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Research on Positioning Algorithm of Forklift-mounted RFID Reader

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Abstract: To conduct real-time and accurate positioning of the forklifts (people) and goods in the warehouse is an effective means for improving warehouse management efficiency. To this end, this article puts forward the active positioning system with the forklift installed with RFID reader and the ground passageway embedded with RFID tag. In the running process, the position of forklift can be determined through recognition of the reference tags which are embedded at both sides of the passageway based on the three-side layout at right angle principle and their RSSI value. The positional accuracy can be improved by adjusting the layout distance of those reference tags. The experimental results show that this system can realize the positioning function of forklift, and it can be used in practical situations. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Forklift active positioning, RSSI ranging, Reflection interference, Reference tag, Positional accuracy.

1. Introduction

With the continuous development of modern logistics industry, the goods and materials types and quantity are increasing continually for the warehouse management. The warehouse management operation is very complicated and diversified. Owing to the low dispatching management efficiency, the traditional warehouse management which is based on the paper documents and is implemented by manual operation has failed to satisfy the requirements of speediness and accuracy of large warehouses nowadays and may seriously impact the operation efficiency of logistics industry and becomes a big obstacle to restrict the development of logistics industry. In order to improve the efficiency of warehouse management system, the people and objects within the warehouse should be positioned in real time and accurately. As the primary operation tool, the real-time positioning of forklift is of vital importance.

Currently, the common indoor positioning technologies include infrared-ray positioning, ultrasonic positioning, WLAN (Wireless Local Area Network) indoor positioning, Bluetooth, ZigBee, wireless sensor network etc. Among these positioning technologies, some can only carry out line-of-sight propagation, some have short transmission distance, some have high investment cost for bottom hardware facilities and some are easy to be disturbed by other signals, therefore, these technologies are not applicable for positioning the motional forklifts within the warehouse. Due to the significant advantages of non-contact, high accuracy, good sensibility, low cost and strong environmental adaptability, RFID (Radio Frequency Identification) technology becomes the optimization in the field of indoor positioning and can be combined with WLAN to apply to position the objects as well as to improve the operation efficiency of logistics and warehousing.

The typical RFID Indoor Positioning System based on RSSI (Receive Signal Strength Indicator) is constituted by reader, reference tag, target tag, data processing unit and positioning algorithm which are shown in Fig. 1. In the RSSI positioning method, through analyzing RSSI of reference tags and target tags read by multiple readers and using the weight thought of "the nearest neighbor" and positioning algorithm to work out the coordinate of target tag, the position of target tag can be obtained, such as the systems of SpotON [1], LANDMARC [2], IMPRO_BVIRE [3], Scout [4] etc. RSSI positioning method can adopt the tags with low cost to replace the readers to reduce the cost for system construction and achieve high positioning accuracy, but this method has the defects such as the reference tag may impact the positioning accuracy and the layout density of reference tags may affect the receipt signal strength of reader and the tracing point calculation will be omitted owing to large calculated amount for the processor when many forklifts are operating simultaneously within the warehouse.

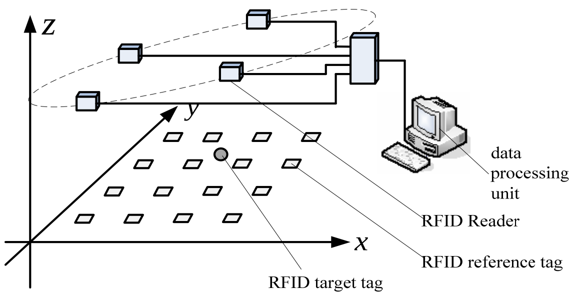

Fig. 1. Schematic diagram of RSSI positioning algorithm.

To solve the above problems, this article proposes an intelligent warehouse management solution which can offer the moving trajectory of forklifts and goods positioning within the warehouse in real time. The roads and goods shelves or storage yard for operations of forklift within the warehouse are embedded with RFID tag (hereinafter referred to as road tag). When the forklifts equipped with RFID readers and data processing module is moving in the warehouse, the road tags and the signal strength indicator can be read in real time and the passed road tags during moving of the forklifts can be obtained through processing the road tag information and signal strength indicator information, thus getting the moving trajectory of forklift; The same tags read in a period of time by the forklift can help us deduce the forklift is loading and discharging the goods here, thus obtaining the position of goods. The handling information about the goods can be gotten according to increase and decrease of goods tags on the forklift, thus realizing intelligent management of forklift and goods within the warehouse. In this solution, the data processing unit can automatically read the road tags during movement of the forklift and judge the position of forklift, therefore after upgrading, this solution can be applied to the unmanned forklift to achieve unmanned operation of warehouse loading and unloading, thus further improving the labor productivity. This solution owns wide range of potential applications.

2. Forklift Trajectory Algorithm

The calculation of forklift trajectory algorithm within the warehouse is based on RSSI ranging algorithm and use indoor signal propagation loss model to reflect the relationship of signal power loss and transmission distance [5].

2.1. Calculation of RSSI

In the free space environment, the power of signal received by the receiver can be expressed as

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}, \tag{1}$$

where P is the power, G is the gain of antenna of receiver and transmitter, λ is the wave length of signal, d is the distance between the receiver and transmitter.

If dBm is the unit, the received signal strength can be simplified as

$$P_R(dBm) = P_0 - 10 * n * \lg(d) + \zeta, \tag{2}$$

where P_0 is the usually taken the magnitude of wireless signal power value received by the receiver when the distance between wireless receiving node and transmitting node is d_0m; n is path loss index; ζ is the random disturbance generated by barriers between receiver and transmitter which is generally assumed as the Gaussian noise with zero-mean variance of σ.

As the complicated environmental structure and motional objects indoors may cause signal reflection, refraction and scattering, resulting in the nondeterminacy of the wireless signal propagation and failing to perform quantitative expression for the signal with analysis formula. So the signal is usually marked using the numerical range of received power, i.e., receive signal strength indicator, the formula (2) is rewrote to RSSI as follows:

$$RSSI = A - 10 * n * \lg(r), \tag{3}$$

$$r = 10^{\frac{A-RSSI}{10*n}}, \tag{4}$$

In the above two formulas, both A and n are empirical value which are related closely to practically used reader, antenna, reference tag and the communication environment of wireless signal and decides the accuracy of RSSI positioning as well.

2.2. Determination of Environmental Parameter

Both A and n related to environment cannot be given accurately, but they can be valued as the means of multiple experimental values (the average value of N samples replaces the lumped parameter). The following formula can be obtained based on formula (3):

$$\begin{cases} n_i = \dfrac{RSSI_{2i} - RSSI_{1i}}{10\lg(\dfrac{r_{1i}}{r_{2i}})} \\ A_i = RSSI_{1i} - 10n_i \lg r_{1i} \end{cases}, \quad (5)$$

$$n = \frac{1}{N}\sum_{i=1}^{N} n_i, \quad A = \frac{1}{N}\sum_{i=1}^{N} A_i, \quad (6)$$

2.3. Three-side Layout at Right Angle Principle for Passageway Sign Reference Tags

Influenced by the indoor environment, there may be large error of distance between reader and tags obtained from formula (3). To increase the accuracy degree, the reference [6] proposes the RSSI ranging algorithm based on the reference tag and reference [7] points out that when the positions of three reference nodes can shape up an equilateral triangle (equilateral trilateration for short), the positioning error will be minimal.

In the equilateral trilateration, the space between two lines of the lags is times of the side. When knowing the length of side, it is necessary to calculate this value. Under normal conditions, the arithmetic speed of the microprocessor served as the data processing unit on forklift is slower than PC. In order to save calculation time, when arranging the reference tags, three reference tags should be arranged to an isosceles right triangle, and by now the space between the two sides of tags is equivalent to the right-angle side length of the isosceles right triangle, thus saving the computation time.

The following passageway signs reference tags (hereinafter referred as passageway tag) layout principles are proposed combining with the specific goods shelves sizes and passageway breadth:

1. Arrangement of main passageway tags. As shown in Fig. 2, at the put area of goods shelves, when the sum of goods shelves width D_1 and the passageway width between the shelves D_2 is less than the read range R_0 of reader, i.e. $D_1+D_2<R_0$ (in most cases, this condition can be satisfied), the space between the passageway tags on the middle passage is $(D_1+D_2)/2$ and the length of midcourt line of the isosceles right triangle is $(D_1+D_2)/4$; when the main passageway width D_3 is less than (D_1+D_2), the distance a of passageway tags from the main passage is $[D_3-(D_1+D_2)/4]/2$; if the main passageway width D_3 is greater than (D_1+D_2), the arrangement of the passageway tags of the main passageway is carried out according to shape of isosceles right triangle;

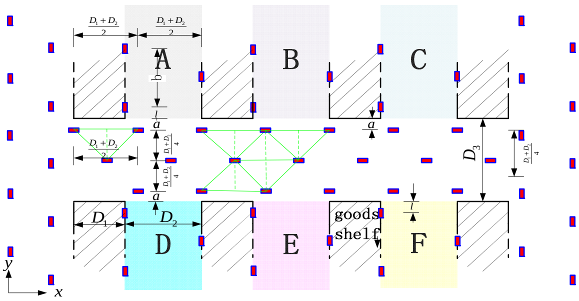

Fig. 2. Schematic diagram of arrangement of passageway signs reference tags.

2. Arrangement of passageway tags between shelves. The tags marked with shelf number are usually adopted for the passageway between the shelves and it is unnecessary to arrange other passageway tags. But the marking tags for shelves should be interlaced to form the isosceles triangles for every three shelves.

After arranging the passageway tags based on the above principles in warehouse, the forklift will read at least two tags during moving. Through the passageway tags and their position information read by the reader, the location of forklift can be obtained quickly.

2.4. Trajectory Algorithm Based on Reference Tags

The common-used reader with UHF usually adopts the patch antenna with a beam width of about 90° [8]. Therefore, during movement of the forklift (assume that it is moving along the center line of the passageway and moving along the arc when turning the corner), the tag number read by it is minimal when its antenna beam just passes a passageway tag which is the PA point shown in Fig. 3. Assume the width of middle passageway D_3 is less than (D_1+D_2).

When the forklift is at PA position, corresponds to A1 point in Fig. 4, the tag it just passes locates at A_2 point. As $|A_2A_4| = (D_1+D_2)/4$, we can know from the Fig. 4 that $|A_2A_3| = |A_3A_4| = (D_1+D_2)/8$, $|A_3A_6| = (D_1+D_2)/4$ and $\angle A_2A_1A_3 = \angle A_4A_1A_3 = 45°$, so

$$|A_1A_3| = \frac{1}{2}|A_2A_4| = \frac{1}{8}(D_1+D_2), \quad (7)$$

$$|A_1A_7| = \sqrt{|A_1A_6|^2 + |A_6A_7|^2} = \frac{\sqrt{10}}{8}(D_1 + D_2)\,, \quad (8)$$

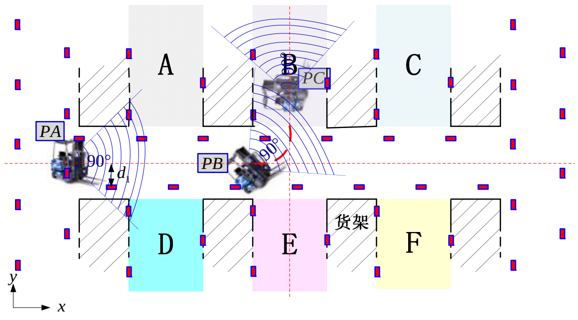

Fig. 3. Schematic diagram of tag number read by the forklift when it is moving.

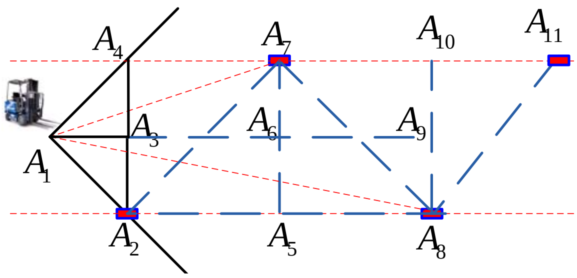

Fig. 4. Distance relationship of forklift with the tags when it locates at PA.

The formula (9) can be obtained in a similar way:

$$\begin{aligned} |A_1A_8| &= \frac{\sqrt{26}}{8}(D_1 + D_2)\,, \\ |A_1A_{11}| &= \frac{\sqrt{50}}{8}(D_1 + D_2) \end{aligned} \quad (9)$$

The position A_1 of the forklift locates at $\frac{1}{8}(D_1 + D_2)$ backward of position of reference tag A_2, i.e.

$$\begin{cases} PA_x = A_{2x} - \frac{1}{8}(D_1 + D_2)\,, \\ PA_y = A_{2y} \end{cases} \quad (10)$$

When passageway tag of A_7 point is within the coverage range of reader beam, the position of the forklift is deemed to be at A_1 point, therefore the maximum value of positioning error is

$$|A_2A_5| = \frac{D_1 + D_2}{4}\,, \quad (11)$$

Meanwhile, when the reader on the forklift read the passageway tags of A_2, A_7, A_8… successively, we can determine the forklift is moving along the center line of passageway.

3. Experimental Results and Analysis

3.1. Determination of Environmental Parameter

To confirm (A, n) of warehouse environment, the simulation environment is constructed on the corridor of experimental building. Read the corresponding RSSI value (average value) of tags at 0.2 m, 0.4 m, …, 10 m from the reader respectively using ALR-9900 application-specified reader of American Alien Company and substitute into formula (4) and formula (5) to get the value of (A, n) and establish the ranging model for positioning of forklift in the warehouse

$$RSSI = -38 - 20\lg(r)\,, \quad (12)$$

The comparison of RSSI value of tags calculated according to formula (12) and the actual measured value is shown in Fig. 5.

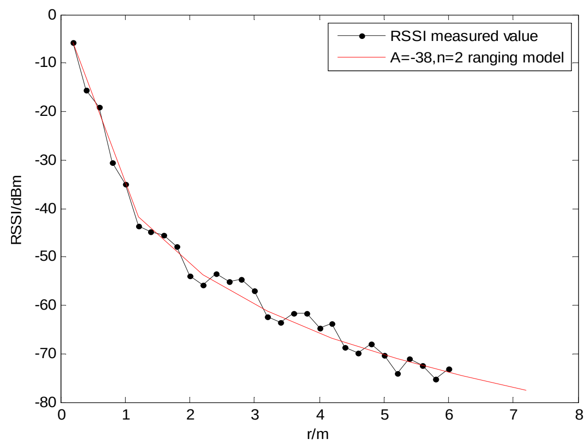

Fig. 5. Comparison of RSSI value computed by model and the actual measured value.

We can see from the figure that within rang less than 6 m, the values are basically identical, and therefore this ranging model can determine the tags whose distances from the reader are less than 6 m.

3.2. The Readable tag Number During Movement of the Forklift

Based on the arrangement principles for passageway tags in 2.3, assume the onward forklift is used in the warehouse as the main tools for piling up the goods. According to the distance requirement of passage width which should not be less than 3 m, the multi-layer shelves are generally put with the objects with the width less than 1 m. The effective read range of reader with UHF is generally 6 m. Thus the parameter values in 2.3 are: D_1=2 m, D_2=3 m, D_3=3 m, R_0=6 m, then

$$|A_1A_7| = \frac{\sqrt{10}}{8}(D_1 + D_2) = 1.98m$$
$$|A_1A_8| = \frac{\sqrt{26}}{8}(D_1 + D_2) = 3.19m < 6\text{m}, \qquad (13)$$
$$|A_1A_{11}| = \frac{\sqrt{50}}{8}(D_1 + D_2) = 4.42m$$

We can know from formula (13) that if the read range is 6m, the reader is able to read more than 3 tags every time.

3.3. Moving Trajectory Description

To verify the above trajectory algorithm, in a meeting room with about 51 m *37 m, apply the meeting room to simulate warehouse passageway to arrange the tags at interval of 2.5 m. A person holding the reader will replace the forklift. According to the tag ID and RSSI value read by the reader, the person's walking direction can be obtained and the nearest tag ID can be found as well. Adopt formula (10) to calculate person's position, thus obtaining the moving trajectory of the person which is shown in Fig. 6.

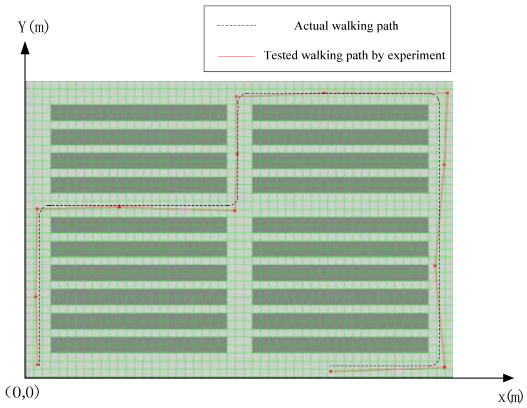

Fig. 6. Comparison of actual walking path and the computed path.

The Fig. 6 is comparison drawing of the moving trajectory of reader (people) calculated through algorithm and the actual walking trajectory. We can see from the figure that the all calculated nodes are within the passageway range and the error comparing with the actual walking path is small, marking it better to realize the positioning of people.

4. Conclusions

With the speedy development of internet, the common people has recognized and attached importance to the value of network marketing. Fast development of the logistics industry and increase of the large warehouses leads to the rise of goods entering and discharging from warehouse surges. To guarantee the efficient operation of warehouse, it is necessary to position the people and goods within the warehouse in real time. To adapt to modern fast pace and reduce errors and workload of manual operation, this article proposes the active positioning system for forklift. When the forklift passes the reference tag embedded in the passageway ground, the tags and RSSI value will be read. Through the position of reference tag and calculation, the current position of forklift will be obtained, thus getting forklift trajectory in the warehouse. The active positioning system of forklift can provide the position of goods loading and discharging, thus getting the position for putting the goods. Then according to RFID tags of goods, the workload of goods loading and discharging can be obtained, realizing the automatic statistics of quantity and position of the goods entering and discharging from the warehouse, and reducing a lot of manual statistics work and the losses caused by human errors, making it possible to improve the work efficiency.

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