A Optimization High Precision Indoor Location System for AGV Based on UWB

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Abstract. AGV is a necessary production equipment device in modern manufacturing and warehousing logistics systems. AGV indoor guidance is usually leaded by magnetic tape/magnets, inertia, optics, laser radar, machine vision, etc. These methods are affected by laying, positioning accuracy, light interference, etc. There are some disadvantages. We use advanced UWB, improved TW-TOF and optimized triangulation algorithm to achieve accurate indoor positioning, and add laser radar guidance to solve UWB accuracy problems caused by obstacles, thus achieving accurate indoor positioning and movement of AGV. The design of the navigation of the trajectory enables AGV to meet the requirements of high-precision positioning in industrial production.

Introduction

The automatic guided vehicle-AGV is a necessary equipment for automatic production in modern flexible manufacturing systems and warehouse logistics systems. AGV can be accurately positioned by the satellite positioning system outdoors, but the indoor GPS signal cannot be covered, you can only use magnetic strips or magnets, light, laser radar guidance or inertial guidance. The magnetic stripe/magnetic nail is used to lay the magnetic stripe underground. The AGV can only use the Hall magnetic sense to select the running route. The magnetic nail positioning is realized by the Hall sensor and the counter to achieve the AGV guidance. The AGV guide or positioning accuracy depends on the density of the magnetic nail laying and the Sensing recognition accuracy to determine the location, the accuracy is not very accurate. The laser radar achieves distance measurement and positioning by transmitting back laser signals, but its transmission distance is near, and the positioning can only be achieved based on the launch of the surrounding obstacles. The increase in the number of radar wiring harnesses is very expensive and not suitable for popularization. The light is positioned on the surface with a colored band, which is subject to changes in light intensity and contamination, it is difficult to be accurately identified by the phototransistor. Its positioning also has certain deficiencies. The inertial navigation positioning accuracy is limited by the gyroscope cost and has not been widely used. However, UWB wireless positioning realizes low-cost and high-precision positioning, therefore it is the best navigation option for AGV.

In practice, we use the positioning module of Mini3s based on Decawave DM1000 to build an indoor precise positioning system based on UWB. Mini3s uses a low-ripple and high-precision crystal design. STM32F103T8U6 is used as the master chip to control the DM1000 module, send and receive information in serial way.

The Improvement Precision Navigation Design Of AGV

As shown in Figure 1(b) below, the system consists of three fixed Anchor base station modules. The tag module located on the AGV and the three base station modules implement accurate ranging
using the TW-TOF, and precise calculations of the AGV position is implemented by the enhancing three-edge algorithm, supplemented by discrete Kalman filtering, enable accurate navigation of AGV.

UWB achieves precise positioning. Its greatest weakness is in the indoor navigation. If it is empty, its measurement accuracy is very good. Once the AGV encounters obstacles in the process of moving, UWB accuracy will be seriously impaired, and the measurement accuracy will be greatly reduced. In the engineering practice, we adopted the low-cost RPLidar A3 omnidirectional laser radar. The laser radar has a short transmission distance, but its monitoring of obstacles is very accurate. In practice, we use UWB to achieve positioning, when positioning data changes, monitor whether the laser radar is affected by obstacles. UWB positioning data will be corrected if obstacles are detected. Otherwise, UWB positioning data will continue to be used[1].

UWB Indoor Precise Positioning

UWB positioning system can be used to obtain accurate indoor positioning with precision of 10-12cm. In practice, we use TW-TOF frame synchronization and Kalman filtering to improve positioning accuracy. The accuracy of 8-10cm basically satisfies the navigation of the AGV at the industrial production site. There are some common UWB positioning, for example, TOA (Time of Arrival Time), TDOA (Time Difference of concatenated) and AOA (Angle of arrivals from), TOF (Time of flight) algorithm, and we adopted the TW - TOF algorithm in practice[2].

**TW - TOF Algorithm.** TW-TOF (two way-time of flight) means that there are two nodes, in which module A sends a pulse signal of a request nature at timestamp $T_{a1}$, and module B sends a signal of the nature of the response at $T_{b2}$, module A receives the response signal at its own timestamp $T_{a2}$. Thus, the flight distance $S$ of the pulse signal between the two modules can be calculated.

$$S = \frac{C \times (T_{a2} - T_{a1}) - (T_{b2} - T_{b1})}{2}$$  \hspace{1cm} (1)  

(C is the speed of light)

**Frame Synchronization.** When using UWB positioning, due to the difference in the hardware of each base station, the crystal oscillator may have slight differences, which will cause the clock synchronization to be affected. It is estimated that every 1 ns of the clock synchronization signal will cause 30cm error in positioning, and such an error cannot be tolerated in accurate positioning. On the one hand, we selected a local high-precision external non-crystal-less Mini3S positioning module; the positioning accuracy of the positioning base Anchor and the tag Tag was further improved; and in the wireless signal transmission, we used the frame synchronization algorithm: in this mode Next, the Tag sends out a broadcast packet. When multiple clocks are synchronized, the Anchor simultaneously accepts the packet from the Tag. After receiving the TW-TOF, it obtains multiple sets of time information, and then calculates the position coordinates of the Tag according to the multi-lateration method. As a result, the clock synchronization error between the Anchor and the Tag is further reduced, and the positioning accuracy of the Tag is further improved. In addition, we can also use DecaWave’s synchronous bit synchronization method to achieve clock synchronization. Due to the complexity of the algorithm, we are temporarily unable to use it in practice.

**Enhance Trilateration Localization Algorithm**

The traditional Trilateration algorithm can be implemented by the three Anchor and Tag structure to achieve its positioning algorithm, but due to hardware and other differences, it is impossible to obtain perfect operation accuracy, so we use the optimized extended Trilateration algorithm to achieve AGV based on TAG nodes the precise positioning[3].
Trilateration Measuring Principle.

The principle of the trilateration method is shown in Figure 1 above. The three circle centers are A, B, and C. The coordinates of the three points are \((x_a, y_a), (x_b, y_b), (x_c, y_c)\), and the three circles converge theoretically at a point D, the distance between point D and the three circle centers is \(d_a\), \(d_b\), and \(d_c\), and if the coordinate of D point is \((x, y)\), then:

\[
\sqrt{(x - x_a)^2 + (y - y_a)^2} = d_a \tag{2}
\]

\[
\sqrt{(x - x_b)^2 + (y - y_b)^2} = d_b \tag{3}
\]

\[
\sqrt{(x - x_c)^2 + (y - y_c)^2} = d_c \tag{4}
\]

From the above formula, the coordinates of the D point are

\[
\begin{pmatrix}
x \\
y
\end{pmatrix}
= \begin{pmatrix} 2(x_a-x_b) & 2(y_a-y_c) \\
2(x_b-x_c) & 2(y_b-y_c)
\end{pmatrix}^{-1}
\begin{pmatrix}
x_a^2-y_a^2+y_b^2-y_c^2+d_a^2-d_b^2 \\
x_b^2-y_b^2+y_c^2-y_a^2+d_b^2-d_c^2
\end{pmatrix} \tag{5}
\]

According to the traditional trilateration method, since the hardware of each node and the TW-TOF have slight differences, which make them different, the measured distance cannot be an ideal value, resulting in the above three circles may not be exactly at a point, This makes the positioning there is a certain amount of error, in order to improve this error, we extend the trilateral centroid Trilateration algorithm to optimize the further positioning accuracy [4].

Optimization Trilateration Algorithm. In order to solve the problem of non-coincident intersection of three-sided positioning, usually three circles often intersect at a single area in actual measurement. In this case, a weighted three-edge positioning algorithm or centroid algorithm or use is usually used in this case. Maximum likelihood estimation method and least squares method are used to estimate. We use the weighted three-edge least squares estimation algorithm to achieve further optimization of the Trilateration algorithm based on many algorithms. In UWB positioning, since the ANCHOR and TAG spacing will cause errors, as the distance increases, the error will also increase. Therefore, when the weighted three-edge algorithm is actually calculated, different distances give different weights. More accurate calculation results; and the centroid algorithm regards the three circles intersect as a triangle, and mathematically finds the center of mass of the triangle, and then obtains the TAG positioning coordinates. Whether it is a three-side positioning algorithm or a centroid algorithm or a weighted three-sided positioning algorithm, there are always certain defects. In engineering practice, we introduce a three-edge algorithm based on least squares estimation, which can obtain satisfactory calculation results.

In practice, it is known that the base station coordinates are \((x_1, y_1), (x_2, y_2), (x_3, y_3)\)...
\((x_{n-1}, y_{n-1})\) and the unknown terminal coordinates are \((x_n, y_n)\), then there are the following equations:

\[
\begin{align*}
(x_1-x)^2 + (y_1-y)^2 &= d_1^2 \\
&\vdots \\
(x_n-x)^2 + (y_1-y)^2 &= d_n^2
\end{align*}
\]
For the above nonlinear equations, after subtracting the nth equation from the first n-1 equations, the linear equation is obtained:

\[ A_x = b, A = \begin{bmatrix}
2(x_1-x_n) & 2(y_1-y_n) \\
\vdots & \vdots \\
2(x_{n-1}-x_n) & 2(y_{n-1}-y_n)
\end{bmatrix} \]

\[ b = \begin{bmatrix}
x_1^2 - x_n^2 + y_1^2 - y_n^2 \quad \cdots \\
x_n^2 - x_n^2 + y_n^2 - y_n^2 \\
\cdots
\end{bmatrix} \]

(7)

The least-squares method is used to solve the above equations. The following equations can be obtained:

\[ X = (A^T A)^{-1} A^T b \]

\[ X \text{ is the unknown terminal coordinate value} \] [5].

**Laser Radar Aided Positioning Optimization Design**

In UWB ranging, if the measuring environment between AGV and ANCHOR is relatively empty, the basic error of the measured data is within an acceptable range, but when the measuring environment is more complex and there are many obstacles in the AGV running circuit, the measured data A large amount of error has occurred, which has seriously affected the navigation of AGV. In engineering practice, infrared laser radar has a short measurement distance, but its measurement accuracy is better than that of UWB measurement. Its measurement principle determines that its monitoring of obstacles is more accurate. Therefore, we have added a low-cost omnidirectional laser in practice. Radar to correct the error in UWB measurement, to obtain a relatively satisfactory measurement accuracy of low measurement error, so as to achieve accurate AGV indoor navigation[6].

The distance between ANCHOR and TAG is measured by UWB first. With the aid of coordinate conversion, it is concluded that the AGV carries the TAG in the indoor coordinate position. In order to achieve accurate positioning, the data transition in wireless transmission is eliminated and the positioning data is eliminated. Discrete Kalman filtering is implemented, which eliminates errors due to system transmission. If an obstacle is encountered in the AGV movement path, the positioning data will produce a large error. Therefore, we judge in the program if the AGV moves. The resulting positioning data is a linear increase or decrease, the data is considered to be the correct positioning data, if the positioning data has undergone a jump, does not meet the linear change characteristics, the UWB measurement data and the SLAM laser radar measured obstacles data is corrected to obtain positioning data litter errors[6,7].

**Experiments and Verification**

The experimental validation process is as follows:

1) Firstly, laser radar compensation is not added, and UWB alone realizes measurement. When the mobile phone remotely controls Mcnamrar AGV to move in real time, the data between AGV/TAG and each base station is recorded and the base station projection center and base station are measured with a soft ruler. The distance between ANCHOR and TAG is recorded and compared.

2) UWB is used to implement distance measurement separately. In the AGV moving route, a carton or a metal stool is placed between the TAG and the base station ANCHOR, and the UWB measured distance is measured and recorded. When there is an obstacle between the base station and the AGV, the distance measurement will appear jump of data and a large measurement error occurs compared with the actual measurement.

3) With UWB additional laser radar ranging, when the TAG and ANCHOR are unobstructed and relatively empty, the side measurement data is basically the same as the process 1), and the data transition is small.

4) With UWB additional laser radar ranging, In the AGV moving route, a carton or a metal stool is placed between the TAG and the base station ANCHOR, The experimental data is calculated by the program, there is a small error between the experimental data and the actual measurement. The
data is basically similar to the process 1). Compared with process 2), the data greatly improved the measurement accuracy. the experimental data and the actual measurement in table 1.

Table 1. UWB range alone compared with additional radar compensation range [m].

| physical/experiment | UWB range without laser radar compensation () | UWB range Additional laser radar compensation () |
|---------------------|---------------------------------------------|-----------------------------------------------|
| ANCHOR0             | 5.660/                                      | 5.660/                                        |
| ANCHOR1             | 3.830/                                      | 3.830/                                        |
| ANCHOR2             | 4.380/                                      | 4.380/                                        |
| ANCHOR0             | 5.588/                                      | 5.588/                                        |
| ANCHOR1             | 3.740/                                      | 3.740/                                        |
| ANCHOR2             | 4.301/                                      | 4.301/                                        |
| Physical2           | 4.950/                                      | 4.950/                                        |
|                     | 6.230/                                      | 6.230/                                        |
|                     | 4.070/                                      | 4.070/                                        |
| Physical2           | 4.865/                                      | 4.865/                                        |
|                     | 6.157/                                      | 6.157/                                        |
|                     | 3.982/                                      | 3.982/                                        |
| Physical3           | 5.060/                                      | 5.060/                                        |
|                     | 6.240/                                      | 6.240/                                        |
|                     | 3.180/                                      | 3.180/                                        |
| Physical3           | 5.060/                                      | 5.060/                                        |
|                     | 6.240/                                      | 6.240/                                        |
|                     | 3.180/                                      | 3.180/                                        |
| Physical4           | 4.959/                                      | 4.989/                                        |
|                     | 6.122/                                      | 6.170/                                        |
|                     | 3.078/                                      | 3.116/                                        |
| Physical4           | 4.959/                                      | 4.989/                                        |
|                     | 6.122/                                      | 6.170/                                        |
|                     | 3.078/                                      | 3.116/                                        |
| Physical5           | 4.560/                                      | 4.560/                                        |
|                     | 7.470/                                      | 7.470/                                        |
|                     | 3.760/                                      | 3.760/                                        |
| Physical5           | 4.560/                                      | 4.560/                                        |
|                     | 7.470/                                      | 7.470/                                        |
|                     | 3.760/                                      | 3.760/                                        |
| Physical6           | 4.459/                                      | 4.492/                                        |
|                     | 7.356/                                      | 7.416/                                        |
|                     | 3.641/                                      | 3.691/                                        |
| Physical6           | 4.459/                                      | 4.492/                                        |
|                     | 7.356/                                      | 7.416/                                        |
|                     | 3.641/                                      | 3.691/                                        |
| Physical6           | 0.980/                                      | 0.980/                                        |
|                     | 6.240/                                      | 6.240/                                        |
|                     | 6.940/                                      | 6.940/                                        |
| Physical6           | 0.980/                                      | 0.980/                                        |
|                     | 6.240/                                      | 6.240/                                        |
|                     | 6.940/                                      | 6.940/                                        |
| Physical6           | 0.878/                                      | 0.918/                                        |
|                     | 6.139/                                      | 6.163/                                        |
|                     | 6.823/                                      | 6.873/                                        |

Based on the experimental data, an additional laser radar can be used to correct the error caused by obstacles in the distance measurement based on UWB ranging, and more accurate measurement data can be obtained.

The Conclusion and Improvement

The test results and experiments show that using UWB to achieve ranging between AGV and base station can obtain with 10-12 cm precision measurement data. After the calculation, it can obtain AGV high-precision indoor coordinates. Realize accurate navigation of AGV indoors. When running in indoor open environment, UWB can achieve navigation accuracy by itself, but when the indoor environment is complex, especially when there are obstacles between the base station and the AGV during navigation, the navigation precision is greatly reduced. We assisted in scanning the obstacles with a low-cost omnidirectional laser radar and corrected the UWB measurement data. This enabled us to achieve 8-10 cm precision navigation in practice, which can fully meet the logistics requirements of some industrial sites. UWB is easy to lay and high precision. Combined with the precise measurement of laser radar, this type of navigation method can be applied to a wide range of applications, economical and practical, and it has a broad market for flexible automated transport equipment.

The development of technology is extremely rapid. We deploy and implement to apply DecaWave's new product the DW1001, which was born in February. Its new product has a multi-path attenuation correction, 6 MHz transmission rate, better than 2 cm positioning accuracy, so we should keep up with the pace of technology, this new research and development plans to meet further high-precision navigation requirements and meet the needs of industrial production

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