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Development of a High Precision UWB/Vision-based AGV and Control System

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***Abstract*—AGVs play an important role in unmanned factories and have broad prospects for development. Indoor vehicles are usually guided by magnetic tape / magnet, inertia, lidar, etc. These methods have some disadvantages. For example, magnet method is inconvenient due to a regular repair or replacement of tapes. In this paper, an advanced UWB method is used to navigate the AGV to the vicinity of the working position, and then computer vision technology is used to accurately determine the position of the vehicle, thereby establishing a high-precision AGV self-localization method. UWB can be applied to the situation of multi-AGVs interaction. Depth camera can also be used for obstacle detection and workpiece detection. Meanwhile, in order to make all different hardware and software work properly, an easy-scalable AGV control system is designed. Simple sensors can achieve complex functions.**

Keywords-AGV; computr vision; UWB; control system

I. INTRODUCTION

The automatic guided vehicle (AGV) is a necessary equipment for automatic production in modern manufacturing systems. Generally, compared to outdoor auto-navigation vehicles, indoor AGVs can only use magnetic strips or magnets, light, lidar navigation or inertial navigation [1]. The magnetic stripe/magnetic method need to lay the magnetic tracks underground. The AGV can only use the Hall magnetic sense to select the running route. Meanwhile, the self-localization is realized by the Hall sensor and the guidance of AGV is achieved by counter. In this method, the AGV guidance or positioning accuracy depends on the density of the magnetic tracks laid and the sensing recognition accuracy. Lidar method uses distance laser signals to achieve distance measurement and positioning, but its transmission distance is limited, and positioning can only be achieved based on the emission of surrounding obstacles. The increase in the number of radar wiring harnesses is expensive, it is not suitable for promotion. The light method spreads the ribbon on the ground, and the phototransistor recognition is easily affected by light intensity and pollution, the accuracy is insufficient, and the positioning is also inaccurate. The inertial navigation positioning accuracy is limited by the gyroscope cost and has not been widely used. Ultra-wideband (UWB) and vision-based automatic positioning achieve low-cost and high-precision positioning and have broad development prospects. In this paper, a UWB and computer vision combined method is used to localize and navigate the indoor AGV.

UWB works like an indoor version of GPS, which provides the absolute positioning to the vehicle in warehouses environment. The precision of UWB self-localization is about 10cm [2], which is not enough for this project. But pure vision-based self-localization and obstacle detection require a lot of computer computing resources. Therefore, we use UWB to provide self-positioning for the vehicle before it reaches the specified target and combined with visual obstacle detection to guide it. When the AGV reaches the target position, the vision-based self-positioning function is activated to provide higher positioning accuracy.

Computer-vision-based self-localization and guidance provide several notable advantages: one depth camera can replace multiple sensors, instead of obstacles recognition and navigation purpose, computer vision allows a robot to perform multiple tasks like cargo identification.

The workflow of the system is as follows, before the AGV starts working, the depth camera should be used to record the internal map information of the factory, EKF-SLAM (SLAM) based on extended Kalman filter [3-4] is used for high precision mapping. The collected depth and feature information will be stored in the central computer. After that, based on the path coordinates information already stored and the data provided by UWB base stations, the vehicle will automatically calculate the best path and travel to the vicinity of the work position after receiving the order. Meanwhile, as the vehicle moves forward, vision-based obstacle detection [5] will ensure worker safety. After the AGV reach, the depth camera starts to work to capture the coordinates of feature points [6]. The position &direction of the vehicle will be re-calculated in order to improve the accuracy. After this step, all the position and location coordinate of the vehicle collected by the sensors will be transferred to the processor. Finally, the difference between the collected data and the target location will be treated as a distance parament to perform distance compensation. Meanwhile, in order to make all these different hardware and software work properly, an easy-scalable AGV control system is designed.

II. Construction of the AGV

The purpose of this object is to design a high precision self-localization and self-navigation indoor vehicle based on UWB and computer vision. Multi-axis robots on the vehicle will be transported between workplace. The hardware and the software structure are as follows:

A. The Hardware Structure

The prototype and physical picture of the vehicle are shown in Fig. 1 and Fig. 2:

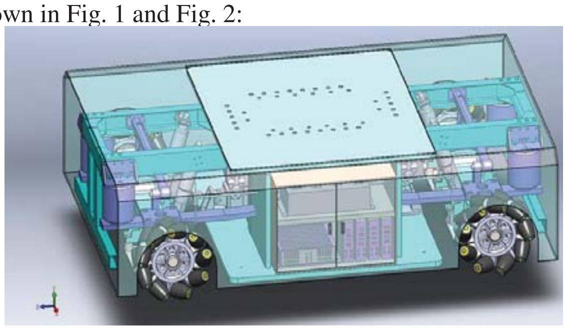

Figure 1. The prototype of the AGV

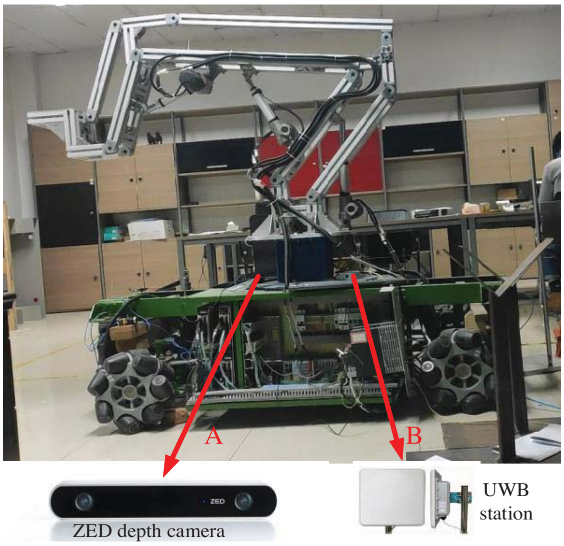

Figure 2. High precision AGV carrying a three-axis robot

From the bottom to top, four Mecanum wheels carry the entire vehicle, all of them are driven by servo motors. Since the Beckhoff windows based real-time industrial operating system is chosen in this project, all motors are connected in series through Ethernet cable and the last motor is connected to EK1100 coupler. Central computer, server drivers, large capacity battery and other electrical equipment are placed on the chassis. Above the chassis is a platform which is designed to place the load, in test process, a light truss structure three-axis robot arm is fixed to the platform. According to the large load capacity of Mecanum wheels and the strength of the vehicle structure, a heavy six-axis KUKA robot can even been placed. The ZED stereo camera is fixed on the front side of the platform (Fig. 2A) and the UWB signal receiver is placed on the side (Fig .2B). The UWB base stations are placed at the corner of the room which serves as a reference of the indoor vehicle's absolute positioning.

In order to give a more intuitive hardware connection and relationship, a configuration diagram of the AGV is shown in Fig. 3:

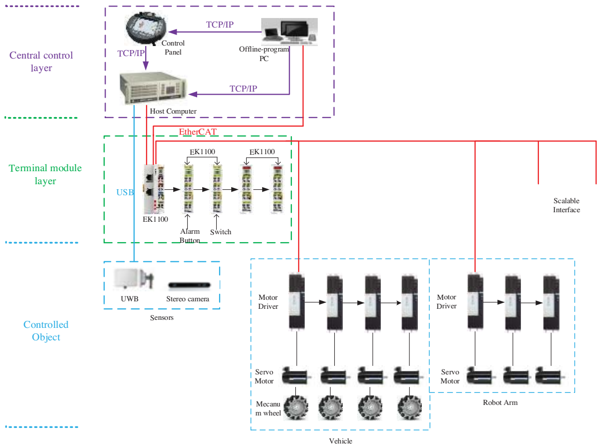

Figure 3. Hardware configuration diagram of the AGV

B. The Software Structure

The entire control system operates on Windows system, Beckhoff TwinCAT3 is chosen as the motor control software. It is a secondary development software based on Visual Studio, this software is becoming more and more widely used in industrial fields because of the modular design style. The functional module diagram is shown in Fig. 4:

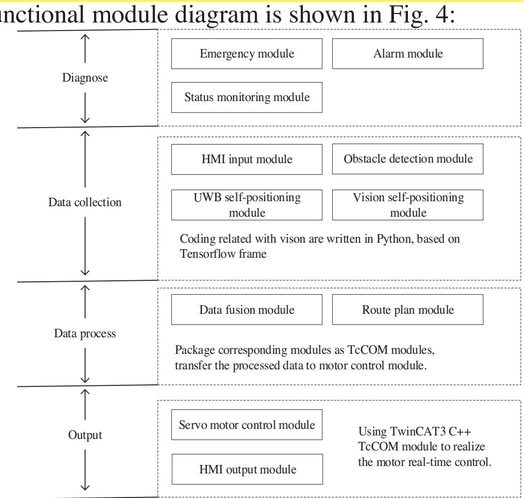

Figure 4. The functional module diagram of the system

Before the AGV software starts working, the depth camera should be used to record the internal map information of the factory, and the depth and feature information should be stored in the central computer. By doing that, the computer calculation resource can be saved because the AGV do not need to build the surroundings environment real time.

When the entire system begins to work, the self-test module will be called first to check whether all hardware is in the correct state. Since AGV works in the factory, it is necessary to ensure the safety of the workers, and the obstacle detection module and the emergency module should run in a specific thread to ensure safety. After receiving the user's order, the vehicle will call the UWB self-localization module to obtain position and direction information, and then call the route planning module to calculate the best route based on the saved map. The camera is occupied by obstacles detection module while the vehicle is moving, when an obstacle is detected within the safety range on the path, emergency module will be called at once and the vehicle will be stopped immediately.

When the vehicle reaches near the target position, the UWB self-localization module will be turned off and the visual self-localization module starts to work. The depth camera will be used to collect the surrounding feature points, and these feature points will be matched with the saved feature points for further high-precision positioning. The AGV system flowchart is shown in Fig. 5:

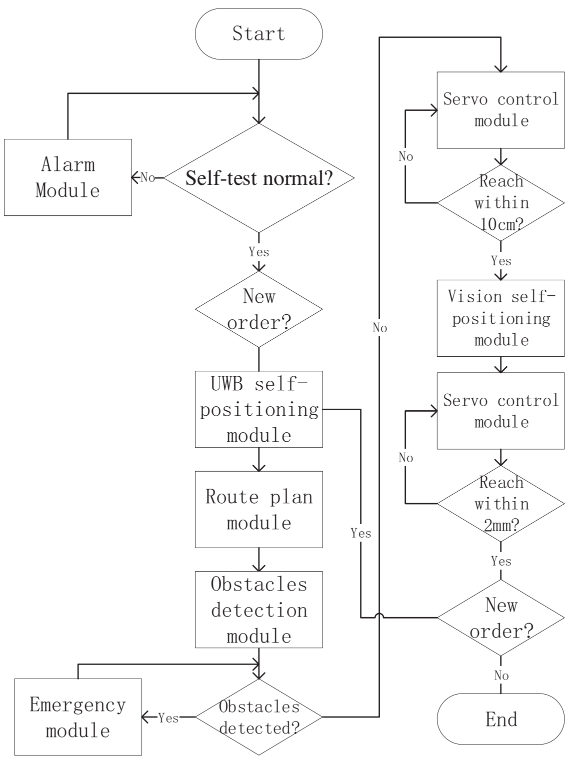

Figure 5. The AGV system flowchart

III. UWB Self-Localization

The UWB self-location system consists of three fixed base station modules and a tag module. The two-way time-of-flight (TW-TOF) principle is used to achieve accurate ranging between the tag and the base station, and the enhanced three-edge algorithm is used to achieve the accurate calculation of the AGV position, supplemented by discrete Kalman filtering.

A. TW-TOF

TW-TOF is a two-way ranging method that does not require time synchronization between the two communication parties, avoiding get the added cost of time synchronization. This ranging method requires both the base station and the tag have the function of transmitting and receiving signals, initialize the distance measurement information, real time signals receive and reply. The steps of this method are shown below in Fig. 6:

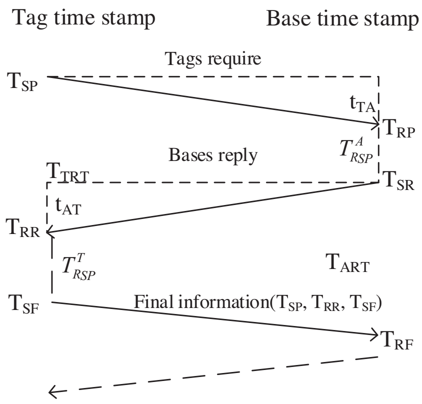

Figure 6. Steps based on TW-TOF

When the base station receives the tag's requirement information, the base station records the time T_{RP}, and send a reply message to the tag, meanwhile, record the sending time T_{SR}. When the tag receives the reply message, record the receiving time T_{RR}, and send the tag record time (T_{SP}, T_{RR}, T_{SF}) to the base station in time T_{SF}.

After base station receiving the final information from tag, the distance of AGV can be calculated by following formulas (1) ~ (5):

$$T_{TRT} = T_{RR} - T_{SP} \tag{1}$$

$$T^{A}_{RSP} = T_{SF} - T_{RP} \tag{2}$$

$$T_{ART} = T_{RF} - T_{SR} \tag{3}$$

$$T^{T}_{RSP} = T_{SF} - T_{RR} \tag{4}$$

T_{TRT} is the delay time of tag signal round-trip, T^{A}_{RSP} is the reaction time of the base station, T_{ART} is the delay time of base station signal round-trip, T^{T}_{RSP} is the reaction time of the tag.

Signal one-way transmission time TOF can be calculated by formula listed below:

$$TOF = \begin{cases} \dfrac{(T_{RR} - T_{SP}) - (T_{SR} - T_{RP}) + (T_{RF} - T_{SR}) - (T_{SF} - T_{RR})}{4} & T_{RSP} = T_{RSP}^{T} \\ \dfrac{T_{TRT} * T_{ART} - T_{RSP}^{A} * T_{RSP}^{T}}{T_{TRT} + T_{ART} + T_{RSP}^{A} + T_{RSP}^{T}} & T_{RSP} \neq T_{RSP}^{T} \end{cases} \quad (5)$$

The final distance between the tag and base station equals to TOF multiplied by the speed of light, shown in formula (6):

distance = TOC * c (speed of light) (6)

B. Three-edge Algorithm

After obtaining the distance between the tags of three different base stations through the TW-TOF method, a three-edge algorithm positioning method (as shown in Fig. 7) can be used to calculate the position of AGV.

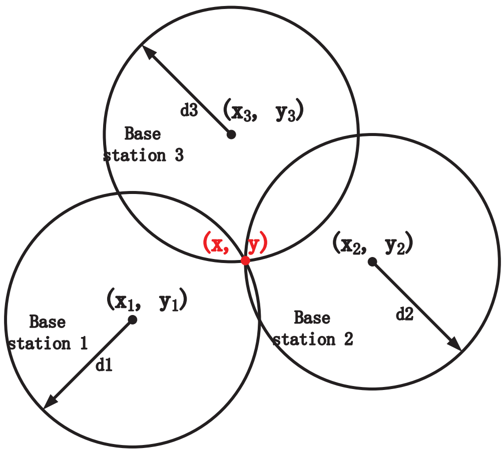

Figure 7 Three-edge algorithm

The position of AGV can be calculated by the formulas (7) ~ (10) below:

$$x = \frac{(y_2 - y_1)\gamma_1 + (y_2 - y_3)\lambda_2}{2((x_2 - x_3)(y_2 - y_1) + (x_1 - x_2)(y_2 - y_3))} \quad (7)$$

$$y = \frac{(x_2 - x_1)\gamma_1 + (x_2 - x_3)\lambda_2}{2((x_2 - x_1)(y_2 - y_3) + (x_2 - x_3)(y_1 - y_2))} \quad (8)$$

$$\gamma_1 = x_2^2 - x_3^2 + y_2^2 - y_3^2 + d_3^2 - d_2^2 \quad (9)$$

$$\gamma_1 = x_1^2 - x_2^2 + y_1^2 - y_2^2 + d_2^2 - d_1^2 \quad (10)$$

(x, y) is the coordinate of the vehicle, d_1, d_2, d_3 are the distances between the three base stations and the vehicle, (x_1, y_1), (x_2, y_2), (x_3, y_3) are the location of three base stations.

IV. VISON-BASED FUNCTIONS

In this AGV project, the ZED depth camera is chosen to achieve the obstacle detection and self-localization purpose.

A. Obstacles Detection

In this project, the neural network was used for object detection. Modified YoloV3 model based on the TensorFlow framework was combined with the depth camera API to get the position of the object. The video of the target detection will be displayed on the monitor in real time.

B. Vision-based Mapping and Self-localization

SLAM technology creates a map of unknown environments and focuses on real-time operations to locate sensors on the map. Among the different sensor, cameras are cheap and provide rich information of the environment that allows for robust and accurate place recognition. Therefore, in this paper, a visual SLAM solution method will be used to map the indoor environment of the factory and locate the position and direction of the camera sensor.

Before AGV started working, the features were extracted from the environment using a ZED stereo camera and geometric figures were constructed according to the SLAM principle. At the same time, the error caused by the internal sensors can be eliminated by the extended Kalman filtering method, and the best estimate of the landmark position in the map can be obtained. After the AGV reaches the designated work place through UWB navigation, the camera originally used for obstacle detection will be used to find feature points around the work place. After comparing the found feature points with the stored map, the relative distance and angle between the vehicle and the feature points can be determined, so as to calculate the high-precision coordinates and pose of the vehicle in the factory environment.

V. EXPERIMENTS

UWB-based indoor self-positioning error in this project is around 8cm. Using the depth camera to reposition the vehicle after it has reached the designated location can improve the accuracy to about 1cm.

The CPU used in this project is Intel(R) Core(TM) i7-7700HQ. After testing, the FPS for real-time obstacle detection can reach 2-3. If the GPU is used to process the picture, the FPS can reach 20-30. A screenshot of the detection video is shown in Fig. 8, the point within the rectangular area is the point closest to the camera. The coordinates of this points relative to the center point of the camera are also displayed in the picture.

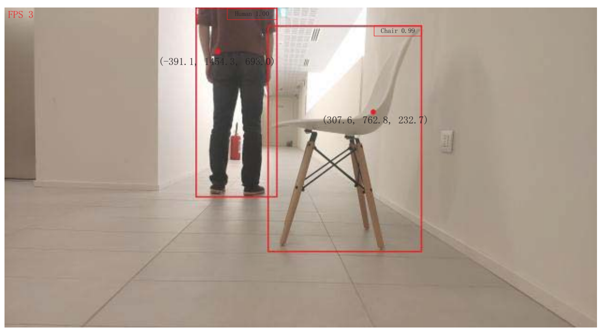

Figure 8. Obstacles detection and localization

VI. Conclusion and Outlook

This article proposes a UWB / Vision-based high precision AGV solution. Meanwhile, an easy-scalable AGV control system is designed in order to make all different hardware and software work properly. The hardware construction of the entire AGV has been completed, and all parts have been debugged and run normally. AGV's control system framework has been set up, with numerous interfaces for easy expansion. The AGV achieves indoor centimeter-level self-positioning through the improved UWB module. After calculation by the path planning module, it can successfully run to the designated work place by combining the obstacle recognition module and the motion control module.

The positioning method combining UWB and machine vision has the characteristics of high accuracy, simple sensors, and low cost, and provides the possibility for the development of multi-AGVs navigation and workpiece recognition functions.

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