Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: Xudong Li and Ruiming Wu 2023 *J. Phys.: Conf. Ser.* **2632** 012020

Journal of Physics: Conference Series **2632** (2023) 012020 doi:10.1088/1742-6596/2632/1/012020

Design and Research of AGV Indoor Positioning System Based on Visual and Ultra Wideband Combination Positioning

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Abstract. Aiming at the problems of cumulative error in monocular visual positioning and Non-Line-of-Sight (NLOS) error in UWB positioning for the automated guided vehicle (AGV) in indoor environments, a combined method of vision and Ultra-Wide Band (UWB) is proposed for indoor AGV positioning. Firstly, the overall structure and system of the AGV are designed to achieve indoor navigation and positioning functions. Secondly, the monocular visual and UWB positioning data are fused using the Error State-Extended Kalman Filter algorithm (ES-EKF) to obtain the optimal pose estimation of the AGV. Finally, the AGV is used as a mobile platform to conduct positioning experiments in different indoor environments. The experimental results demonstrate that the navigation and positioning system has high accuracy and robustness in indoor environments with obstacles, and no significant drift or discontinuity phenomena occur during the positioning process, indicating its practicality in indoor settings.

1. Introduction

At present, the indoor navigation and positioning technologies of AGVs are mainly divided into magnetic navigation [1-2], inertial navigation [3], and visual navigation [4]. Among them, vision is the most widely used navigation and positioning technology for AGVs, which has the advantages of low cost, simple installation, and high positioning accuracy and has received wide attention from the industry [5].UWB is one of the few wireless positioning technologies that can meet the indoor positioning needs of AGVs, which can not only provide position information by itself but also combine with other positioning sensors to improve the accuracy of the positioning system. [6-7]

Vision is a passive positioning technology, and the accumulated errors that exist over time cannot provide reliable indoor positioning information for AGVs. UWB is an active positioning technology, and the signal propagation is susceptible to occlusion by non-visual obstacles, and UWB alone cannot provide stable and reliable indoor positioning information for AGVs. To address the above problems, Wang [8] et al. constructed a positioning system consisting of visual odometry and UWB. Experiments showed that UWB range measurement can eliminate the drift phenomenon generated by visual positioning; Shi [9] et al. constructed a navigation and positioning system consisting of a monocular camera and UWB, which can achieve real-time positioning with typical centimeter accuracy.

In complex indoor environments, it is difficult to obtain high accuracy and robust localization results for AGVs with only a single localization method. For the practical needs of AGV navigation and positioning indoors, this paper designs an AGV system with combined vision and UWB indoor positioning, which combines the positioning data obtained from vision and UWB solving with filtering algorithms to achieve positioning data fusion, improve the positioning accuracy of AGVs in indoor environments, and provide a reliable real-time positioning strategy for AGVs.

2. AGV Structure Design

The structure design of the vision and UWB-based AGV designed in this paper is shown in Figure 1. To ensure good motion stability and load-carrying performance during the experimental process, a robust six-wheel structure is adopted for the AGV. The AGV is propelled by two differential-drive wheels. The dual-drive wheels of the AGV are controlled by DC brushless motors for rotation, and there is a passive wheel positioned around the chassis at each corner to support the frame. At the front end of the AGV, a monocular camera is installed to capture indoor environment images. UWB positioning tags are mounted at the center of the chassis to collect positioning information transmitted by UWB positioning base stations. The drive motors adjust the speed and direction of the driving wheels based on the commands sent by the controller, enabling motion control of the AGV. The overall controller of the AGV is an industrial computer, responsible for communication among various sensors and electronic devices.

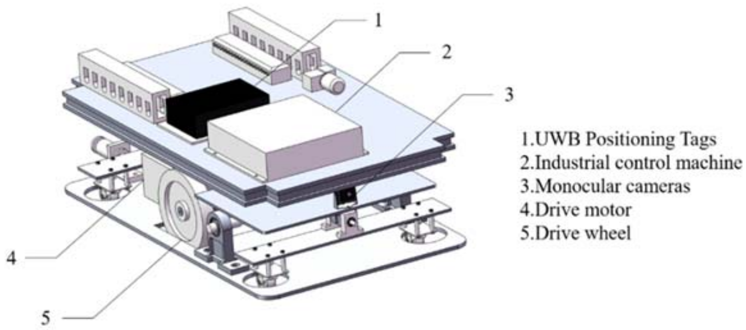

Figure 1. AGV structure design

3. AGV System Composition

AGV mainly consists of a power system, a sensor system, and a drive system. The composition of the AGV system is shown in Figure 2. The mechanical body takes the indoor working conditions and workspace into consideration, and the overall design of the AGV is determined based on motion stability and carrying capacity. The drive system is designed based on the actual carrying capacity and safety factor of the AGV. In this study, the AGV adopts a two-wheel differential drive. The power system includes two power modules, where the power supply for the drive system depends on the number of drive wheels, and the power supply for the control system depends on the overall power consumption of the AGV control system.

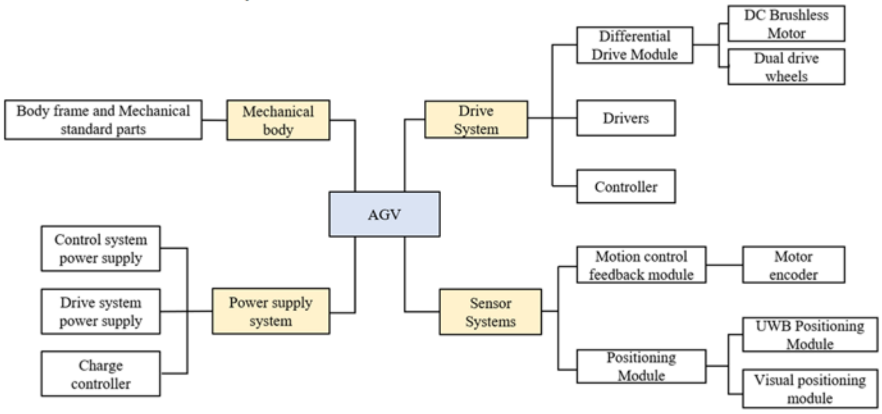

Figure 2. AGV system composition

4. Navigation and Positioning System Design

The system consists of positioning sensors, an industrial computer, and a communication module. The positioning sensors are primarily responsible for collecting positioning data and performing data preprocessing. The communication module utilizes a serial port to aggregate the preprocessed positioning data into the onboard industrial computer. The operating environment of the industrial computer is Ubuntu 16.04 + ROS Kinetic. The AGV navigation and positioning hardware include a monocular USB camera and an LD-150-L ultra-wideband positioning system. The UWB positioning system mainly consists of a positioning tag on the body of the AGV and three UWB positioning base stations placed in the experimental environment. The composition of the AGV positioning system is shown in Figure 3.

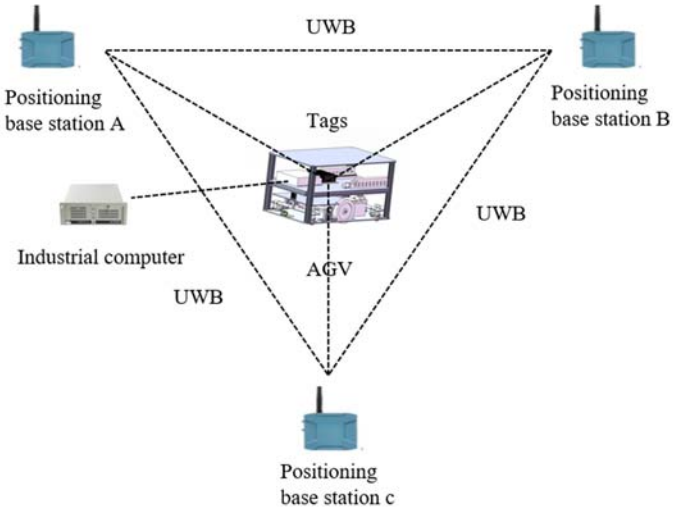

Figure 3. Composition of the AGV positioning system

5. Data Fusion System Design

The combined vision and UWB-based AGV positioning system is a nonlinear system, so the error-state extended Kalman filter algorithm for handling nonlinear systems is used for fusion [10]. The flow of the combined positioning method is shown in Figure 4.

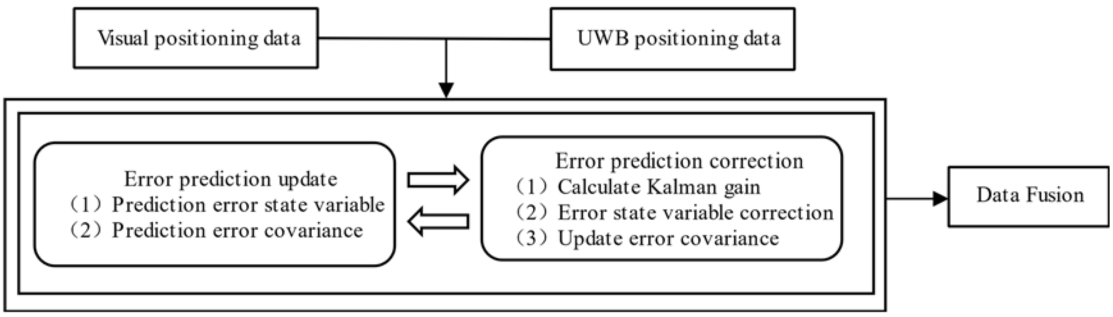

Figure 4. Combined positioning method data fusion process

The Kalman filter incorporates the pre-processed data from the ultra-wideband localization system and the visual localization system. The error extended Kalman filter is divided into two steps: an error prediction step and an error update step.

The error prediction process predicts the state through the system model, including position, velocity, etc., followed by the error prediction of the covariance matrix of the state, i.e., the uncertainty of the predicted state estimate. The error models are considered separately for vision and UWB positioning systems, and the error prediction is performed by the corresponding covariance matrices.

The error update step calculates the observation residuals by acquiring the measurements for vision and UWB localization, including position, distance, etc. Subsequently, the Kalman gain is calculated based on the covariance matrix of the observation residuals and the measurement noise. Using the Kalman gain, the predicted state estimates are fused with the measured values to obtain the updated state estimates and error covariance matrix. Finally, the optimal position estimate of the AGV is output.

6. Experiments and results analysis

In order to verify the accuracy and robustness of the combined vision-based and ultra-wideband localization method proposed in this paper, we conducted the localization experiments in unused indoor environments respectively, and also chose 13:00 pm to avoid the influence of light on the experiments, when there is sufficient light to facilitate the experiments. An independently designed AGV was used as the mobile platform, as shown in Figure 5.

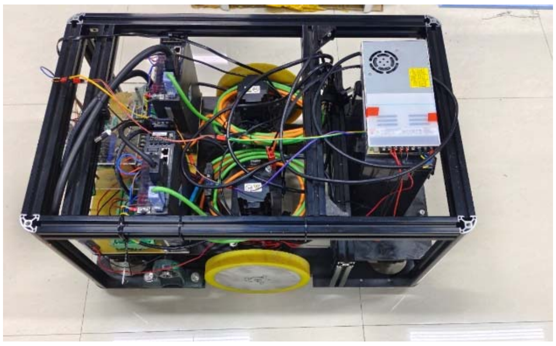

Figure 5. AGV physical object

6.1Indoor positioning experiment site selection

The experiments were conducted in the unobstructed small field and the obstructed large field, where the large field was disturbed by the indoor load-bearing column obstacle. Three UWB positioning base stations were placed two by two at equal intervals to ensure the accuracy of UWB positioning, and the AGVs collected indoor positioning data uniformly and at low speed along the preset trajectory route. The indoor test site and AGV driving trajectory are shown in Figure 6.

(a) Barrier-free small field site and AGV driving trajectory
(b) Obstructed large field site and AGV driving trajectory

Figure 6. Indoor test site and AGV driving trajectory

6.2Experimental results and analysis

After performing a series of data processing operations, such as time synchronization, on the data obtained from the two mentioned positioning methods in the article, a comparative analysis of the positioning results based on visual and UWB single positioning and combined positioning is obtained. The comparison of positioning results for the three positioning methods is shown in Figure 7 and Figure 8.

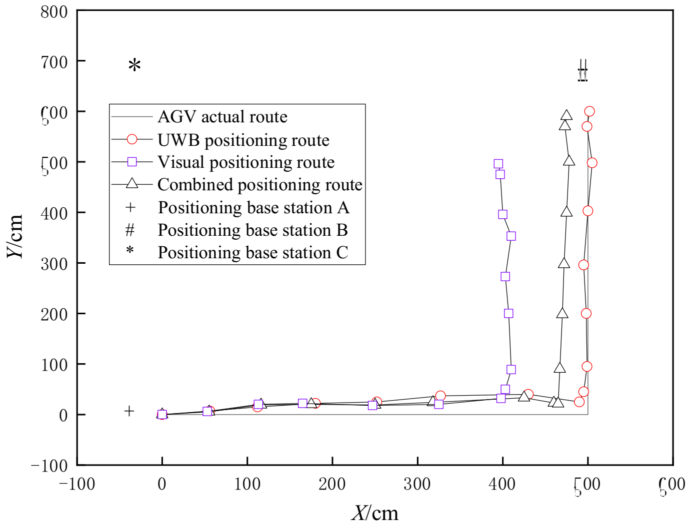

Figure 7. Indoor small-site positioning results

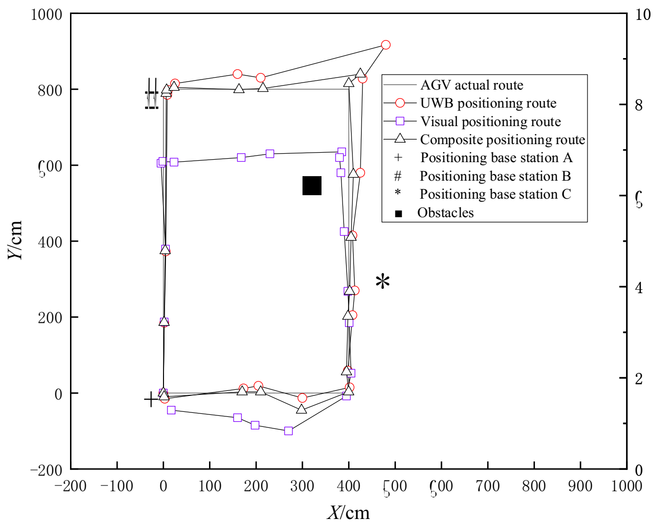

Figure 8. Indoor large-site positioning results

From Figure 7, it can be observed that the AGV achieves centimeter-level positioning accuracy solely with UWB positioning technology. The visual positioning technology provides good initial positioning results for the AGV, but as time progresses, accumulated errors lead to significant drift, resulting in poorer positioning performance in the latter part. At this point, the AGV's combined positioning system performs worse than the UWB positioning method but still outperforms the visual positioning method.

From Figure 8, it can be observed that under the condition of no obstacle interference, the single UWB positioning method achieves centimeter-level positioning accuracy. However, when there are obstacles present in the indoor environment, the UWB positioning accuracy is significantly affected by non-line-of-sight errors, resulting in noticeable jumps and errors. In the early stages of the experiment, the visual positioning results are relatively smooth overall. However, when the AGV makes turns, there are significant environmental changes within the field of view of the monocular camera, leading to the loss of feature points and tracking failures. Additionally, with the accumulation of errors, drift occurs in the later part of the trajectory. In this situation, the designed combined positioning method in the paper, through the ES-EKF data fusion algorithm, achieves higher positioning accuracy compared to the above two single positioning methods. The AGV's positioning trajectory aligns more closely with the actual trajectory.

7.Conclusions

In the face of complex indoor environments, AGVs commonly encounter challenges such as NLOS errors and low positioning accuracy during the positioning process. To address these issues, a visual and UWB-based AGV system was designed. In this system, the positioning data obtained from visual and UWB measurements were used as observations, and the ES-EKF algorithm was proposed for data fusion, leading to the optimal pose estimation of the combined positioning system for the AGV. Experimental results demonstrate that the proposed combined positioning method effectively improves the positioning performance of the AGV, with enhanced accuracy and robustness. The designed AGV system in the paper meets the practical requirements of indoor positioning in terms of scalability, stability, accuracy, and real-time capability. Moreover, the various electronic devices can communicate with the onboard industrial computer in multiple ways, providing a reference for addressing AGV navigation and positioning challenges in future work.

Acknowledgment

This research is supported by the Zhejiang Institute of Science and Technology Postgraduate Research Innovation Fund (Grant No. 2021yjskc03).

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