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A Research Personnel Positioning Based on UWB for Improving Efficiency of Smart Factories

Min-Chen Yeh.,[1*] Yao-Min Fang.,[2] Tien-Yin Chou.,[2]

[1]*Ph.D. Program for Infrastructure Planning and Engineering Feng Chia University, Taichung, Taiwan (R.O.C.)*

Abstract: After the fourth industrial revolution, artificial intelligence and 5G began to enter society. Coupled with the rapid development of wireless communication technology and the Internet and the continuous development of indoor space, the demand for high precision is urgent in today's society. And a large number of indoor positioning services, such as workshop material distribution, hypermarkets, and even the more famous smart factories are all indoor spaces. The emergence of ultra-wideband (UWB, Ultra-wideband) positioning, through its unique pulse signal transmission, its bandwidth is large, it has an excellent ranging ability, and the positioning accuracy can reach centimeter level. Therefore, it is the best choice to apply it to smart factories. Finally, we will also conduct tests in different fields to find the most suitable location for installing the positioning base station and placing the positioning card, and transmit the data back to the terminal server. You can observe people's behavior at the first time, whether they are in a safe area, and make continuous coordinates appear on the map more smoothly. Appropriate values can ultimately improve the productivity and efficiency of smart factories through UWB positioning technology.

Keywords: Indoor Positioning System, Personal Management, Smart Factory, Smart Management, Triangulation, UWB

I. Introduction

With the progress of the times and the development of communication technology, positioning has always been closely related to us. Positioning technology started with the Global Positioning System (GPS), the most commonly used positioning system in daily life. Its applications include navigation, engineering construction, traffic monitoring and emergency rescue. GPS can be accurate to 50 cm to 100 cm outdoors. Because GPS needs to use satellite signals, it cannot be effectively used in indoor environments. In indoor environments, it is easy to be interfered by walls and equipment, resulting in reduced penetration and signal power attenuation. Therefore, GPS technology is not suitable for indoor positioning. In order to solve the above problems, many indoor positioning technologies have been gradually extended, for example: Wi-Fi positioning technology, Bluetooth (Bluetooth) positioning technology, ZigBee positioning technology, radio frequency identification (RFID) positioning technology, infrared ray, ultrasonic positioning technology, etc. Each technology has its own field and its advantages and disadvantages. It may have high precision but the signal transmission distance needs to be farther, or the signal coverage may be wide enough, but its construction cost is too high, and indoor positioning needs to be built. Several evaluations were performed to determine the best targeting method for the field.

According to the US EPA statistics, people spend 70% to 90% of their time indoors, so it is necessary to expand indoor services. Due to the changing indoor environment, radio signals are easily blocked. To solve the problem that indoor positioning is easily affected by the environment, the current market positioning the more sophisticated UWB indoor positioning is used as the test of this experiment. With the rise of smart factories in recent years, many traditional factories are gradually becoming smarter. There are many problems in traditional industries, such as personnel management, factory safety, and the inability to detect machine failures in the first place. Smart factories can be matched with machines to communicate with each other. Cooperate and observe whether the production capacity and efficiency have been improved by comparison before and after. In order to achieve more precise personnel management, a positioning device is added to the machine operator. The positioning device has an alarm function, which can know whether the personnel are safe at the first time. Confirm whether personnel are staying in the workplace, and deal with personnel control issues in real time through the positioning system. At present, there are still many aspects to be considered in the transformation of traditional factories into smart factories. In addition to high positioning accuracy, the positioning accuracy must be within 50 cm. In addition, the transmission rate is also very important. The factory has a large area. The advantages of UWB positioning are fast transmission rate, low power consumption and penetrating ability, which can save costs and ensure real-time data. According to this experiment as a result, we believe that UWB indoor positioning is most suitable for application in smart factories.

The emergence of UWB indoor positioning can break through the limitations and precision of other indoor positioning technologies in the past. Judging from the current market, it can meet the needs of various indoor positioning communications. This experiment combines smart factories and other fields through UWB indoor positioning, using its low power consumption and high transmission wireless personal area network communication technology with unique non-sinusoidal carrier pulse transmission data, but UWB will produce multi-path interference and non-line-of-sight effects in practical applications, which will easily cause the positioning signal to weaken, so Special attention must be paid to the construction of basic equipment and environmental planning in use. UWB indoor positioning is used to improve the safety and personnel management of the factory area, and to improve the efficiency and utilization rate of production capacity. Therefore, through a series of tests, the positioning accuracy and the location of the basic equipment to the signal are compared between multiple fields. impact and find out the rationale for how a person might wear a positioning device to find out what is appropriate for each field.

The main purpose of this study is to analyze the suitability of UWB indoor positioning combined with smart factories and other fields. The following points are provided as the main purpose of this study:

1. Discuss indoor positioning technology, collect various positioning technologies in the current field, compare the distance measurement method, accuracy, penetration, power consumption, and cost, and compare the differences of different indoor positioning technologies in various applications.
2. In the smart factory field, try to use triangulation to compare the erection position of the basic equipment, its distribution point, or how the positioning device is arranged on the personnel, so that the indoor positioning accuracy can be maximized.
3. Analyze whether the application of UWB indoor positioning in smart factories can be used with positioning devices to accurately locate the location and movement path of personnel in the factory, so as to improve the efficiency of smart factory personnel

II. Literature Review

2.1 Advantages and disadvantages of indoor positioning technology

There are many kinds of indoor positioning technologies on the market. This section discusses the standard solutions in the market by comparing the distance measurement methods, accuracy, penetration, power consumption, cost, and suitable places for installation. Different indoor positioning technologies.

2.2 Introducing UWB Indoor Positioning

UWB indoor positioning has become a fascinating field nowadays. UWB is not a new technology. In the early 19th century, radio waves were invented and spark gap radio was created. Due to the lack of large-scale implementation, UWB was forgotten in the early 19th century, leading to being used by others. It was replaced by positioning until it was re-studied by Marconi and Hertz [1] in 1930 to solve the problem of broadband antennas. With the increase of radio frequency, the wavelength became shorter, so the accuracy of implementation was also improved, and it has continued to this day.

UWB is a short-duration pulsed radio frequency communication technology [2], which has become a unique transmission technology in position-aware sensor networks. Large, with excellent ranging capability in specific situations, UWB technology is usually used in communication, radar and ranging applications. The positioning can be accurate to within 20-30 cm, and the power consumption is relatively low. Unlike the continuous carrier method used in common communications, UWB indoor positioning uses two-way time-of-flight (TW-TOF, two way-time of flight)[3], mainly using the time of flight between two different transceivers (Transceiver) to measure the distance between nodes, the transceiver is mainly composed of a sensor and a receiver device, each module (Module) starts from the beginning Each time, an independent time point will be generated.

2.3 Indoor Positioning Design and Considerations

The following introduces the indoor positioning consideration design and factors:

(1). Cost considerations. To build an indoor positioning system, you first need to purchase indoor positioning hardware equipment, deploy some anchor points, and develop suitable software for this field, all of which require detailed evaluation.

(2). The number of base stations and the layout of basic equipment are different from traditional GPS positioning. GPS uses outdoor positioning and is equipped with 31 active satellites as its base station.

The indoor positioning environment is different, and there will be space constraints that will lead to the location and location of the base station. The number is limited. From the existing space, find ocould you ut the site exclusively for the field to build the base station.

(3). The complexity of the indoor environment and the distance measurement signal will be significantly affected by the indoor angle. It may be because there are many electrical equipment in the room that easily interfere with the accuracy, such as walls, electrical products and other obstacles, resulting in backhaul The route to the platform is different from the actual situation [4].

At present, the positioning system in the indoor environment faces different challenges from the outdoor positioning system. Although the size of the indoor environment is limited to rooms and buildings, the indoor environment contains multiple walls and obstacles composed of various materials. From the perspective of indoor positioning system, theyet to be is no complete solution. Each indoor positioning system has its own shortcomings, such as: low precision, complex infrastructure, limited coverage or high cost, etc. The most important reason is, At present, the technology used in indoor positioning is difficult to provide a wave band that can penetrate building materials, and these impenetrable building materials will interfere with indoor signals and affect the longitude of positioning. I hope this problem can be overcome and solved in the future. [5].

2.4 Triangulation

Triangulation is the most commonly used positioning technique. It uses triangular geometry to estimate the position of an object. The role of the target object requires at least one side length and two reference points. Wherein, the intersection of these distances is the position, and the signal strength measurement is used. And calculate the user's approximate location probability, and find out the most likely location from it [6].

Triangulation is a well-studied method, which first selects three non-collinear points on a plane, and centers a circle point on the measurement target point, and transmits signals between access points, when an intersection occurs When, there will be three or more access points within the measurement range, and finally the final position is estimated and sent back to the terminal. In triangulation, in order to observe the vertex of the triangle, the three adjacent points must look at each other, otherwise the signal strength measurement will be affected by the interference of obstacles.

Among them, the triangulation method uses the time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AOA) and signal strength (RSSI) to estimate the distance between the mobile terminal and the base station. In the TOA system, Direct Sequence Spread Spectrum (DSSS, Direct Sequence Spread Spectrum) measurement [7] is used. DSSS can spread random codes, also known as chips (Chips), and transmit them to a wide frequency band, which will have the same The pseudo-random code of the original state, in addition to DSSS will also use ultra-wideband measurement, the base station sends a signal to the mobile terminal, so that it can be used to calculate the distance. In the TDOA system, the mobile device proposed for Wi-Fi sends positioning signals to the surroundings and evaluates the time difference of arrival of the received signals. The main advantage of the TODA system is that only the measurement units (base stations) need to be synchronized. This synchronization is usually through the backbone network (Backbone Network) [8], the backbone network is the core of the Internet and is composed of several large networks. Usually, the well-designed capacity is much larger than that of the general network, and the problem of network transmission data delay can be ignored, so it can realize mutual communication between cities. data transmission.

The measurement method in the AOA system is to use the antenna or antenna array (antenna array) [9] to measure the angle of the input signal sent by the mobile phone. In the RSSI system, the characteristics of radio propagation are used to calculate the distance between base stations, so as to obtain the position of the item. Although RSSI is the basic method of ranging, RSSI is easily affected by the environment, so more attention should be paid to its use [10].

III. Introduction to the Method

This research focuses on whether UWB indoor positioning can improve the accuracy of personnel positioning to improve the efficiency of smart factories. At present, a number of tests will be carried out in the demonstration field, including testing various placement methods, including the location of the base station and the height of the positioning card. , map settings, environmental parameters, warning message return, and the impact of electromagnetic waves on accuracy, and whether the setting of the imported filter can improve the accuracy of indoor positioning. After repeated tests, the indoor positioning that is most suitable for the field is found. The research structure is mainly divided into the following parts:

(1) Select the environment where UWB indoor positioning needs to be set up.

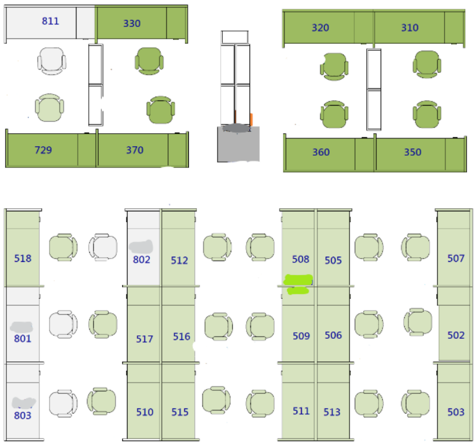

Figure 1.Demonstration field plan (field area 1227 cm x 1101 cm).

(2) Use a distance meter to measure the size of the demonstration site and convert the drawn picture into a vector map through the Algolab photo vector.

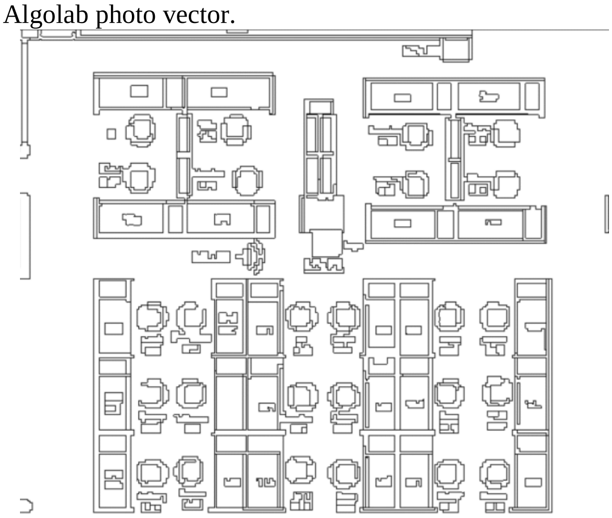

Figure 2. Convert to vector image through Algolab photo vector.

(3) Plan the erection of hardware equipment and find the most suitable location. (Try to keep the same height when the base station is installed so as not to affect the positioning accuracy)

Figure 3.Planning hardware installation.

(4) After the hardware is set up, open the UWB positioning software through Microsoft Visual Studio 2019, arrange the base station on the map, and adjust the height of the positioning card, map settings, environmental parameters, warning message return, and filter according to the requirements of the site environment set up.

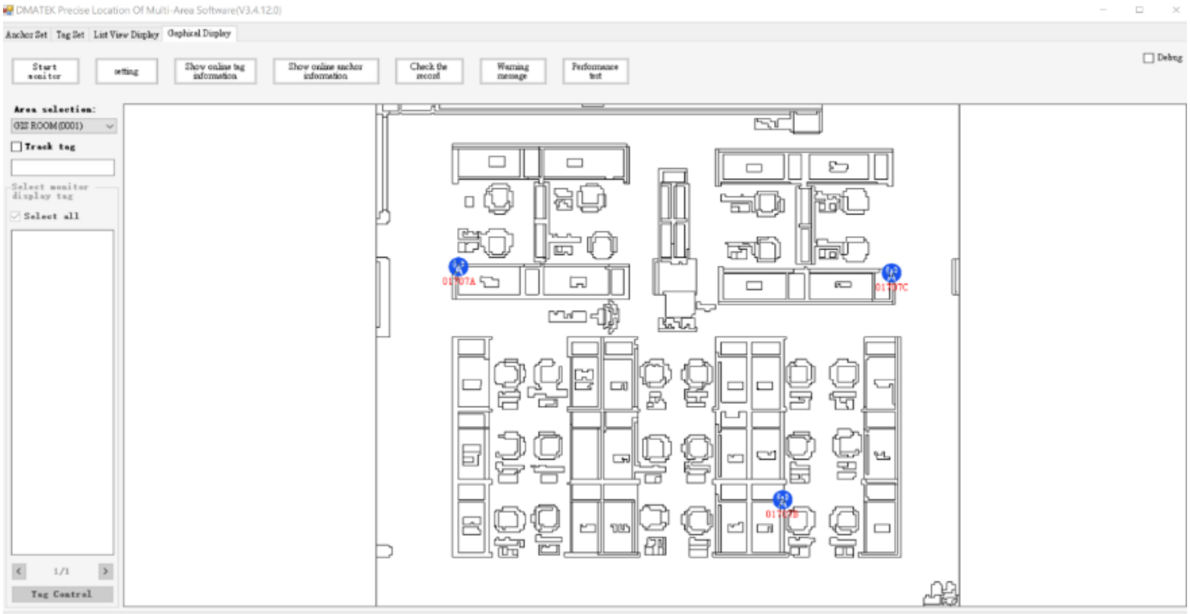

Figure 4. Microsoft Visual Studio 2019 opens UWB indoor positioning software.

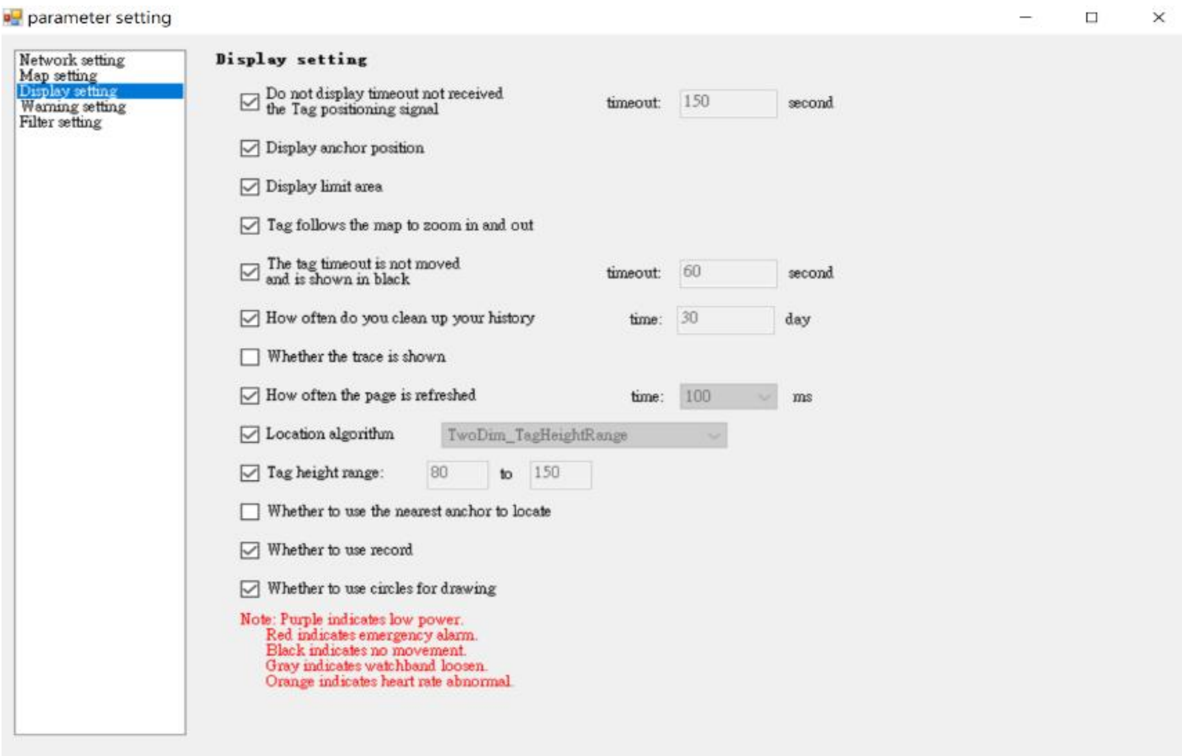

Figure 5. Set location card and data return time.

(5) After completing the above steps, you can start indoor positioning and receive data.

Figure 6. Schematic diagram of indoor positioning feet (a).

3.1 Experiment Equipment

The following will introduce UWB indoor positioning and the equipment used in smart factories to discuss, including function introduction and related specifications.

3.1.1 UWB Dongle

Function and introduction:

(1). UWB wireless two-way high-frequency communication is adopted.
(2). Its USB expansion feature can be connected to PCs and Android phones for use.
(3). Assist positioning software to adjust card parameters and set base station parameters.
(4). Assist in shutdown mode operation.
(5). Assist the device to update the firmware during operation.

Table 1 UWB Dongle Specifications and Parameters

Specifications	
Communication Specifications and Frequency Bands	802.15.4a UWB / 3.25(GHz)-6.75(GHz)
Transmission Distance	The maximum transmission distance is about 50 meters (20 meters is recommended as the optimal transmission distance)
Size and Weight	1. Length 68×W25×H12.0(mm) 2.172g
Function	Contains FT32 chip, can be used on PC and Android system
Power Supply	Standard USB DC +5V
Newsletter Introduction	USB TO RS232
Product Code	UWB-USB-01

3.1.2 Indoor Positioning Card

Function and introduction:

a. Alarm button: When an emergency occurs, it can send a message back to the platform.
b. Setting button: Turn off the power switch, press the setting button, and then turn on the power; the card will enter the setting mode. At this time, the blue light of LED2 means entering the setting mode, and the setting button can be released.
c. LED1 indicator lights: power indicator, power on, signal sending and setting mode indicators.
d. LED2 indicator light: charging indicator light (red for charging, green for fully charged), software control light (displayed according to software settings).

e. Micro USB charging port: used for card charging and firmware compilation.
f. Power switch: Turn on the power and turn off the power.

Table 2 Indoor positioning card specification parameter

Specifications	
Communication Specifications and Frequency Bands	802.15.4a UWB / 3.25(GHz)~6.75(GHz)
Transmission Distance	The maximum transmission distance is about 50 meters (20 meters is recommended as the best transmission distance)
LED light indicator	LED light display: alarm and location, the standard configuration is red, and there are three optional colors (yellow, green, blue)
Button function and charging voltage	1. Planning as a power switch 2. Charging voltage: DC 12 volts (7~28 volts input can be used)
Battery capacity and service life	1. Lithium battery 1000mAh 2. On average, it can be used for more than 240 days
Function	Built-in accelerometer and buzzer function, can automatically sleep and shake to wake up
Applications	Indoor object positioning and positioning alarm
Product Code	UTAG-7045
Size and Weight	1. Length 70×W70×H45(mm) 2. 225g (including wire and bracket)

3.1.3 Industrial Positioning Base Station

Function and introduction:

(1) The positioning software can control the warning functions of the positioning card light, vibration, and sound through the positioning base station.
(2) Regularly return the signal of its own equipment to let the positioning software know whether the positioning base station is still operating normally.
(3) When setting the software, the parameters of the positioning card can be updated in batches through the remote positioning of the positioning base station.
(4) Updating the software can remotely update the firmware version of the device by locating the base station.

Table 3 Indoor positioning card specification parameter

Specifications	
Communication Specifications and Frequency Bands	(1) 802.15.4a UWB (2) 3.25GHz~6.75(GHz)
Transmission Distance	The maximum transmission distance is about 100 meters (recommended 30~50 meters is the best transmission distance)
Positioning Mode	TOF mode (time of arrival)
Antenna Placement Angle	The recommended placement angle is 360 degrees, and the antenna must face up, so as not to affect the signal interference and cause problems
Installation Method	Wall-mounted or on the same level, and there must be no interfering devices nearby
Size	L147×W86×H4 mm
Product Code	UWB-02

3.2 Indoor Positioning Accuracy Test

This time, Figure 9 was selected for the UWB indoor positioning accuracy test, and the difference between the actual measurement error value was compared. In this experiment, a relatively open site was selected for testing. Devices with different wavelengths in the space are likely to affect the base station’s signal transmission. After measuring the site through the measurement instrument, the base station was installed at the same height with the triangulation method, and the positioning card was placed Set it to be sent back to the platform every second, and you can receive the location information in time. After repeated tests, you can find that the positioning error is about 20-45 cm. This is the result that all indoor positioning on the market cannot do. At present, most of the precision on the market is 100 cm to 300 cm.

Judging from the results of this experiment, UWB is very suitable for indoor positioning in smart factories or places with large venues. Table 4 shows the results of this measurement. It can be found that the first and second tests are very close to the actual distance. When applied to large factories, it is possible to control the safety of personnel more accurately and whether there are people in the workplace. On the domain, in order to improve the management of personnel and the control of production capacity, the signal of the base station can also be displayed on the map through the adjustment tool (debug). Figure 10,11 shows the signal on the map. When people pass through the base station, the base station will generate a red circle to represent their current position, and a green circle will be generated when you leave this point. With these functions, it is more convenient to view the current location. However, some shortcomings were found in the experiment. If the base station is not set at the same level as the horizontal plane, the data sent back when walking is likely to be affected. Therefore, when setting up, pay attention and the antenna must also face upwards, so as to achieve more precise positioning.

Table 4 Indoor Positioning Accuracy Test

Indoor Positioning Accuracy Test				
Actual Value	Test	point C to point B	point B to point A	point A to point C
A: 540 CM B: 403CM C: 0 CM	First Time	A: 425 CM B: 0 CM C: 402 CM	A: 4 CM B: 403 CM C: 550 CM	A: 575 CM B: 450 CM C: 0 CM
	Second Time	A: 422 CM B: 0 CM C: 393 CM	A: 0 CM B: 409 CM C: 567 CM	A: 581 CM B: 406 CM C: 0 CM

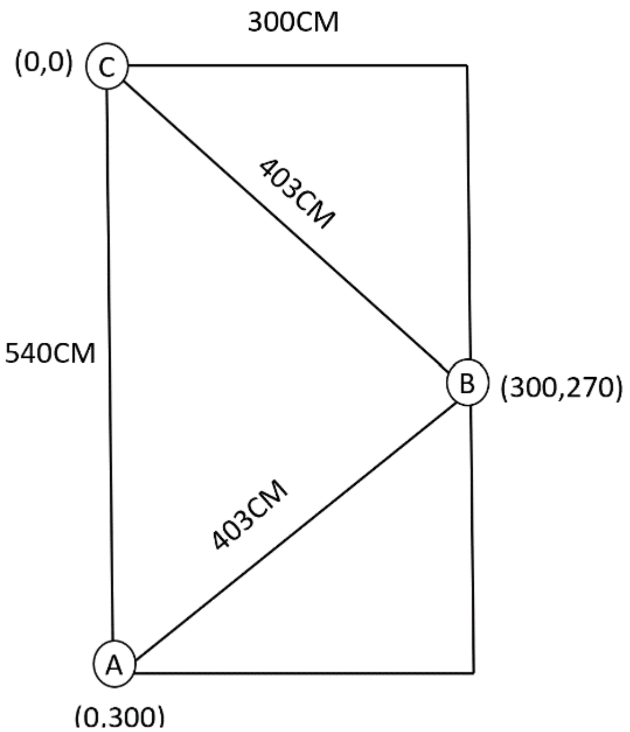

Figure 7. Schematic diagram of indoor positioning accuracy test site.

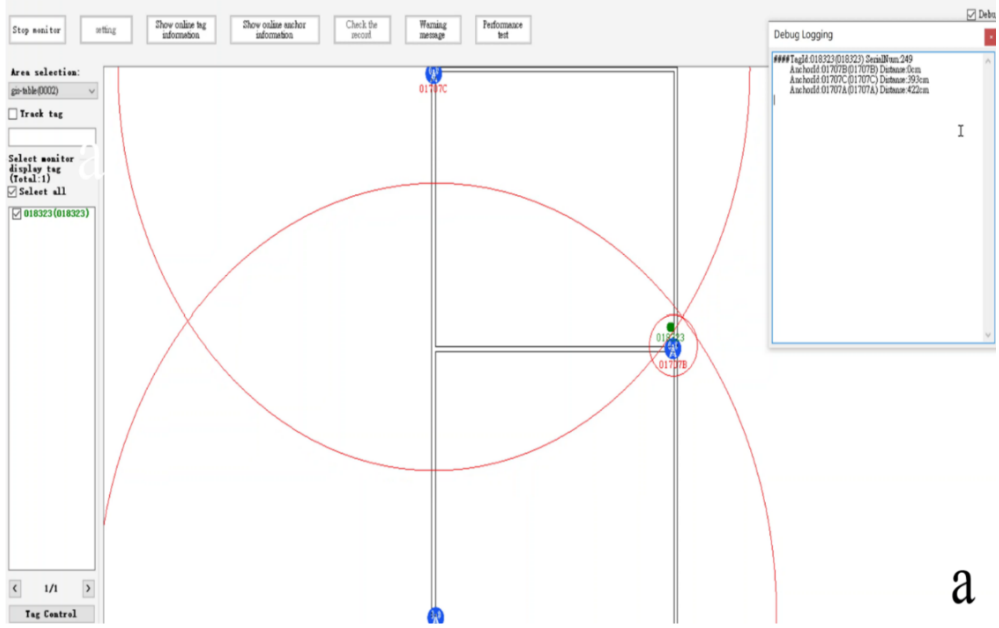

Figure 8. Indoor positioning accuracy test chart (a).

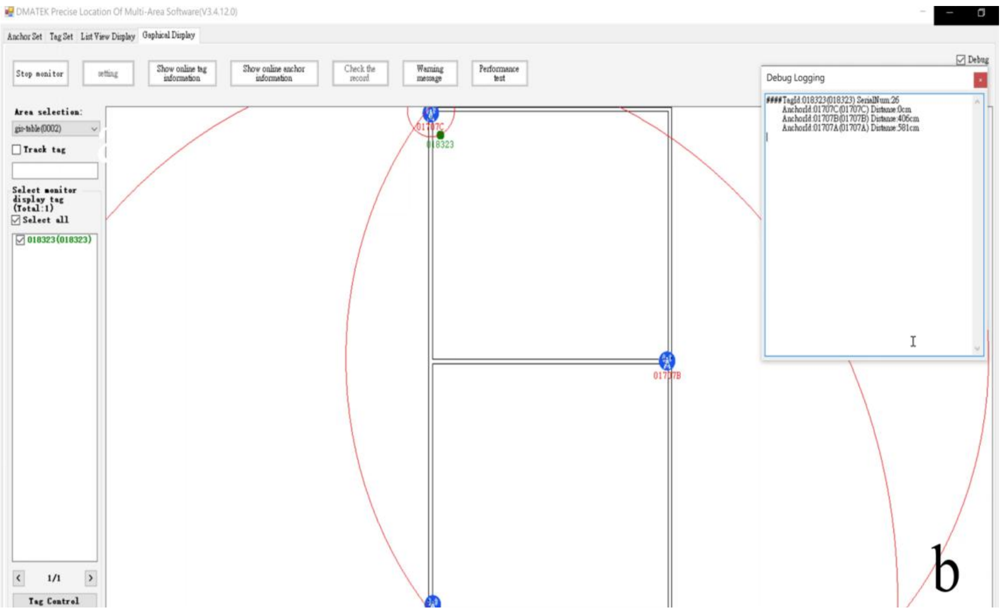

Figure 9.Indoor positioning accuracy test chart (b).

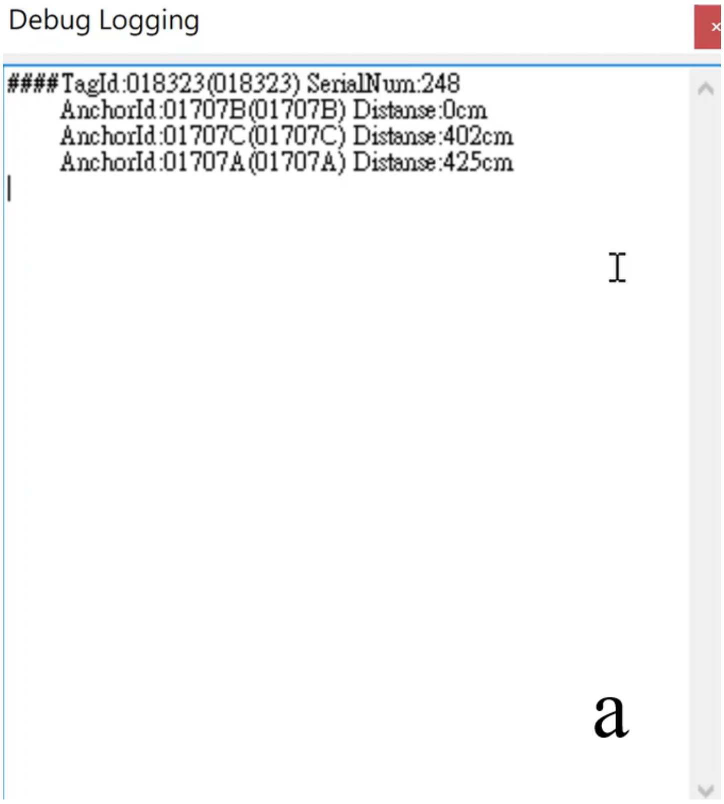

Figure 10.Accuracy test point C to point B (a) the first test.

IV. Results and Discussion

4.1. Personnel positioning card placement

This section mainly discusses whether, after the base station is erected, whether the location of the positioning card will affect its accuracy. The main test is to place it in the hand, pocket and hang it on the body. Use a variety of methods to find the targeting mode that works best for the field. (The measurement results are divided into line shape and footsteps.)

4.1.1 Isosceles triangle (placed in pocket)

It can be seen from Figure 18 that the base station is arranged in an isosceles triangle, and the positioning card is placed in the pocket to move from 01707A to 01707C. From the figure, it can be seen that the error is tiny. Still, because the environment under this experiment is a general office area, there are many electrical equipment, so there are some errors. The reason why the isosceles triangle is used as the positioning is because it can be seen from Figure 18 that in the triangular positioning[11], it can be seen that there are three base stations A, B, and C without intersection, and An unknown terminal D, assuming that the three base stations arrive at the terminal as R1, R2, and R3, and the coordinates of the three base stations are used as the center of the circle, the distance radius from the three base stations to the terminal can draw a circle with three points intersecting at one point at the same time, so the reception The signal is strong, and because the base station and the positioning card are set at the same height, it will not move up and down when placed in the pocket, causing signal interference.

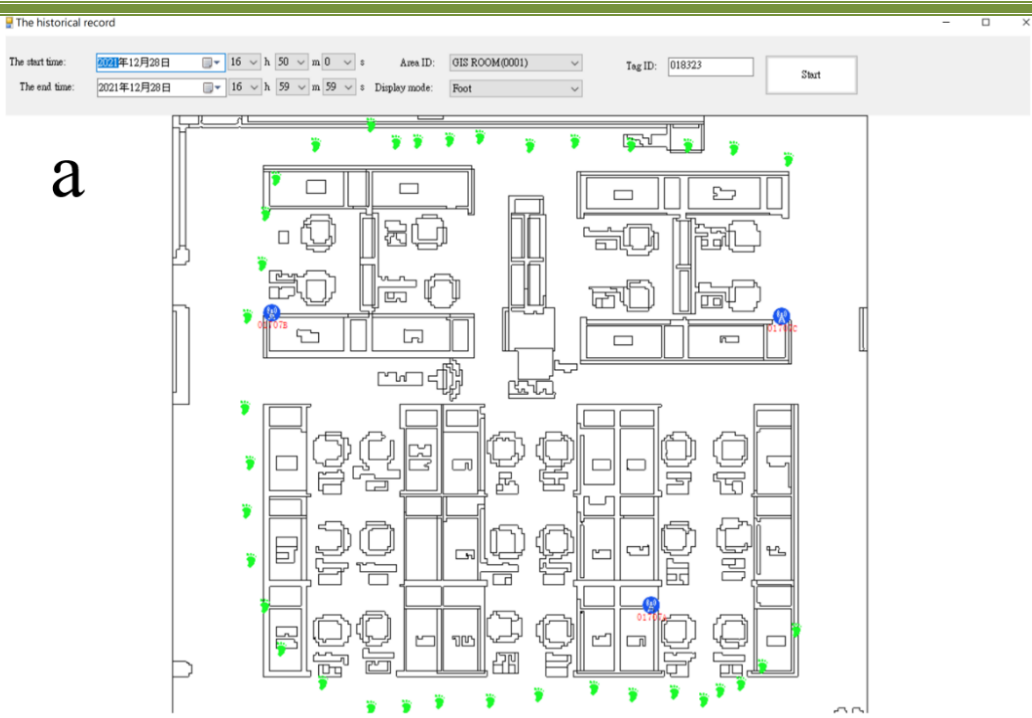

Figure 11.Isosceles triangle placed in a pocket (a) footstep.

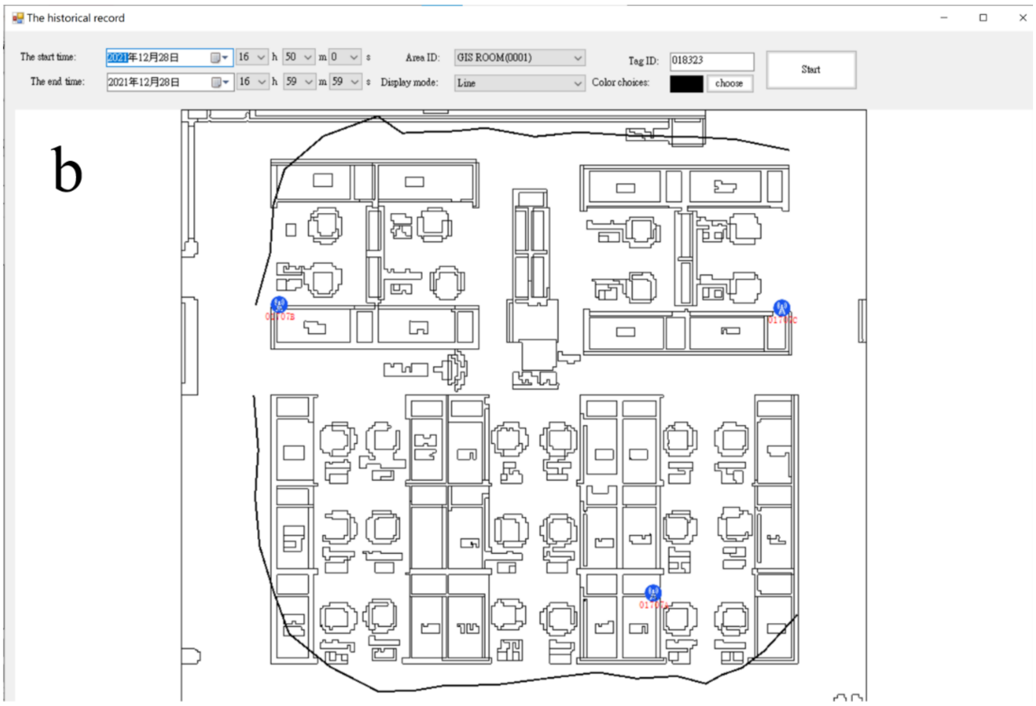

Figure 12.The isosceles triangles are placed in the row of pockets (b)line.

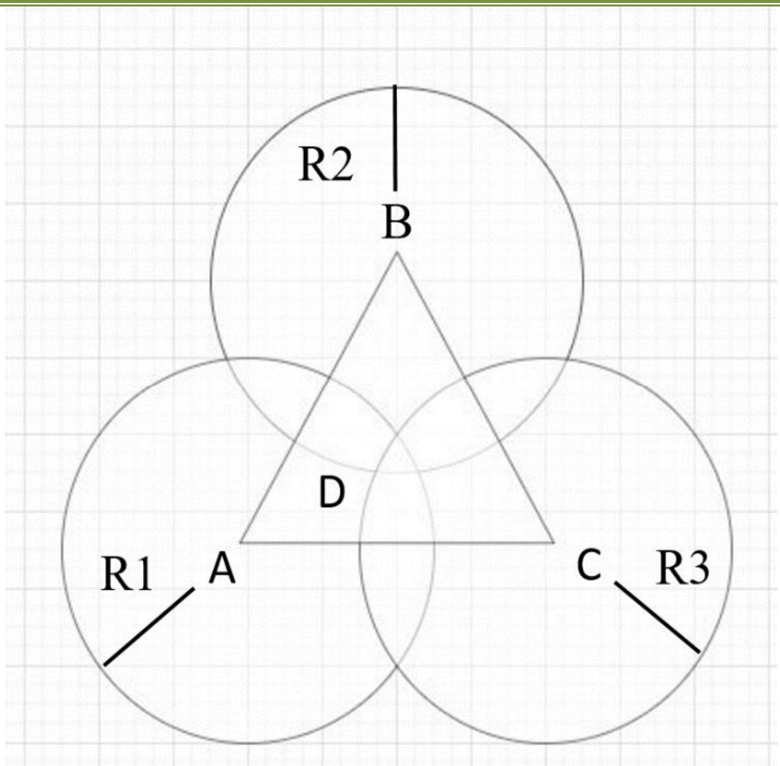

Figure 13. Triangulation Location.

4.1.2 Isosceles triangle (hanging on the chest)

Fig. 14 is also the manner in which the base stations are arranged in an isosceles triangle. It works and fits the same way it would fit in your pocket, and it will not cause mutual interference between the base station and the positioning card.

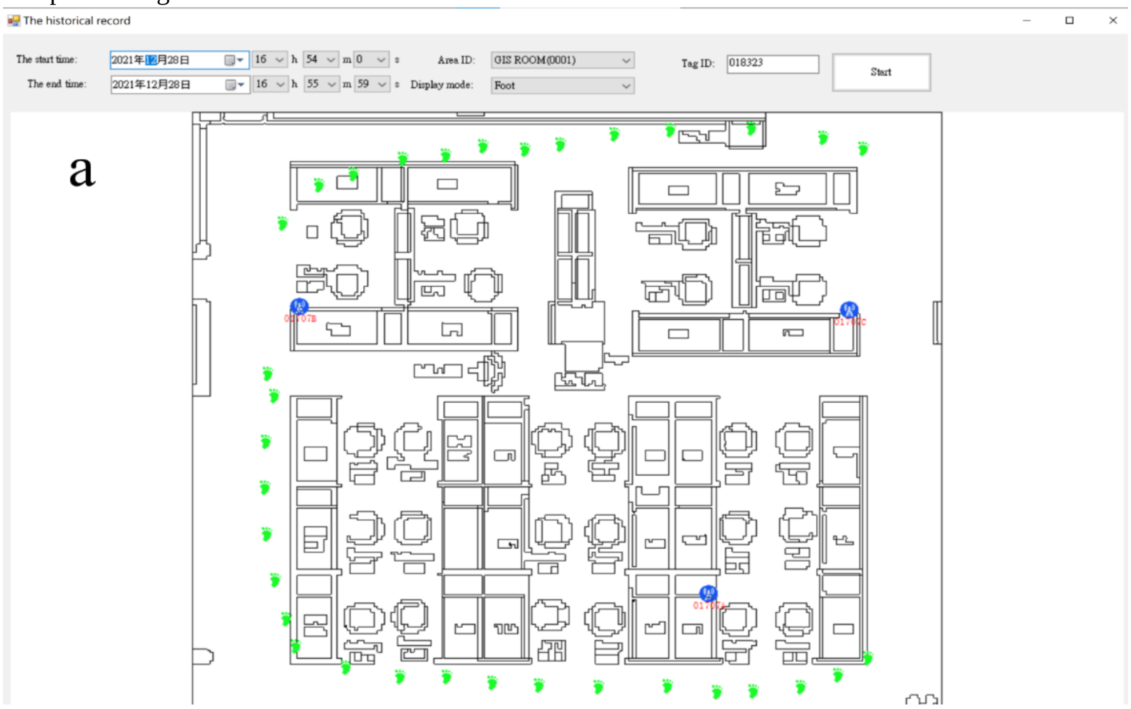

Figure 14. Isosceles triangle hanging on the chest (a) Footsteps.

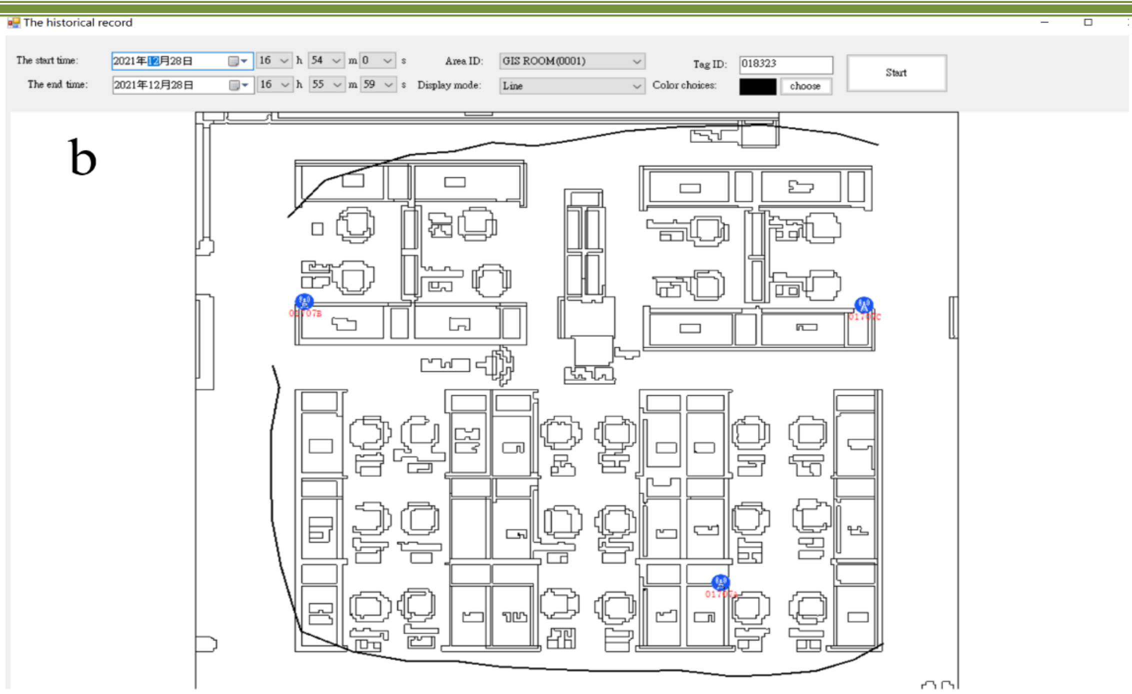

Figure 15. Isosceles triangle hanging on the chest (b) line.

4.1.3 Isosceles triangle (placed in hand)

The base station in Figure 16 is also arranged in an isosceles triangle. The only change is that the positioning card is placed in the hand. As can be seen from the figure, just putting the positioning card in different places will lead to a very large positioning accuracy error, because The human body has the problem of penetration loss. When you hold it in your hand, the entire positioning card is covered, which makes the signal return time longer. The longer the return time, the positioning card will mistakenly think that it is farther away from the base station, resulting in precision The degree is offset, so errors are prone to occur.

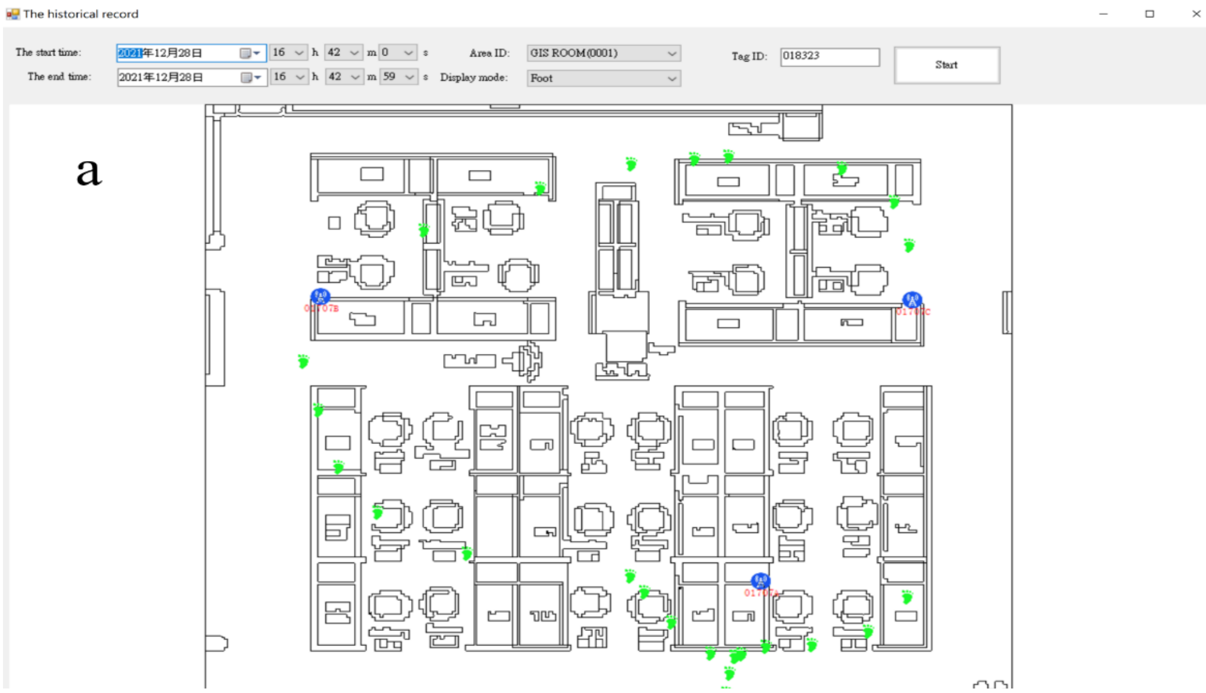

Figure 16. Isosceles triangle placed in hand (a) Footsteps.

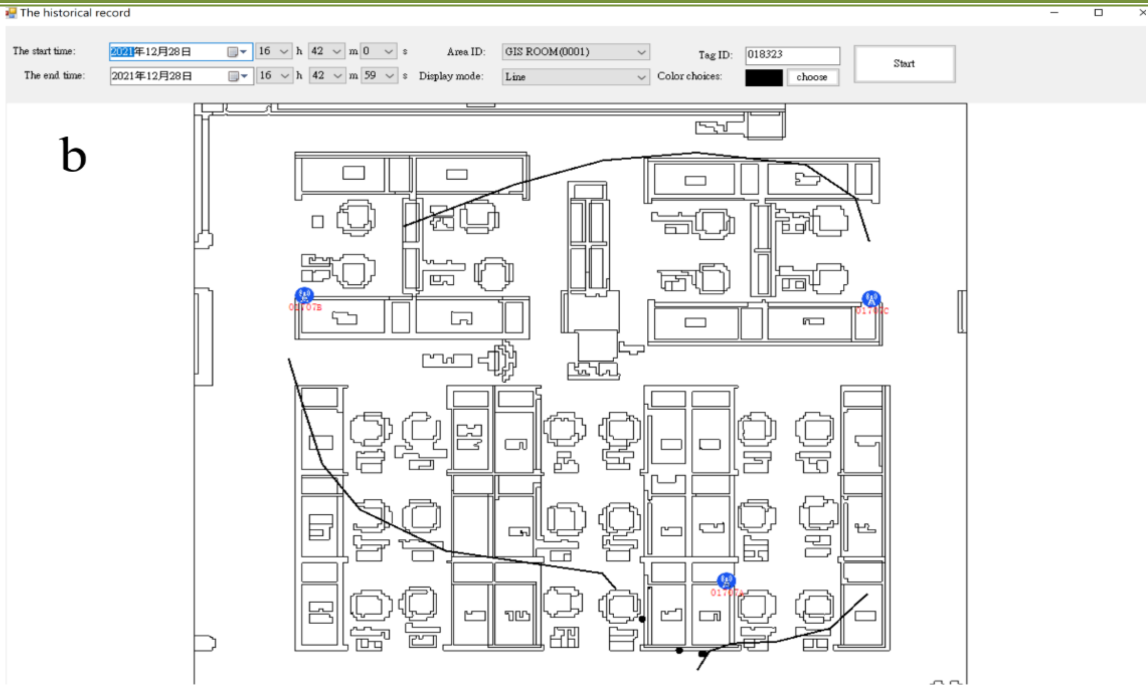

Figure 17. Isosceles triangle placed in hand (a) line.

4.1.4 Straight line (placed on chest, pocket, hands)

Figure 18 shows that the base station is arranged in a straight line, and the positioning card is placed on the chest and pocket. From 01707C to 01707B, the result is not as expected. From Figure 20, there are three lines on the line. Base stations A, B, and C without intersection, and an unknown terminal D, assuming that the arrival terminals of the three base stations are R1, R2, and R3, and using the coordinates of the three base stations as the center of the circle, it can be found that it is different from triangular positioning. Triangular positioning is at When the radius of the distance from the three base stations to the terminal can draw a circle with three points intersecting at one point at the same time, but on a straight line, no matter how they are arranged, they will never intersect. Therefore, through this test, it can be found that the base stations are arranged in a straight line and applied in It cannot be positioned indoors.

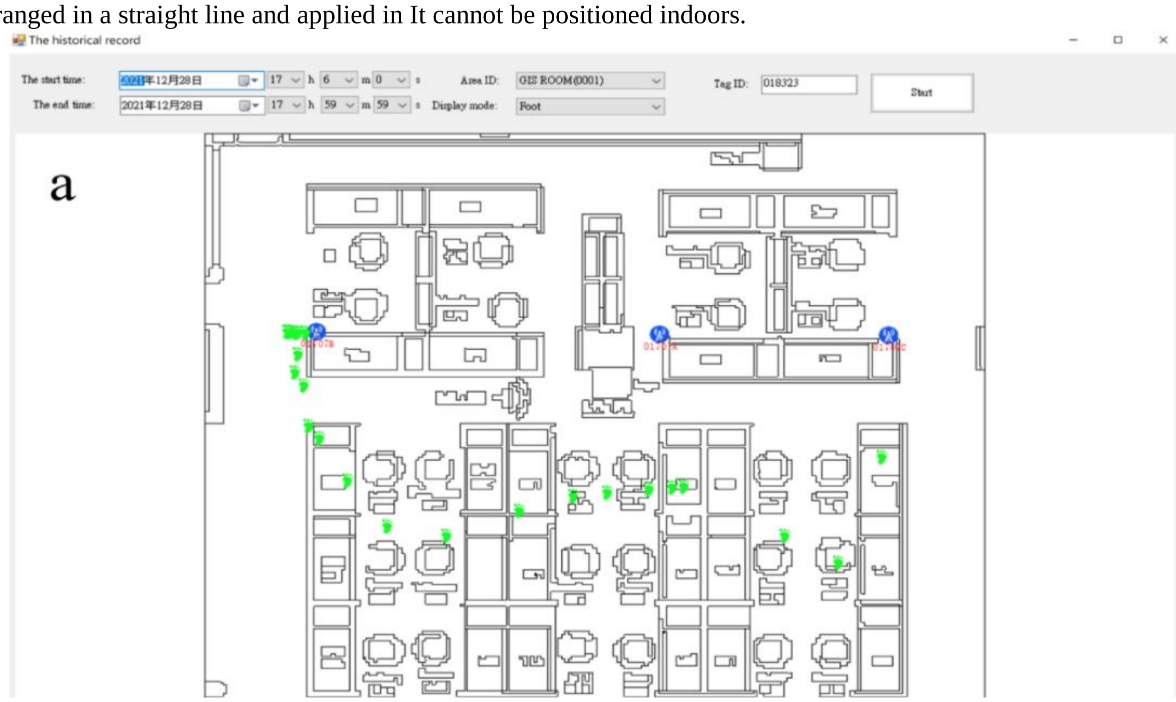

Figure 18. put on chest, pocket (a) Footsteps.

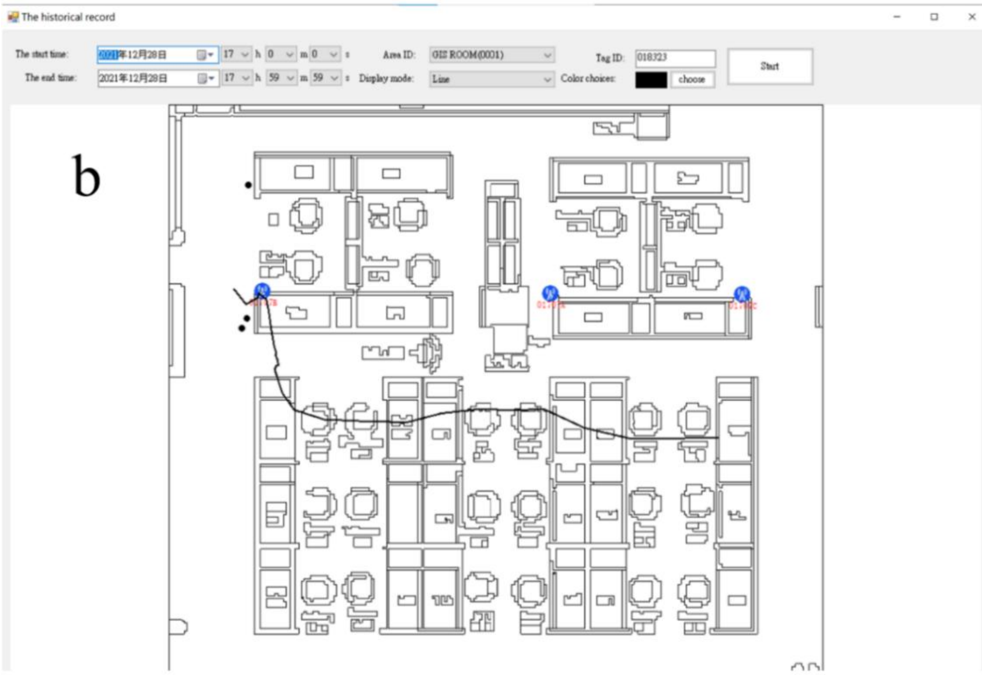

Figure 19.put on chest, pocket (b) line.

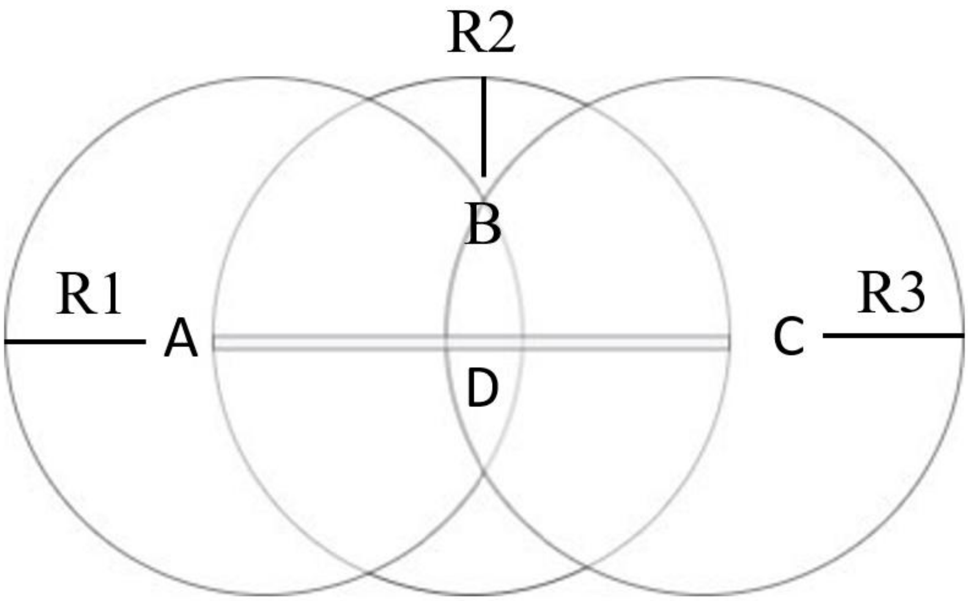

Figure20. Schematic diagram of linear positioning.

V. Conclusions and Recommendations

5.1 Conclusion

This study focuses on UWB indoor positioning to improve the work efficiency of smart factory personnel. It compares the differences of various indoor positioning technologies by comparing ranging methods, accuracy, penetration, power consumption, cost, and suitable installation fields. , and finally aiming at its personnel positioning effect applied in the smart factory, combined with the indoor positioning device, the positioning device can accurately return the personnel position and send an emergency message through the positioning device.Here are some conclusions:

1. In the early stage, the office was used as a demonstration site for UWB indoor positioning, the location of the hardware equipment was selected through triangulation, and the environmental parameters were set to find the most suitable positioning mode for this site as a template.

2. In the later stage, the device will be transferred to the traditional transformation of the smart factory as a research field. Through the experience of setting up in the office in the early stage, plus a series of research on the smart factory field, it is concluded that the triangulation method is not suitable for erecting hardware devices. All fields should carefully evaluate whether the real field environment and environmental equipment interfere with the positioning device, and finally the effectiveness of UWB indoor positioning can be fully utilized.
3. In addition to setting up the location of the hardware equipment, this article also studies how to configure the indoor positioning device on the person. After research, it is found that it is placed in various positions, and it is found that it is easy to cause interference when placed in the hand, because the signal penetration of the human body is relatively weak. Low and hanging on the chest, it is easy to cause danger between the machine and personnel. Therefore, torments, showt placing it in the pocket is most suitable for smart factories. Its accuracy is stable, compared to placing it in the hand. , it will not cause signal interference and will not cause danger between personnel and machines like hanging on the chest. After a series of tests, the final decision of the smart factory research is obtained.

5.2 Recommendations

After the above research, it is concluded that UWB indoor positioning is more suitable for use in smart factories than other joint indoor positioning on the market. However, UWB indoor positioning in the actual field will easily cause interference with the positioning device due to the environment and equipment, which will affect its Accuracy, so in the future, it can be combined with other systems to assist positioning. For example, image recognition can be combined with UWB indoor positioning to further improve accuracy. Cameras can also be used to observe blind spots in the field, and 5G networks can also be used. Send personnel location data to the platform more quickly. By connecting the report of factory capacity and combining machine networking data, by combining the above data with personnel location data, it is possible to analyze the time of personnel staying in front of the machine and the time of personnel in the smart factory. Whether there is a corresponding efficiency between the moving path and the production capacity of individual personnel, so that managers can more effectively manage the configuration on the smart factory.

References

[1]. Hans G. Schantz Three Centuries of UWB Antenna Development. 2012 IEEE International Conference on Ultra-Wideband, pp. 506-511, 2012

[2]. Yi-Min Lu, Jang-Ping Sheu, Yung-Ching Kuo. Deep Learning for Ultra-Wideband Indoor Positioning., 2021 IEEE 32nd Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), pp. 1260-1265, 2021

[3]. Haohao Yin, Weiwei Xia, Yueyue Zhang, Lianfeng Shen. UWB-based indoor high precision localization system with robust unscented Kalman filter., 2016 IEEE International Conference on Communication Systems (ICCS), pp. 1-6, 2016

[4]. Chouchang Yang, Huai-Rong Shao. Wi-Fi-Based Indoor Positioning., IEEE Communications Magazine, vol. 53, no. 3, pp. 150-157, 2015

[5]. Rainer Mautz. Overview of current indoor positioning systems., pp.18-22, 2012

[6]. EmreTeoman, Tolga Ovatman. Trilateration in Indoor Positioning with an Uncertain Reference Point., 2019 IEEE 16th International Conference on Networking, Sensing and Control (ICNSC), pp. 397-402, 2019

[7]. Da Gang XIE, Nan WU, Chun Wang, Qi Feng Liu. Performance analysis and simulation of DSSS in tactical data link communication system., 2012 6th Asia-Pacific Conference on Environmental Electromagnetics (CEEM), pp. 194-197, 2012

[8]. A. Markopoulou, G. Iannaccone, S. Bhattacharyya, C. Chuah, Y. Ganjali and C. Diot. Characterization of Failures in an Operational IP Backbone Network., in IEEE/ACM Transactions on Networking, vol. 16, no. 4, pp. 749-762, 2008

[9]. R. J. Mailloux. Antenna array architecture., in Proceedings of the IEEE, vol. 80, no. 1, pp. 163-172, 1992

[10]. Y. Wang, Xu Yang, Yutian Zhao, Yue Liu. Bluetooth positioning using RSSI and triangulation methods and L. Cuthbert., 2013 IEEE 10th Consumer Communications and Networking Conference (CCNC), pp. 837-842, 2013

[11]. E. Teoman and T. Ovatman, Trilateration in Indoor Positioning with an Uncertain Reference Point., 2019 IEEE 16th International Conference on Networking, Sensing and Control (ICNSC), pp. 397-402, 2019