandwidth, accurate positioning, and minimized power costs[1]. The mainstreams of indoor positioning approaches include UWB(Ultra Wide Band), WIFI(Wireless Fidelity) and Bluetooth. Although UWB technology has superior accuracy, it is expensive to implement and maintain. WIFI technology is widely used due to low cost but the accuracy is unsatisfactory. Owing to the influence of transmission distance, the positioning error of bluetooth technology is particularly large in the scene with many occlusion objects. In order to achieve efficient and accuracy data transmission, the LTE-MTC(Long Term Evolution Machine Type Communication) technology is wildly utilized. However, the LTE stations are far away from targets, the positioning accuracy is between 50 and 150m under TDOA(Time Difference of Arrival) method, nevertheless combined with an Extended Kalman Filter (EKF) for movement tracking with a positioning error once indoors smaller than 8m in 50% of cases[2]. LTE-MTC positioning is obviously not suitable for indoor positioning. In order to address these issues, we propose a weighted quadrangle positioning algorithm based on the FM radio signal to achieve accurate indoor positioning, and combined with LTE-MTC technology to real-time data transmission in intelligent factory. The experimental results show that compared with other approaches, the error of the proposed scheme can be controlled around 1 meter.

Ⅱ. Related works

This section introduces two basic positioning algorithm and analyze their strengths and weaknesses in detail as the reference basic theory of the new weighted positioning algorithm proposed in this paper.

2.1 Fingerprint positioning algorithm

Fingerprint positioning algorithm is a common indoor positioning algorithm. It is utilized for indoor positioning with WIFI[3] and UWB. The existing literature[4-5] reduces positioning errors by optimizing K-values and combining spatial multipoint fingerprint matching. In the new dynamic KNN algorithm[6], UWB fingerprinting is superior to WIFI fingerprinting due to the hardware characteristics of UWB. As the fingerprint approaches need to collect samples in advance, it takes a lot of training and intensive learning to identify the fingerprint database. In addition, fingerprinting method can achieve positioning function in offline environment by using fingerprint database. However, once the environment or positioning area changes, the fingerprint data needs to be collected again, hence, positioning accuracy will decrease obviously. The existing literature[7-8] Wireless Sensor Network(WSN) application and literature[9-10] experimental scheme of cut-off indoor positioning based on RSSI signals shows that fingerprint positioning algorithm determines the position according to the RSSI(Received Signal Strength Indication) signal strength, the error is proportional to the signal strength. Therefore, weighted quadrangle positioning algorithm based on triangulation is adopted to measure distance for fiting the principle of high convenience and low cost.

2.2 Triangulation algorithm

TDOA, TOA(Time of Arrival) and AOA(Angle of Arrival), are usually used to achieve triangulation. The existing literature[11] using triangulation algorithms to made a detailed analysis based on above three approaches. Triangulation algorithm needs to accurately calculate the distance between the locating target and the receiving station. Therefore, the triangulation-based algorithm is adopted to measure distance for fiting the principle of high convenience and low cost. Due to the high complexity, positioning error is easy to occur in the indoor positioning calculation. The existing literature[11-13] has optimized the triangulation method by comparing and analyzing various techniques including the UWB technique and literature[14-15] optimizes triangulation of TOA by different algorithms to reduce positioning errors. However, as the UWB approach requires additional equipment, this approach is accurate but high cost. Therefore, in order to decrease the error, the distance measured between the target and the receiving station can be automatically corrected by the linear programming model.

2.3 Trigonometric centroid algorithm

Triangle centroid algorithm is a common method of reducing positioning errors. The positioning experiment, the calculated three feature points by the intersection of three circles, and use three points to form a triangle. The centroid of the triangle is the coordinate of the target point. the existing literature[16] adopt wireless sensor network positioning algorithms to optimized the mathematical model of triangular centroid positioning algorithm based on RSSI, then, the centroid centering algorithm is adopted to obtain final positionings, this method significantly reduces positioning errors. However, there is a problem with this method, due to the characteristics of RSSI, when the distance between the measured target and the distribution point is too far, the positioning accuracy will apparently decrease. Nevertheless, the trigonometric centroid algorithm is significantly improved in positioning accuracy by combining weights.

2.4 LTE-MTC technology

Table 1 shows the performance comparison between LTE-MTC and NB-IoT(Narrow Band Internet of Things). LTE-MTC and NB-IoT are the most widely utilized in IoT devices. Compared with NB-IoT, LTE-MTC has lower maintenance cost, supports a large-scale connection and low device power consumption, provides wide coverage, low latency and an advanced QoS(Quality of Service)[17]. Therefore, this technology is suitable for machine-to-machine data transmission in intelligent factories.

Table 1. The performance comparison between LTE-MTC and NB-IoT.

Information	LTE-MTC	NB-IoT
3GPP Release	Release 13	Release 13
Downlink Peak Rate	1 Mbit/s	26kbit/s
Device Receive Bandwidth	1 Mbit/s	66kbit/s(multi-tone) 16.9kbit/s(single-tone)
Latency	10~15ms	1.6~10s
Receiver Chains	1(SISO)	1(SISO)
Device Transmit Power	20/23 dBm	20/23 dBm

Ⅲ. Weighted Quadrangle Positioning Algorithm

The experimental algorithm updates the weights from the center point to each indoor station, and the distance between the target and the receiving station is automatically corrected by dynamic weight values. Finally, the current target position is calculated by combining the trigonometric positioning algorithm and the centroid algorithm.

3.1 Dynamic weight value calculation

In the actual distance measurement, due to external factors may lead to inaccurate determination of distance, we measure the distance by weighted method, and calculate the distance between the static point T and each indoor station and the actual distance to collect weight values to prepare for the following calculation. As a result of indoor environment existence uncertain influence factor, before positioning, the weight value must be recalculated.

Due to equipment and environmental factors, we adopt FM signal transceiver device to calculate the actual propagation velocity by formula (1) and take the average speed as the actual propagation speed of FM signal. N is the number of calculations, si is the distance, and ti is the time difference between the base station and the transmitter.

$$\bar{v}=\frac{1}{N}\sum_{i}^{n}\frac{s_i}{t_i} \tag{1}$$

The coordinates of the center of T, and the actual distance d1. Then, the actual distance between point T and each station is calculated by formula (2), denoted as d0. Then transmits the FM signal at the center point T and records the transmitting time.

$$d = (t_1 - t_0) \times \overline{v} \tag{2}$$

The weight value ***w*** is calculated by formula(3) and linear programming model to obtain weight ***w*** between true distance and measured distance.

$$w = \frac{d_0}{d_1} \tag{3}$$

3.2 Three-point coordinate calculation based on triangulation algorithm

Fig. 1 shows the weighted quadrangle positioning algorithms, assuming four known points: A(x1,y1), B(x2,y2), C(x3,y3), D(x4,y4) and unknown point (x0,y0) with d1, d2, d3, d4 ,in order to improve the measuring precision of the distance, we use weighted values to dynamically calibrate the measured distance and obtain the weighted distance directly between the target and each station, denoted as dw, target measurement distance, denoted as dc.

Then the weighted distance formula (4) can be expressed as

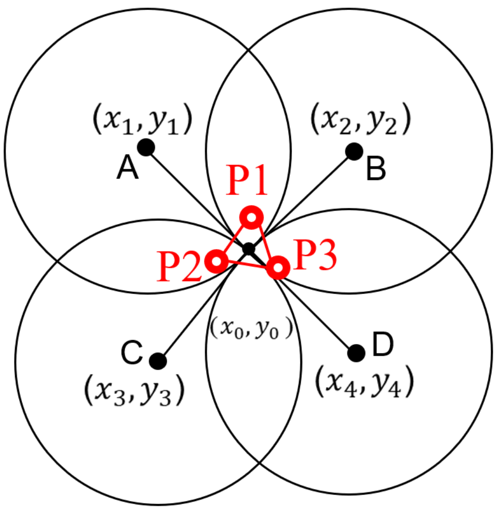

Fig. 1. Weighted quadrangle positioning algorithms.

$$d_w = d_c \times w \tag{4}$$

As shown in Fig.1, assuming the receiving station ABC, ABD and BCD serve as three groups of stations to calculate points P1, P2, P3 by triangulation formula (5). d1, d2 and d3 are the weighted distances between the target point and each base station, (x0, y0) is the target coordinate.

$$\begin{cases} (x_1 - x_0)^2 + (y_1 - y_0)^2 = d_1^2 \\ (x_2 - x_0)^2 + (y_2 - y_0)^2 = d_2^2 \\ (x_3 - x_0)^2 + (y_3 - y_0)^2 = d_3^2 \end{cases} \tag{5}$$

3.3 Trigonometric centroid calculation

In the actual measurement, due to the error of measurement, three circles do not intersect at a point. The least square method is used to calculate the average of positioning error, and the estimated accuracy can only be improved by 22.27%[18]. To decrease error, we adopt the trigonometric centroid algorithm, then the center of mass of points P1, P2 and P3 is calculated by formula (6) to obtain the accurate positioning result C.

$$C = \left(\frac{x_1 + x_2 + x_3}{3}, \frac{y_1 + y_2 + y_3}{3} \right) \tag{6}$$

Finally, the average error of positioning target d(x,y) is calculated by euclidean distance formula (7). Existing literature[16] shows that the centroid algorithm can effectively reduce the positioning error. (x1,y1) is target real coordinates, and (x2,y2) is target coordinates.

$$d_{(x,y)} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{7}$$

Ⅳ. Performance comparison and application scenario analysis

4.1 The environment of performance evaluation

In this section, we provide a detailed analysis of the experimental environment. We choose a 20mx20m building and since it is an indoor positioning, there is no need to consider the weather. We use four Raspberry Pi 4B and Tea5767 radio modules as receivers and distributed in 4 corners. Then using a Raspberry Pi 3B+ as a radio wave transmitter for signal transmission. Finally, we place a Raspberry Pi 4B at the center point T of the four receivers to calculate the weights, which reduce the error by weighting transmission speed. We set up randomly positioned target points for real-time measurement and record each target point 10 times to obtain average accuracy.

4.2 Performance comparison between different positioning algorithms

Fig. 2, 3, 4 shows the Error of triangulation, weighted triangulation, weighted quadrangle positioning under different distances. This experiment carried out on-site measurement of the target positioning coordinates. Data measurements are taken with the distance of 1, 2, 3, 4, 5, 6, 10, 15, 20 and 25 meters as the reference. Fig. 2. shows the positioning error of the general triangular positioning algorithm. The error fluctuates greatly within 5 meters of the target distance from the receiving end, and the error tends to be stable after 10 meters in Fig 2. Fig. 3 shows the positioning error of the weighted triangulation algorithm. Although the positioning error is reduced, the error fluctuation is still very large when the target is within 5 meters from the receiving end. Whereas no matter how far the distance is in quadrilateral positioning method as we see in the Fig. 4. The positioning error fluctuates less

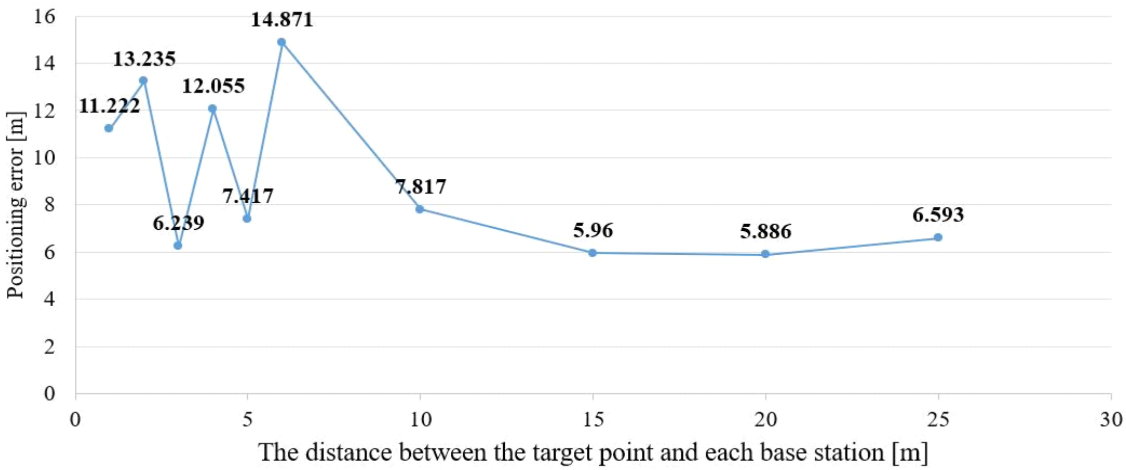

Fig. 2. The positioning error of triangulation under different distances.

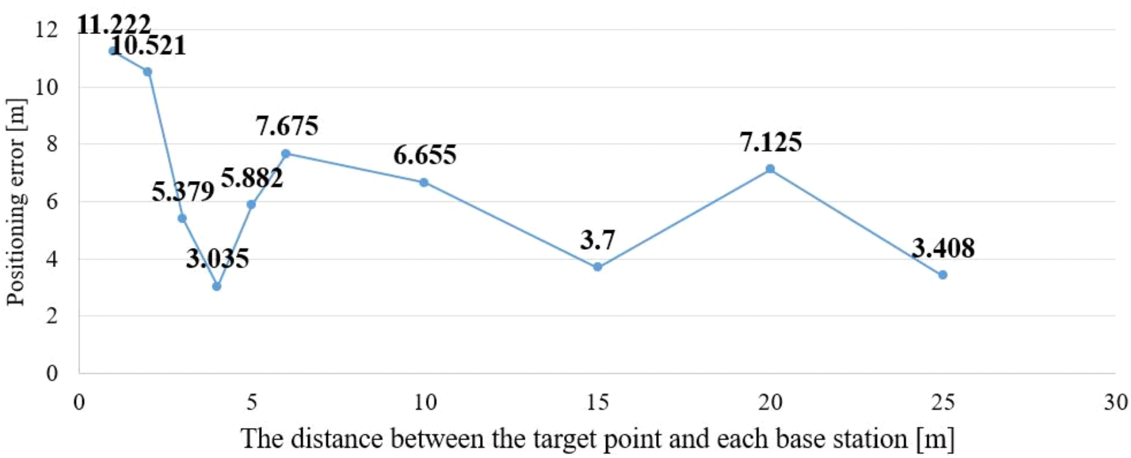

Fig. 3. The positioning error of weighted triangulation under different distances.

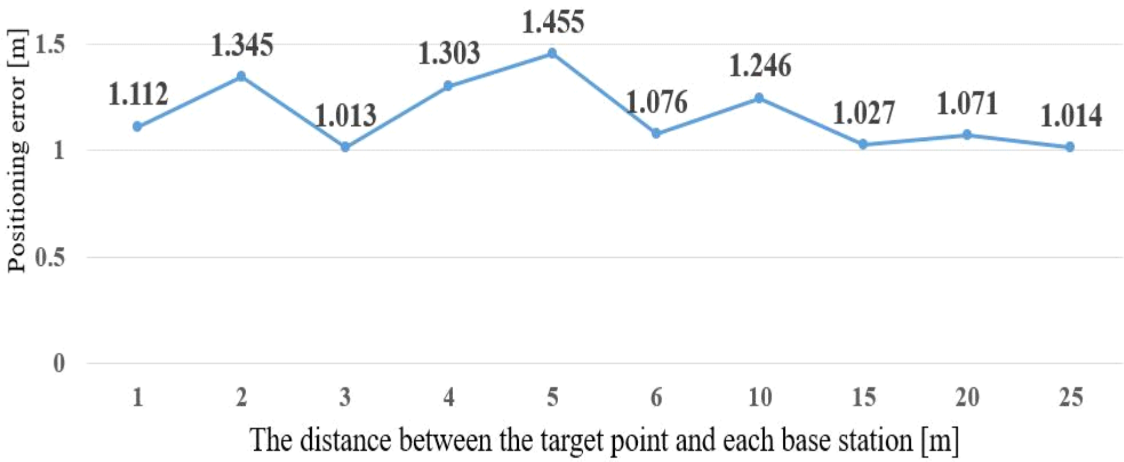

Fig. 4. The positioning error of weighted quadrangle positioning under different distances.

and the error is also low.

Fig. 5 shows the positioning error of each algorithm. The average positioning errors are 1.2666, 6.4602 and 9.1295 respectively. Compared with FM-based triangulation approach and FM-based weight triangulation approach, the positioning accuracy of weighted quadrangle positioning algorithm based on FM-RS is improved by 4.1 and 6.207 times.

Fig. 6 shows the Positioning errors between different positioning techniques. The fingerprint positioning with a maximum positioning error of 1.4m[3], LTE based on EKF positioning error is 8m[2], weighted quadrangle positioning algorithms outperform other techniques.

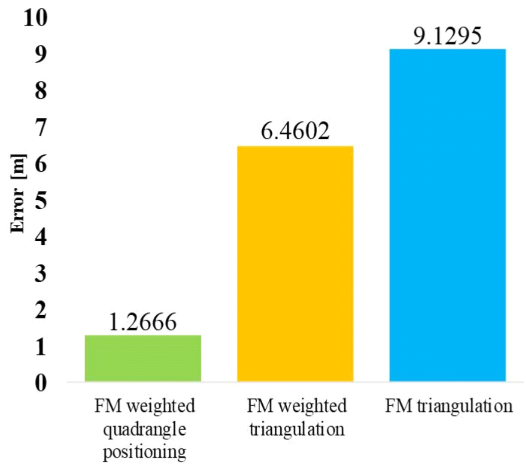

Fig. 5. Positioning errors between different positioning algorithms.

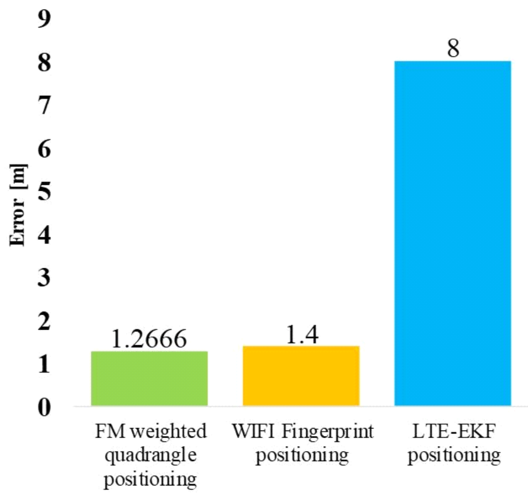

Fig. 6. Positioning errors between different positioning technologies.

4.3 Application scenarios

Fig. 7 shows the proposed weighted quadrangle positioning architecture in intelligent factory. FM-based transmitting devices and LTE-MTC module are bound to robots. The server obtains FM-based station data by LAN for accuracy positioning calculation. It can low-delay transmit data between robots by LTE-MTC module to realize

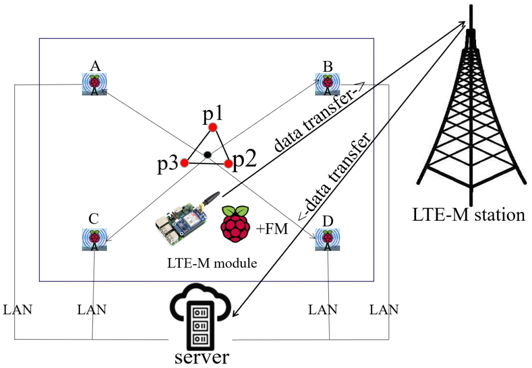

Fig. 7. Weighted quadrangle positioning architecture.

real-time control. The existing literature[19] has applied the triangulation method to mobile machines, but the result is not ideal. Therefore, the weighted quadrangle positioning method proposed in this paper can be applied to intelligent factories.

V. Conclusions

In this paper, we propose a quadrangle positioning algorithm by optimizing the triangulation method based on FM radio signal to achieve more accurate indoor positioning and combine LTE-MTC technology to achieve real-time data transmission in intelligent factories. The experimental results demonstrate that the positioning error of FM-based triangulation method is the largest. The positioning error can be accurate to within 7 meters with the weighted triangulation based on FM. It is obviously not sufficient for intelligent factories with strict positioning requirements. Therefore, in order to reduce the error of FM RS-based triangulation method, quadrangle-weighted positioning method is proposed, experiments show that quadrangle positioning error is within 1.2-1.5 meter.

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