Design of intelligent supervision system for metrology center based on UWB technology

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Abstract. With the comprehensive construction of the provincial metrology center, further digital management requirements are put forward for the daily operation and maintenance inspection work of the automated verification/testing area, the warehouse storage area, the material supporting turnover area and the temporary storage area, and the professional laboratory area. The article explains the UWB (ultra-wide band) technology and its principles and applies it to the smart supervision of the production area. It has developed functions such as basic information management, job attendance, positioning analysis, electronic fence, behavior monitoring, intelligent inspection and data analysis. The digital supervision plan has been verified in the actual production environment.

1. Introduction
Provincial metrology centers have been officially put into production and operation. The automated verification area, the warehouse storage area, the material supporting turnover area and the temporary storage area, and the professional laboratory area are the important work sites of the metrology center. Its daily management, maintenance, heavy inspection workload, frequent operation of automated and semi-automated transportation equipment, frequent foreign personnel and transportation vehicles, and high requirements for management of goods stacking and packaging collection. The above operating characteristics put forward higher management and coordination requirements for the relevant management departments of the metrology center. At present, the department mainly strengthens daily inspections and inspections to improve the operation capacity of the verification area, the reservoir area, the front area of the reservoir, the test area and other places, and prevent the risk of production operations. [1, 2]

Traditional daily inspections mainly have the following disadvantages:
(1) The traditional simple visual inspection is too crude.
(2) It is difficult to supervise and quantify the inspection status and execution quality.
(3) Lack of targeted inspections.
(4) Lack of dynamic supervision plan for key areas and equipment.
(5) Lack image description and real-time feedback.
(6) Inspection results cannot achieve information accumulation and retrospection.
(7) Lack of effective information analysis and data application.

In addition, the material conveying connection area between the automated verification assembly line and the warehouse on each floor has frequent turnover box jams, turnover box reversal,
misplacement of measuring instruments in the box, and foreign objects in the box, which affect the automation operation.

All of the above phenomena occurred for a period of time and the impact was severe, and they were manually inspected and reported to designated personnel to solve the problem on site, resulting in a lot of waste of production capacity. Therefore, it is urgent to realize early warning of abnormal operations in the material conveying connection area between warehouses based on video monitoring technology, and manual intervention in advance to avoid waste of production capacity and risks of automated operations. In response to the above typical problems, this paper proposes a smart supervision technology solution for the automated production area of the metrology center based on UWB(Ultra-Wide-Band) technology [3, 4] to realize smart supervision of the production area operation, further improve the daily operation efficiency and management level, ensure the production safety of the metrology center, and realize the four-line one of the entire centers.

2. UWB technology principle
UWB is a new type of wireless communication technology. UWB signal generation can be realized by modulating to the UWB working frequency band by up-conversion methods such as differentiation or mixing with narrow pulses (such as secondary Gaussian pulses) with very short transmission time (such as 2ns).

The advantages of UWB such as: low power consumption, insensitive to channel fading (such as multipath, non-line-of-sight channels), strong anti-interference ability, no interference to other devices in the same environment, and strong penetration, with high positioning accuracy and positioning accuracy.

The positioning technology used in this article is the fusion technology of ToF (Time-of-flight) and TDoA (Time Difference of Arrival) [5], which can realize demand applications in different dimensions according to the requirements of different scenarios.

2.1. Time-of-flight ranging method
ToF ranging method is to measure the time from departure to return of the pulse signal, multiply it by the propagation speed (the propagation speed of the pulse signal in the air is a fixed value v=300,000 KM/sec) to get the distance of one round trip, half is the distance between the UWB positioning tag and the positioning base station.

The coordinates of the UWB positioning base station are known. After the distance between the tag and the base station is measured, 3 circles are drawn by the three-point positioning method, and the intersection is the location of the UWB positioning tag.

As shown in the Figure 1, the coordinates of the UWB positioning base station are \( R_1(x_1, y_1) \), \( R_2(x_2, y_2) \), and \( R_3(x_3, y_3) \). The positions of the base stations \( R_1, R_2, \) and \( R_3 \) are fixed and the coordinates are known during installation and deployment. The coordinates of the required positioning label are \( R_0 \).
Suppose $d_1$, $d_2$, and $d_3$ are the relative distances calculated by the propagation time of the signal between the 3 positioning base stations and the positioning tag $R_0$, and each base station draws a circular trajectory with the relative distance as the radius. The unique intersection point can be calculated using three circular equations. The calculation formula is shown in Formula (1):

$$
\begin{align*}
\sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2} &= vt_1 \\
\sqrt{(x_0 - x_2)^2 + (y_0 - y_2)^2} &= vt_2 \\
\sqrt{(x_0 - x_3)^2 + (y_0 - y_3)^2} &= vt_3
\end{align*}
$$

The ToF ranging method belongs to the two-way ranging technology, which mainly uses the flight time of the signal to and from the tag and the base station to measure the distance between the nodes. TDoA is a one-way ranging technology, which only needs to measure the one-way distance between the positioning base station and the positioning tag.

2.2. Time difference of arrival

TDoA positioning is a calculation method using time difference. Accurate absolute time is relatively difficult to measure. By comparing the time difference between the signal reaching each UWB positioning base station and calculating the distance difference between the signal and each positioning base station, a hyperbola with the positioning base station as the focus and the distance difference as the long axis can be made. The intersection of the group of hyperbolas is the location of the positioning label.

![TDoA positioning schematic diagram](image)

As shown in the Figure 2, using the TDoA positioning principle and UWB positioning technology to measure the time difference of radio signal propagation between the positioning tag and two different positioning base stations, the distance difference between the positioning tag and the four sets of positioning base stations is obtained, using the following the coordinates of the Formula (2) solving label:

$$
\begin{align*}
d_{i,12} &= \sqrt{(x_1 - x_i)^2 + (y_1 - y_i)^2 + (z_1 - z_i)^2} - \sqrt{(x_2 - x_i)^2 + (y_2 - y_i)^2 + (z_2 - z_i)^2} \\
d_{i,23} &= \sqrt{(x_2 - x_i)^2 + (y_2 - y_i)^2 + (z_2 - z_i)^2} - \sqrt{(x_3 - x_i)^2 + (y_3 - y_i)^2 + (z_3 - z_i)^2} \\
d_{i,34} &= \sqrt{(x_3 - x_i)^2 + (y_3 - y_i)^2 + (z_3 - z_i)^2} - \sqrt{(x_4 - x_i)^2 + (y_4 - y_i)^2 + (z_4 - z_i)^2} \\
d_{i,41} &= \sqrt{(x_4 - x_i)^2 + (y_4 - y_i)^2 + (z_4 - z_i)^2} - \sqrt{(x_1 - x_i)^2 + (y_1 - y_i)^2 + (z_1 - z_i)^2}
\end{align*}
$$

Figure 2. TDoA positioning schematic diagram.
Different from ToF, TDoA determines the location of the mobile station by detecting the time difference between the arrival of the signal at two base stations, rather than the absolute time of arrival, thus reducing the system's requirements for time synchronization. The TDoA algorithm is an improvement to the ToF algorithm. Compared with the ToF algorithm, it does not need to add a special time stamp, and the positioning accuracy is also improved.

3. System architecture design
The intelligent monitoring system for the automated production area of the metrology center based on UWB technology is composed of the application layer, the service layer, the transmission layer and the perception layer (location base station and location tag). The transmission layer backbone network communication method adopts wired or wireless communication. The system architecture is shown in the Figure 3:

![Figure 3. System structure.](image)

3.1. Perception layer
The perception layer mainly includes positioning base stations and positioning tags. The base station and tag are the core equipment of the UWB positioning system. The tag broadcasts the radio signal carrying its own ID number according to the time slot. After the positioning base station receives the signal sent by the tag, it will transmit the time stamp of the received signal and the tag ID card number through the backbone network. For the service layer to complete the positioning of the tag card, the base station can also receive instructions issued by the application layer to complete related settings.

3.2. Transport layer
The transmission layer, also known as the backbone communication network, is the data transmission channel between the base station, the service layer and the application layer. It transmits the related instructions of the application layer to the base station downward and transmits the original positioning data (the distance between the tag and the base station) to the service upward. The transport layer using wired optical fiber for data transmission.

3.3. Service layer
The distance is measured by the tag and the base station that covers the area. The top layer uses the location and tag distance of each base station to calculate the tag coordinates through the TDoA...
algorithm or the ToA algorithm. In addition, the service layer also provides flexible device management and network management functions, as well as various front-end functions and application interfaces.

3.4. Application layer
Obtain the specific location of the positioning tag through the service layer, display the location of the tag in real-time in the form of a one-dimensional, two-dimensional or three-dimensional map, and provide functions such as track playback, personnel information management, and call for help. In addition, the application layer also provides a web socket interface and an http interface. The real-time location data of the tag card can be obtained through the WebSocket interface, and system-related data can be obtained through the http interface. Therefore, the UWB positioning system is easy to re-develop and integrate.

4. System function design
The functional scope of the system is designed as follows, including basic information management, job attendance, positioning analysis, electronic fence, behavior monitoring, intelligent inspection and data analysis, etc.

4.1. Basic information management
Basic information management includes personnel file management, map management, inspection point management, route management and other functional sub-items. Among them, the personnel file management mainly realizes the basic file management of the external personnel of the center, the basic file management of the temporary personnel, and the internal personnel information management of the measurement center.

Map management supports the application display of two-dimensional plane map and three-dimensional space map, realizes the management of inspection work areas such as the front area of the library, the library area, etc., and can accurately define the location information of each functional area and room in combination with CAD drawings.

Inspection point management can define and manage inspection point location information and inspection requirements, apply dot matrix electronic ink screen technology to realize the digitization of inspection point labels, and display inspection point information and inspection operations on the inspection labels status, patrol check-in dynamic QR code and other content, and can be combined with subsequent application needs to expand the display content. Multiple inspection routes can be set, and preset inspection routes can be issued to inspectors, and wearable devices can be used to guide inspection operations.

4.2. Job attendance
The attendance tasks can be formulated according to the team, the attendance/on time/late/early leave of the staff can be counted, and the statistical analysis of the attendance situation can be supported; combined with the electronic fence function, the on-the-job status of the operators can be monitored, and the behavior of leaving the work area for more than a certain time record and early warning reminder.

4.3. Positioning analysis
According to different plant supervision scenarios, the system can provide zero-dimensional, one-dimensional, two-dimensional and three-dimensional positioning analysis services; real-time personnel location tracking, statistical personnel location and distribution heat map, to grasp the dynamics of operators anytime and anywhere; at the same time, for equipment positioning functions, it can realize rapid positioning and identification of mobile and stationary equipment.
Configure identification equipment for key equipment in the front area of the warehouse, such as depalletizers, automated handling Automated Guided Vehicle, manual forklifts and other operating equipment to locate and identify.

4.4. Electric fence
Set up static and dynamic electronic fences to implement regional access authority management, to ensure that only authorized personnel can enter the relevant area, and those without authorization will alarm the electronic fence; set up electronic fences for key operation areas, implement dynamic attendance, and monitor the absence of workers.

4.5. Behavior monitoring
Implement various behavior monitoring in the area, including overtime monitoring, crowd monitoring, immobile monitoring, etc., all-round intelligent management, improve management quality, respond to rescue in a timely manner, and ensure the personal safety of employees; monitor the operation status of automated/semi-automatic equipment, such as equipment anti-collision warning, human and dangerous equipment safety distance warning.

4.6. Intelligent inspection
According to the inspection requirements of the production area and equipment, custom planning inspection points and inspection routes, setting inspection personnel and cycles, formulating inspection tasks, and realizing real-time tracking of inspector routes [6], combined with wearable devices, to achieve real-time two-way interaction and communication.

4.7. Data analysis
Data analysis involves carrying out post attendance analysis, behavior dynamic analysis, key inspection area/route heat map analysis, abnormal inspection analysis, etc.; abnormal inspection tracking, carrying out abnormal inspection analysis, targeting abnormal inspection routes or irregular inspections, the omission of inspection points shall be traced back.

5. Conclusions
The design and application of the intelligent monitoring system for the automated production area of the metrology center based on UWB technology takes full advantage of the high precision, high dynamics, high capacity, and low power consumption of the ultra-wideband, and applies it to the production and operation management of the metrology center. Effectively solve the pain points of disordered operation and maintenance on the production site, lack of operation and maintenance methods, untimely operation and maintenance, and difficulty in quantifying operation and maintenance work.

Through the construction of basic information management, post attendance, positioning analysis, electronic fence, behavior monitoring, intelligent inspection and data analysis and other application functions, the system provides effective solutions for the daily management of the measurement automation production site and promotes measure the development of digital management of production, operation and maintenance.

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