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Application and Research of Active RFID-Based Positioning System in Sport Competition

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Abstract

In this paper, it has made a deep research to the application of RFID positioning in sports competitions. It also researched the application of VIRE algorithm in positioning system, and proposed an improved VIRE algorithm, also chose the appropriate interpolation method. Through the improved location algorithm, it builds a relationship between the distance and time in finish line of the athlete, and solves the function to make sure the time that athletes reach the finish line, so that it can achieve the purpose of timing.

***Keywords**: RFID; Sport Competition; Positioning; VIRE Algorithm*

1. Introduction

In sport competitions, both 100-metre and 800-metre run race, also include shot and triple jump, are all related to a large number of outdoor positioning. RFID technology is a non-contact and automatic recognition technology. It is small in size, wide in range of reading and writing, long in life, and is strong in anti-interference. It also supports fast reading and writing, mobile identification, multi-target recognition, a unique identifier and so on. Compared with the mature GPS positioning technology, RFID is more suitable for small-scale local and low-cost positioning system. At the same time, compared to a passive tag, the active RFID tags identify farther, and are larger in storage capacity. As can be seen, the research based on active RFID positioning system helps to achieve a more accurate personnel management, item positioning and other functions in sports competitions. So it can better achieve fair and just in sports competitions, and has a greater social significance in personnel selection.

RFID positioning technology is also widely spread among the sports events in foreign countries. In August 2014, NFL used the technology program of Zebra, and applied the RFID to rugby race for the first time [1]. There have been many agencies and companies undertook studies and obtained the corresponding results. As in December 2014, *The Application of RFID positioning and three-dimensional technology in highway Construction Safety Management* has passed the acceptance at the research institute of Nanjing road, and used the video recognition, radio positioning and three-dimensional modeling techniques in highway construction safety management for the first time. It also can achieve the accurate positioning and statistics to the on-site vehicle, and improve the construction safety management [2]. Although, RFID positioning system has made great achievements in our country, the maturity has not come. It is still in the research and promotion period, and it still requires further efforts and improvements, and makes the application in more fields.

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2. Wireless Positioning Technology

2.1. RFID Positioning Principle

RFID positioning technology has made the communication between readers and tags by wireless RF, to achieve the identification and application. Although the range is short of RFID positioning technology, the accuracy of non-contact position can reach centimeter-level, and the cost is low. Therefore, it is suitable for small positioning system, its working principle shown in Figure 1[3].

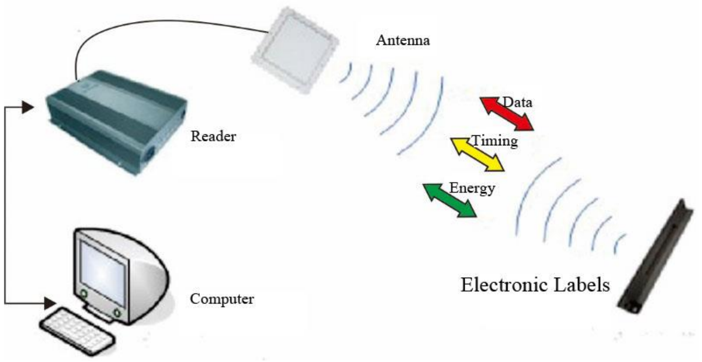

Figure 1. RFID Operating Principle

RFID technology comes from radar technology, so the work substantially of RFID is similar to radar technology. It is easy to see from Figure 1, after the tag enters the reader's electromagnetic field, and receives electromagnetic signals emitted by the reader, and then the built-in antenna of tag will produce magnetic induction current. The energy produced by magnetic induction current returns the formation carried by label back to a confirmed reader; or the tag has its own power bank, and pass the information to the reader actively after entering into the magnetic field [4]. The reader will pass the information to application software in computer terminal for processing and analysis, and generate relevant application.

2.2. RFID Positioning Algorithm

There are many algorithms in RFID positioning system, such as LandMark algorithm, VIRE algorithm, SpotON algorithm, R & PLR-LA algorithm, LocSens algorithm, RADAR and so on [5]. The most classical algorithm is VIRE algorithm, which is different from the traditional approach based on RSSI ranging positioning, and the position has no need to calculate the distance, instead of adapting the form of a reference label for positioning evaluation. It can reduce the impact of environmental factors on RSSI value without knowing RSSI scenes from the model, and the deployment is relatively simple.

2.2.1. VIRE Algorithm: VIRE algorithm is based on the actual reference label of LandMark algorithm deployment and the introduction of virtual reference, which reduces the number of actual reference tag and the difficulty of deploying, and reduces the costs of equipment. For the virtual reference label introduced, VIRE algorithm put network into practice and mesh together with the actual reference label to establish similar map, and clean up some errors of reference point [6]. And also it introduces two factors, which in weighted ways, to further increase the accuracy of positioning. The results show that the positioning accuracy of VIRE algorithm increased by 27% ~ 73% than LandMark algorithm. In the same scenario, if the influence of environmental factors is large, the average error can reach 0.29m.

The specific deployment of VIRE algorithm is shown in Figure 2 [7]. Suppose that arrange four reference labels, wherein covering scope of four labels were grid settings. Although the reader did not show a layout position in the diagram, when you are in actual deployment and out of reference tag, it also makes reference tag in the reading range of readers.

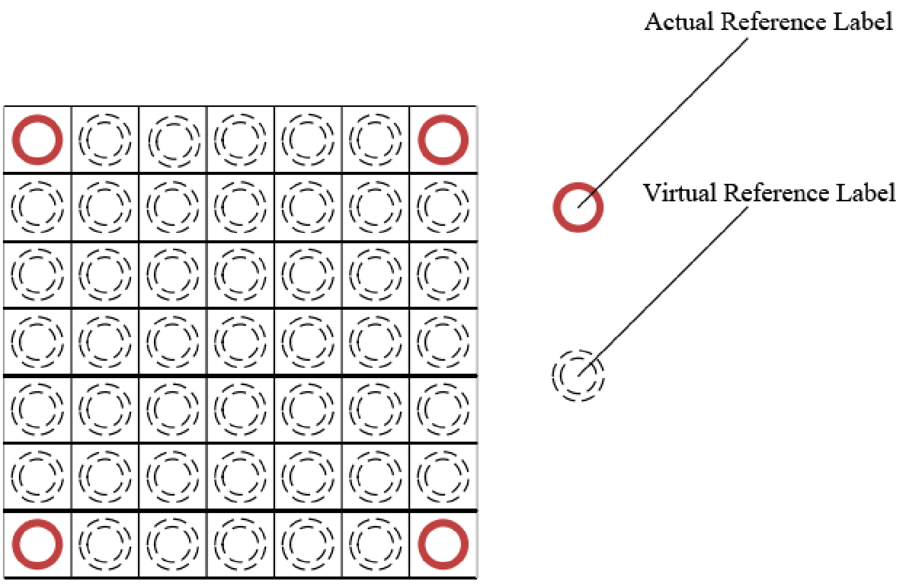

Figure 2. VIRE Algorithm Layouts

During VIRE positioning algorithm, we should get the RSSI value of virtual reference label at first. In VIRE system, all the reference labels are divided into same spaced grid, and each grid is regard as a reference label. The RSSI value of reference tag is obtained by linear interpolation.

Assuming the coordinate of virtual tag is (p, q), and the coordinates of actual reference label is (a, b), and define the RSSI value of the coordinates (x, y) is Sk(Tx, y), then we can be obtain RSSI value by equation (1), (2).

$$S_k(T_{p,b}) = S_k(T_{a,b}) + p \times \frac{S_k(T_{a+n,b}) - S_k(T_{a,b})}{n+1} \quad (1)$$

$$S_k(T_{a,q}) = S_k(T_{a,b}) + q \times \frac{S_k(T_{a,b+n}) - S_k(T_{a,b})}{n+1}$$

Then, by building a similar map, the position coordinates error can be excluded, and the process is shown in fig 3. After obtaining the RSSI of virtual reference tag, it can be compared with the label which needs to be tested. If it is less than a preset threshold, the region is marked as the effective area, and then makes an operation to the close map of readers, and then you can estimate the location of labels [8].

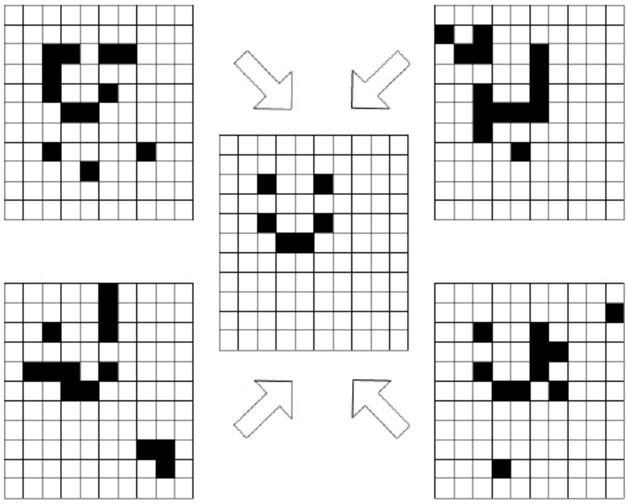

Figure 3. The Process of Eliminating Error Location Coordinate

Finally, through the weighting calculation, we can get the coordinate of the label which need to be tested. In order to improve the accuracy of position, VIRE algorithm introduces two weighting factors. Weighting factor W1i, W2i are as shown in equation (3), (4):

$$W_{1i} = \sum_{k-1}^{k} \frac{\left| s_k(T_i) - s_k(R) \right|}{k \times s_k(T_i)} \tag{3}$$

$$W_{2i} = \frac{P_i}{\sum_{i=1}^{n_0} P_i} = \frac{n_{ci}}{\sum_{i=1}^{n_a} n_{ci}} \tag{4}$$

k is on behalf of the reader, Sk(Ti) represents reader K getting the RSSI value of measured label, Sk(R) is RSSI value of virtual reference label. So W1i means the relationship that the difference of RSSI value between virtual reference label and the actual reference label; na represents the area all selected virtual reference label, and nci represents the continuum area (connected together in grid) that the virtual reference label selected. So W2i represents the proportion that virtual label continuum region in the entire selected region. The weights Wi =W1i*W2i, the measured coordinates of label can be calculated by equation (5).

$$(x, y) = \sum_{i=1}^{n_a} W_i (x_i, y_i) \tag{5}$$

2.2.2. Improved VIBE Algorithm: Since VIRE algorithm uses the way of linear interpolation, but the actual distance loss is nonlinear. Meanwhile, because of the threshold setting of VIRE algorithm also can lead to errors while solving the neighbor label [9]. So this paper presents an improved VIRE positioning algorithm. Improved VIRE positioning algorithm requires arrange the actual reference tag and reader at first, and connect to the computer application software, and set the sub-grid of virtual label. Using quadratic interpolation to calculate the RSSI value of a virtual label, and correct the RSSI value, also reduce the errors caused by interpolation. When the label need to be tested enters the reader and deployment range of reference label, then measuring the RSSI value which needs to be tested. By improving the threshold setting, calculating neighbor label, can reduce the impact that threshold on neighbor labels. Finally, to use weighting, the same to VIRE algorithm, can get the label position.

Improved algorithm is based on deficiency of VIRE algorithm. VIRE algorithm uses linear interpolation on reference labels, which there exists big errors in practice. Because of the distance loss of RSSI is non-linear. So, this paper uses non-linear interpolation method-quadratic interpolation (parabolic interpolation). Of course, there exists interpolation method based on distance loss model, but this method is more complicated. The control of algorithm is not strong. The specific interpolation method using in this paper are as follows:

At first, we assume the coordinates of virtual label are (p, q), and define RSSI value of coordinate (x, y) as Sk(Tx,y), and calculate RSSI value by following steps.

Assuming in the coordinate system, the three actual reference label, which are known as the same in ordinate, their coordinates are （x1,b）, （x2,b）, (x3,b), and the RSSI value of reference label are Sk(Tx1,e), Sk(Tx2,e), Sk(Tx3,e). The equations of building parabolic f(x)=a*x2+b*x+c are as follows:

$$\begin{cases} S_k(T_{x1,e}) = a \times x_1^2 + b \times x_1 + c \\ S_k(T_{x2,e}) = a \times x_2^2 + b \times x_2 + c \\ S_k(T_{x3,e}) = a \times x_3^2 + b \times x_3 + c \end{cases} \tag{6}$$

Interpolation functions as follows:

$$f(x) = S_k(T_{x1,e})\frac{(x-x_2)(x-x_3)}{(x_1-x_2)(x_1-x_3)} + S_k(T_{x2,e})\frac{(x-x_1)(x-x_3)}{(x_2-x_1)(x_2-x_3)} + S_k(T_{x3,e})\frac{(x-x_1)(x-x_2)}{(x_3-x_1)(x_3-x_2)} \tag{7}$$

The transverse RSSI value of virtual reference label Sk(Tp,e) is:

$$S_k(T_{P,e}) = S_k(T_{x1,e})\frac{(p-x_2)(p-x_3)}{(x_1-x_2)(x_1-x_3)} + S_k(T_{x2,e})\frac{(p-x_1)(p-x_3)}{(x_2-x_1)(x_2-x_3)} + S_k(T_{x3,e})\frac{(p-x_1)(p-x_2)}{(x_3-x_1)(x_3-x_2)} \tag{8}$$

Similarly, we can get longitudinal RSSI value of virtual reference label. By the way of quadratic interpolation, the virtual label RSSI value is available of the whole positioning systems.

The advantage of quadratic interpolation is that it is non-linear. The Parabolic function of quadratic interpolation is close to actual distance loss function. Through experiments, we can get the influence of quadratic interpolation and linear interpolation on RSSI value. Experiment is as shown in Figure 4, the three active reference labels are listed in the same line, and the reader beyond the three active reference labels but in the same line, also the area selected is wide. Otherwise, reducing the factor of interference signals.

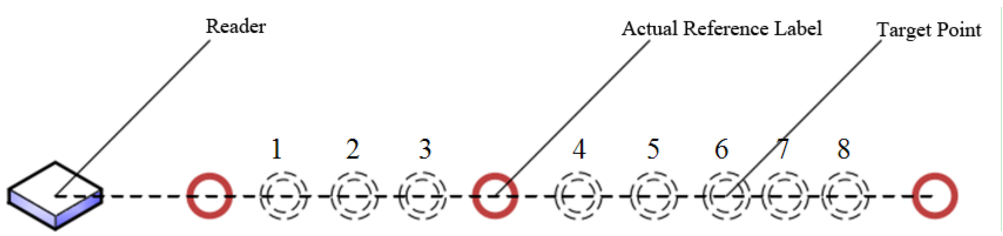

Figure 4. Interpolation Test Scene Diagram

Firstly, measure three RSSI value of active reference label, and select 8 position points which are in three reference labels. Then, we estimate the RSSI value of position points by linear interpolation and quadratic interpolation respectively, and then put them into the actual reference label, and get the actual RSSI value of 8 points, then make a comparison.

It can be found; the error of quadratic interpolation is less than linear interpolation. The error of interpolation is less while near the actual reference label (such as positions 1, 3, 8). The error of linear interpolation is bigger while it is at the midpoint of the actual reference label (such as positions 4, 5,). In some position, the error of quadratic interpolation is larger than linear interpolation. But it can be found in these places the RSSI attenuate particularly powerful. And the impact on position system is smaller.

At the same time, the workload is not large while use quadratic interpolation. If you use distance loss, which refers to exponential and logarithmic arithmetic, while quadratic interpolation only involves the basic arithmetic. Compared with simple addition and subtraction operations, the complexity of exponential and logarithmic arithmetic is obvious [10]. Compared with Newton interpolation, quadratic interpolation does not request the derivation of RSSI and distance function (In practice, derivation is more difficult, because the function curve is unavailable), and is much simpler.

In practice, the reader will re-read the RSSI value of reference labels from time to time, and evaluate RSSI distributions of virtual reference label. If large errors occur, recalculate the RSSI values in time.

2.2.3. Correct RSSI Value: The RSSI exists some errors by quadratic interpolation calculation and distance loss model calculation. Also it has error from the actual RSSI value [11]. Correct the RSSI value and make it close to actual value, and minimize the interference of environment.

Select the middle position of two reference labels, and measure the actual RSSI value of this position. Select three points like this randomly, the actual RSSI values respectively are Si（i=1,2,3）and the obtain RSSI value by quadratic interpolation is Sk(Ti)（i=1,2,3）, then calculate average E of discrepancy between Sk(Ti) and Si. Regard average value as the correct factor, and correct quadratic interpolation to calculate RSSI value. The corrected RSSI value is Sk(Tx,y)- E.

2.2.4. Arrangement of Reference Label: Linear interpolation only requires two endpoints to interpolate, but quadratic interpolation needs three points to interpolate, so this position algorithm squared reference label for deployment. Deployment of reference label is as shown in Figure 5.

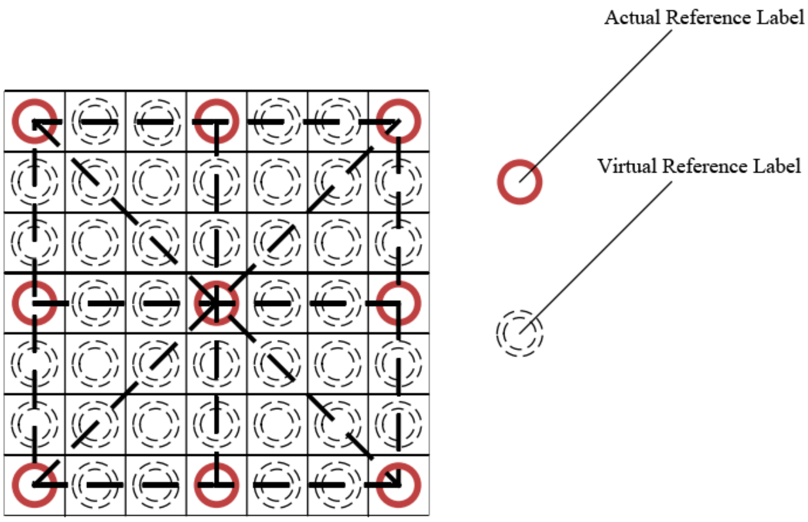

Figure 5. Improved Algorithm Reference Schematic Label Deployment

The actual deployment and VIRE algorithm is same, except that the VIRE algorithm can arrange four reference labels at least, and the improved algorithm needs nine reference labels at least, but the cost of reference label increases is not large, and influence is less. Squares are 6*6m2. Shown in FIG5, the reference labels almost locate at the endpoint, and only one is located in the center. The distance of each grid is 3m, and reader to reference label is 1m away.

2.2.5. Narrow Position Range: As shown in Figure 6, because the improved algorithm reference label uses the squared deployment, so the regional division to virtual label is more detailed than VIRE algorithm. The enhancement of number of reference label is benefit for the construction of RSSI distribution, and is more accurate.

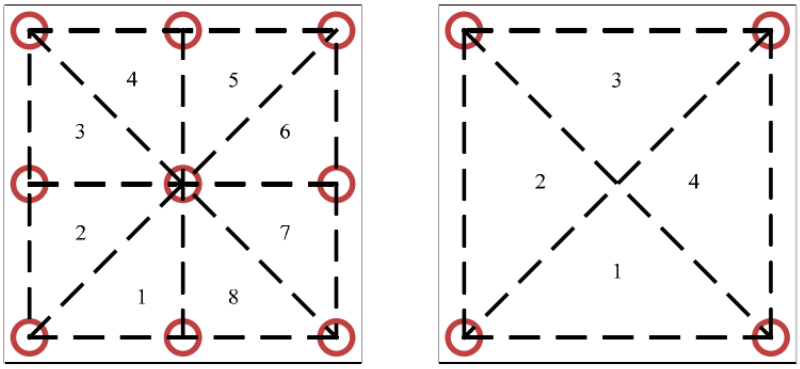

Figure 6. Region Division Comparison

When the RSSI value of a virtual label is determined, after positioned labels entering the measuring range of the reader, the reader will perceive and measure RSSI value of label to be positioned. Take the absolute value after subtraction with virtual RSSI value. If the absolute value is less than the set threshold, the virtual label is considered to be adjacent. Meanwhile, arithmetic with other perceived results, and we can get a group of contiguous virtual reference labels.

However, if the threshold is set too large, the error will be significant, as shown in Figure 7, the position of actual tested label should be close to the following virtual tested label. If the threshold is set too large, the calculated position will be on partial top, Although VIRE algorithm hope that the weighting factor can eliminate this effect as much as possible, there is no much effect. If the threshold is set too low, then the number of neighbor label we can get is too small, the accuracy of position will greatly reduce. Therefore, selecting an appropriate threshold is critical.

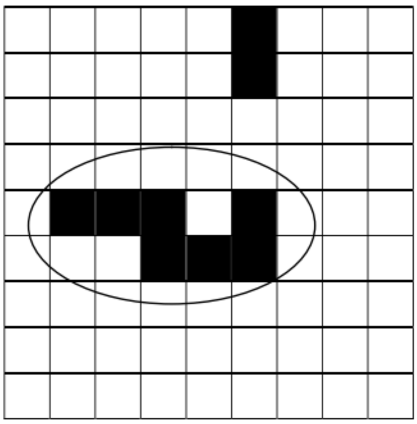

Figure 7. Neighboring Label Distribution

Through the graph up, we can find a phenomenon, after grid the position area, the closest neighbor label must be contiguous. If the selected neighbor reference label is not adjacent and in discrete distribution, and then we can exclude the probability small part.

In view of this, we propose a method of setting the threshold value. As shown in Figure 8, each reader set a larger threshold value initially, the constructed virtual label adjacent map (the absolute value of RSSI between virtual label and measured is less than current threshold), and record the area. Then the threshold value decreases linearly, and gets a new virtual adjacent label area. Make a comparison to the neighboring areas, if regional area is same or similar (the number of different adjacent labels is less than 1), then the threshold value continues to decline. Otherwise it stops decreasing, and remark the adjacent label area of previous threshold value as the ultimate virtual label adjacent area of the reader. Each reader should repeat these steps, and make the intersection operation ultimately. By this way, the threshold value of each reader is not the same, and decrease the decremented times of threshold value. Finally, make a further optimization for the selected adjacent label area, and select these contiguous areas. What is more, the continuous area is the largest area compared to other discrete region, and excludes other small portions.

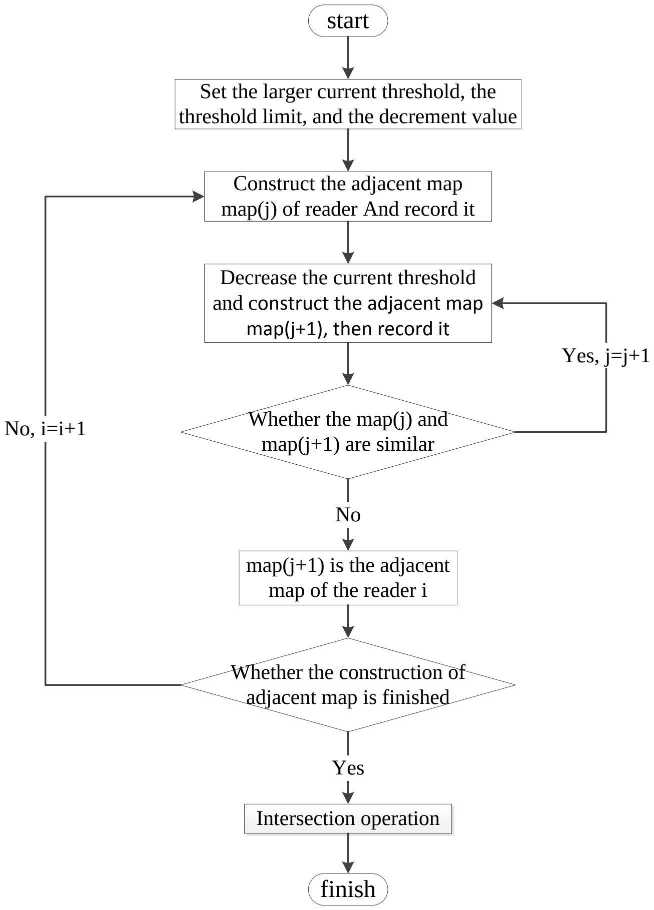

Figure 8. Threshold Setting Mode

3. Active RFID Positioned Timing System Design

This paper presents a small label timing system based on active RFID, and such system needn't to deploy array and antenna. The specific layout of the scene is as shown in Figure 9.

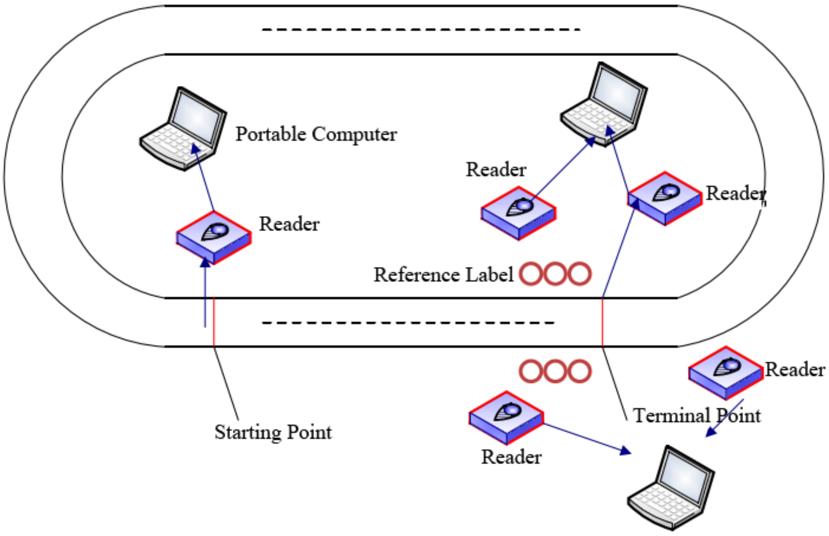

Figure 9. Timing System Diagram of No Array Antenna

When athletes start at the starting point, we can use other sophisticated timing technology for timing. We can connect the electronic starting gun with the timing system to record starting time. When the electronic starting gun produces a sound signal, it can be connected with a loudspeaker, to ensure that the starting signal can be heard by athletes clearly, and transfer signals to timing system in time. Compared with the traditional gunpowder, the electronic starting gun is non-polluting and safe, and is more precise. It can achieve the accuracy about 1ms.

Figure 10. The Range of Label Enter into Reader

When players are arriving end and enter the perceptive range of reader, as shown in Figure 10. Reader transmits emitted signals based on active RFID label (transmitting frequency can be set based on active RFID label according to demand). Then measure the position of player, and record the time of receiving radio signals. Finally, make some mathematical operations to get the time those athletes arriving at the line, and then we can make sure the performance of athletes. The process of the timing system is shown in Figure 11.

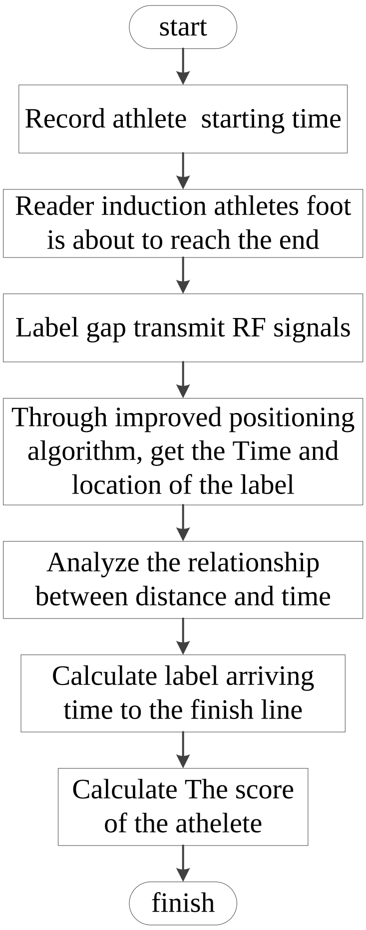

Figure 11. Process of Timing System

3.1. System Structure Design

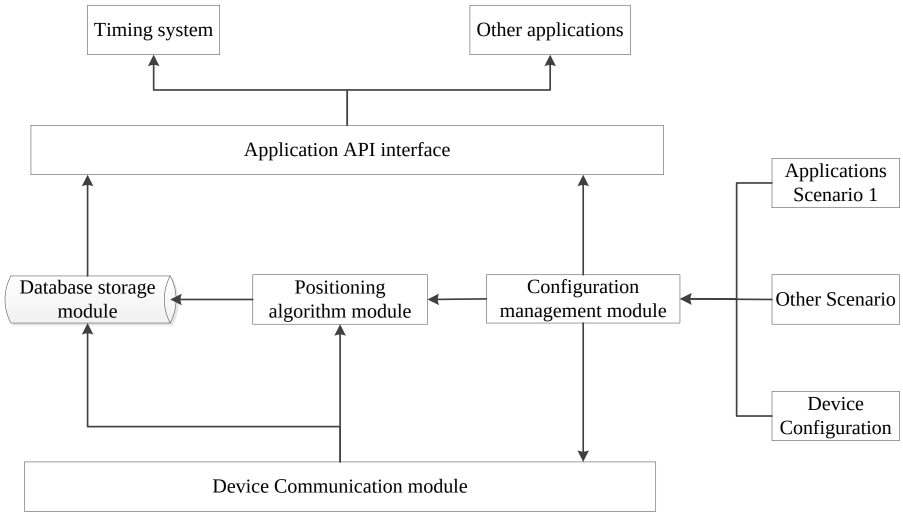

Figure 12. Structure of Timing System

As shown in Figure 12, the whole system is divided into five modules: data storage module, position algorithm module, configuration management module, and device communication module and application API interface.

Data storage module: Responsible for data storage and management of system, including the data carried by RFID chips, data generating from position and some configuration data.

Position algorithm module: It mainly locates by algorithm raised in fifth chapter, and use the appropriate scene.

Configuration management module: It mainly expands system scene and equipment, so that it can match more sense and RFID device.

Device Communication module: It is mainly responsible for communication, including wireless and wire line.

Application API interface: It mainly generates more applications produced by the position algorithm module and other modules, such as timing application.

3.2. Determine Destination Time

When players are arriving at the end and enter into the perceptive range of reader, according to the transmission frequency of active RFID label signal, the system will record many positions and time information continuously after active RFID label entering into the perceptive range of reader. Until the label leaves the perceptive range of reader, or it has got enough read and write times, and it is no longer need.

As is shown in Figure 13, it assumes that the label position of t is solid-line red point $P(x,y)$. In the following coordinate system, the distance d from label to Y axis (the finish line) is x, and the red dotted-line points are the possible position track points in graph. In the process that athletes run to the end, their every position P will correspond to a time t.

And the ports timing system only needs the time that athletes arrive at the finish line, that means the time d=0(the abscissa of P is 0).

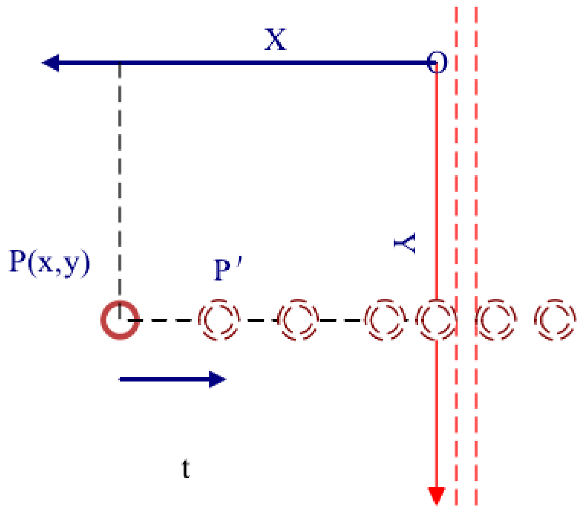

Figure 13. Athletes Positioning Graph

Analysis from above, there exists a certain function relationship between the label position P and the distance d (x) to finish line and time t. Also it maintains continuity.

Through the reader, although we can get some points on the function curve, athletes d run to the finish line is not uniform motion (it is variable deceleration process), so it is difficult to get the function equation directly. The function curve is as shown in Figure 14.

By readers, although we can collect some points, but due process, this is difficult to directly obtain explicit functional equation. Δt is the time stamp that label transmission interval (the reciprocal of transmission frequency).

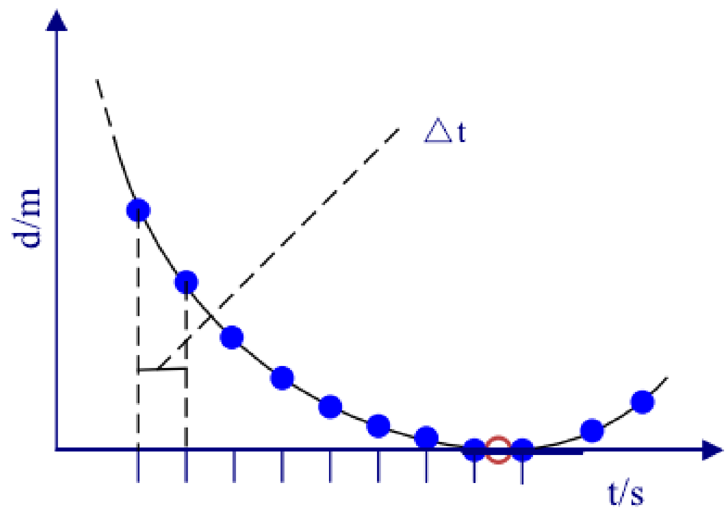

Figure 14. The Function Relationship between Distance and Time

For the certain time that d = 0, selecting 2 points which is larger than the setting threshold value but minimum. At this time there are three cases, as shown in Figure 15, (a) It indicates that the selected two position points are before the end point; (b) It happens to be that one is before and the other is after the end point; (c) The two points just pass the finish line.

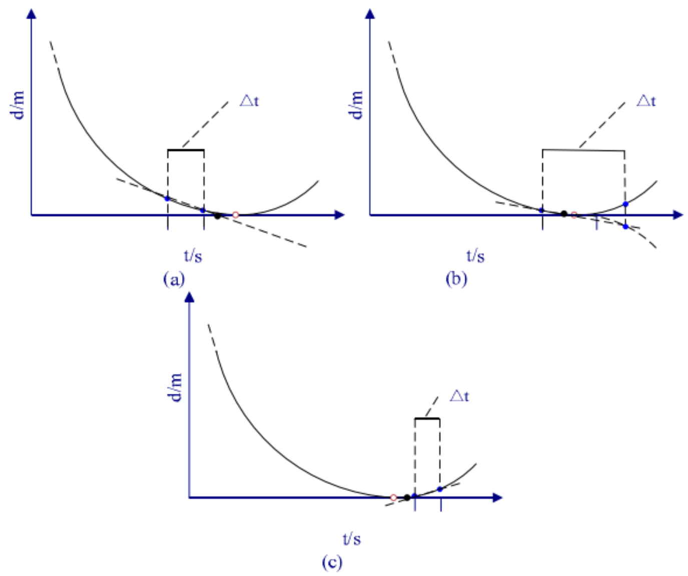

Figure 15. The Three Cases

Dealing with the three cases like this, assuming the when it close to the end, the speed of athlete is uniform, so the relationship between distance and time meets linear function. For cases a and c, form simultaneous equations directly to solve the function expression, and calculate the corresponding time of function d=0. For case b, select one point on x-axis and get its symmetry point. Then, using the symmetry point to form simultaneous equations and solve the function expression, and calculate the corresponding time of function d=0.

In order to reduce the timing error, we can bind some RFID labels on the shoes of athlete. These RFID labels do timing at the same time, and we select the average.

4. Conclusion

This paper has made a deep research on RFID positioning system. The positioning system adopts the improved VIRE positioning algorithms. It can deploy the sport competition scene without undermining the existing environment on site. Through the experiment testing, compared with VIRE algorithm, the improved algorithm has achieved better positioning effect. Through positioning algorithm, form corresponding function relationship between distance and time from the finish line. Then we can get the time that athletes arrive at finish line, so as to achieve the purpose of system timing.

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