A method of tracking and positioning of industrial robots

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Abstract: In this paper, an improved tracking and localization algorithm of an omni-directional mobile industrial robot is proposed to meet the high positional accuracy requirement, improve the robot's repeatability positioning precision in the traditional trilateral algorithm, and solve the problem of pose lost in the moving process. Laser sensors are used to identify the reflectors, and by associating the reflectors identified at a particular time with the reflectors at a previous time, an optimal triangular positioning method is applied to realize the positioning and tracking of the robot. The experimental results show that positioning accuracy can be satisfied, and the repeatability and anti-jamming ability of the omni-directional mobile industrial robot will be greatly improved via this algorithm.

Keywords: Mobile industrial robot, Tracking and positioning, Matching.

Introduction

Across many domains, there is an increasing demand for robots capable of performing complex and dexterous manipulation tasks. A typical example is the need for factory assembly lines. With the combination of a dexter-ous manipulator and mobile platforms, mobile robots are well suited to these complex tasks. Given any complex scenario, the mobile robot must be able to achieve localization (Suwoyo, Abdurohman, et al., 2022; Yu et al., 2023). Localization is a key functionality of any navigation system as it tracks and determines the position of a mobile robot in the environment. This is a challenging topic in the area of autonomous mobile robot research (Akbar Qureshi et al., 2022; J. Zhang et al., 2023).

Many methods are proposed to address the problem of mobile robot localization; these methods can be divided as two categories: relative positioning and absolute positioning. In

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relative positioning, dead reckoning and inertial navigation are commonly used to calculate mobile robots' positions. This method does not need to perceive the external environment, but its drift error accumulates over time. Absolute positioning relies on detecting and recognizing different features in the environment in order to realize the position of the robot. These environment features are normally divided into two types: artificial landmarks and natural landmarks (Suwoyo & Harris Kristanto, 2022). Compared with the natural landmarks, artificial landmarks have advantages of high recognition and high accuracy. There is no cumulative error when a localization method based on artificial landmarks is utilized; however, the key challenge is accurately identifying and extracting the needed information from the artificial landmarks. Researchers have proposed several solutions, such as fuzzy reflector-based localization and color reflector-based self-localization. The main drawbacks of these methods are that the amount of computation power they need is too large and the anti-interference ability is poor (Suwoyo, Hidayat, et al., 2022; Tai & Yeung, 2022).

To tackle these problems pertaining to the localization method based on artificial landmarks, Madsen and Andersen proposed a three reflectors positioning method using the constraints of three reflectors and the triangulation principle to realize positioning. Betke and Gurvits proposed a multi-channel positioning method with the three-dimensional positioning principle and the least squares method to accomplish localization. Because of the unavoidable errors in position and angle measurement of reflectors, use of only a trilateral or triangular method will not achieve the required positioning accuracy (Fan et al., 2023). In the navigation of a mobile robot, some reflectors may be obscured or confused with other obstacles, leading to pose information loss of the positioning system. To solve these problems, this paper presents an improved tracking and locating algorithm of an omni-directional mobile industrial robot. The robot is used in drilling and riveting processing of sheet metal parts, and laser sensors are used to identify the reflectors. By associating the reflectors identified at a particular moment with the reflectors at a previous time, an optimal triangular positioning method is applied to realize the positioning and tracking of the robot in a global environment (Suryaprakash et al., 2021; Tan et al., 2023).

Research Method

Optimal triangulation positioning algorithm based on angle measurement

In order to achieve accurate positioning, a mobile robot must have a basic ability to perceive external information through extracting the reflector features (Zhang et al., 2022). In this research, there are n reflectors, and the feature of each reflector Bi (i = 1,2,⋯, n) is extracted from the measurement data. The feature extraction algorithm consists of three steps: (i) filtering and clustering, (ii) identification, and (iii) feature extraction.

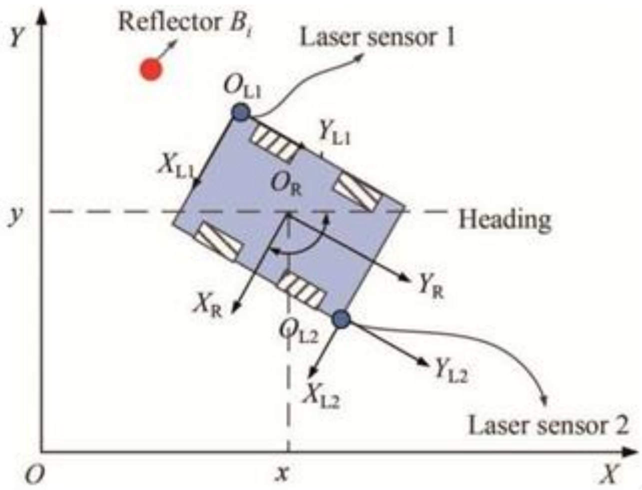

Figure 1 Coordinate system description

Coordinate system description

The measurement data obtained by each scan cycle of the laser sensor are a set of discrete data sequences $\{\{(\gamma, \phi), \lambda\}i \mid i = 1,2, \cdots, n\}$, where (γ, ϕ)i is the polar coordinate, γ the distance from the target point to the sensor, ϕ the polar angle, and λi the intensity value of the ith data point. In the process of data analysis, the outlier points that are contaminated by noise need to be filtered out (D. Zhang et al., 2023).

Considering that the density of the collected data points is proportional to the distance from the target point to the laser sensor, and to improve the efficiency of the feature extraction process, an adaptive clustering method is adopted. Unless the distance between two data points is less than the threshold d, these data points are clustered for one reflector (Li et al., 2023; Ostanin et al., 2022).

$$\delta = \gamma_{i-1}\left(\frac{\sin\Delta\phi}{\sin(\beta - \Delta\phi)}\right) + 3\sigma_\gamma \tag{1}$$

where γi–1 is the distance value of the i – 1th data point, $\Delta\phi$ the angle resolution of the laser sensor, β an auxiliary constant parameter, and σy the measurement error. The values of parameters σy and β are given as 0.01 m and 10°, respectively.

Result and Discussion

The experimental data are obtained by the LMS 100 laser sensor with a scanning range of 270° and an angular resolution of 0.25°. The outside of the reflector is wrapped by reflective tape. In the experiment environment, five reflectors are placed around the robot. Their global coordinate values are (0, 995), (0, 0), (0, 1 774), (2 905, -2 449), (3 956, -2 032), and the unit is mm, as shown in Fig. 2.

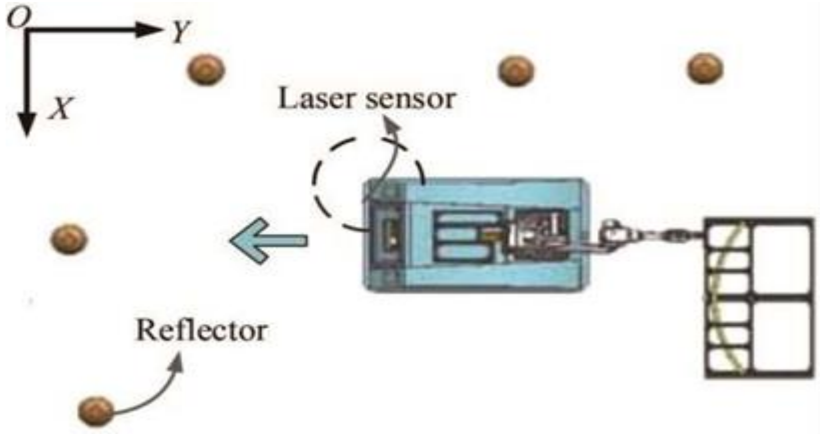

Figure 2 Experimental environment

Repeatability positioning results

The optimal triangulation method based on the angle measurement is used for validation by the repeatability of the omni-directional mobile industrial robot. In the stationary state of the omni-directional mobile industrial robot, the environment is scanned by laser sensors to realize the positioning of the robot. Each positioning result is indicated by a red dot in Fig. 3. The repeatability obtained by the trilateral method is nearly 18 mm, while the repeatability of the optimal method is only 9 mm. It can be shown that the optimal method is better than the traditional method (Sun et al., 2023).

Positioning accuracy results

The omni-directional mobile industrial robot moves in the direction of the arrow in Fig. 3, and each time the robot moves a certain distance, the navigation and positioning system will perform a positioning experiment, i.e., it will use the left rear laser sensor to calculate the current position. An average of 30 samples is taken for each experiment. Figure 4 shows the results of static positioning accuracy. The maximum distance error is 18 mm and the maximum angle error is 2°, which satisfies the positioning requirement of the omni-directional mobile industrial robot.

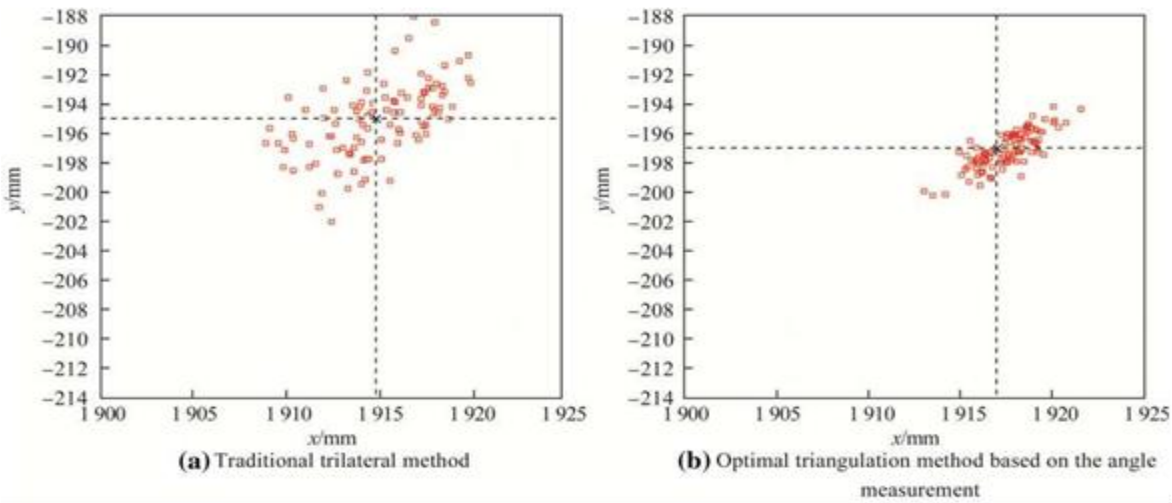

Figure 3 Repeatability positioning of the robot at the same location

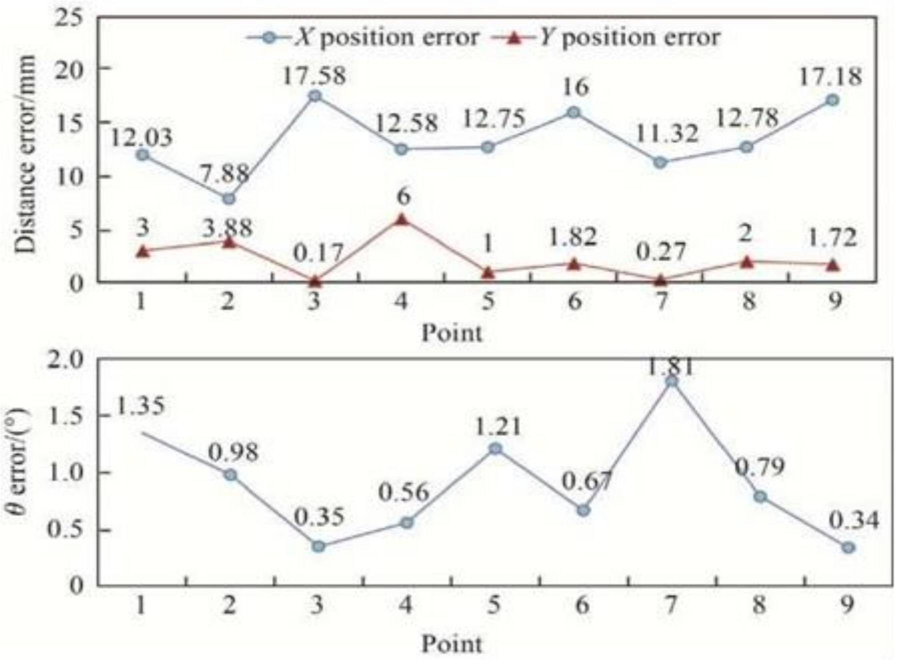

Figure 4 Omni-directional mobile industrial robot positioning error

Tracking location results

The omni-directional mobile industrial robot moves in the designated route, and it needs to constantly calculate and record its own positioning in the moving process. As shown in Fig. 5, the trajectory of the moving robot based on the tracking and positioning method is smoother.

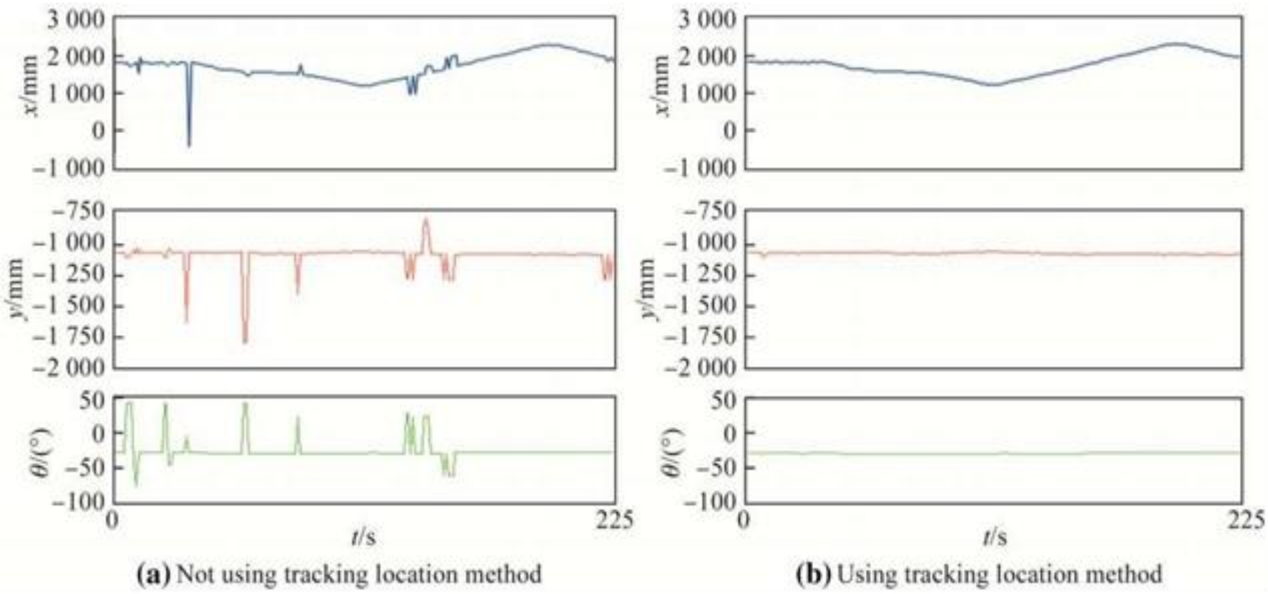

Figure 5 Robot tracking positioning results

Conclusions

This paper demonstrates the feasibility of a tracking and locating algorithm for omni-directional mobile industrial robot. The following conclusions can be drawn from this study: (i) In the detection of a reflector in the sensor coordinate system, the angle repeatability of the reflector is better than that of the distance repeatability based on the feature extraction algorithm; (ii) The repeatability positioning accuracy using the optimal triangulation method based on the angle measurement is nearly 9 mm, which is better than that of the trilateral method; (iii) The positioning error of the robot is 18 mm, which satisfies the positioning requirement of omni-directional mobile industrial robot. Improvements in the location method based on reflectors, such as optimizing the layout of reflectors and the map of reflectors selection strategy for positioning, are still needed. In the future, we intend to extend our work to research a positioning method based on reflectors and the environmental profile, and achieve better accuracy on the localization of the mobile robot.

References

Akbar Qureshi, Z., Bilal, S., Khan, U., Akgül, A., Sultana, M., Botmart, T., Zahran, H. Y., & Yahia, I. S. (2022). Mathematical analysis about influence of Lorentz force and interfacial nano layers on nanofluids flow through orthogonal porous surfaces with injection of SWCNTs. *Alexandria Engineering Journal*, *61*(12), 12925-12941. https://doi.org/10.1016/j.aej.2022.07.010

Fan, F., Xu, G., Feng, N., Li, L., Jiang, W., Yu, L., & Xiong, X. (2023). Spatiotemporal path tracking via deep reinforcement learning of robot for manufacturing internal logistics. *Journal of Manufacturing Systems*, *69*, 150-169. https://doi.org/https://doi.org/10.1016/j.jmsy.2023.06.011

Li, R., Ding, N., Zhao, Y., & Liu, H. (2023). Real-time trajectory position error compensation technology of industrial robot. *Measurement*, *208*, 112418. https://doi.org/https://doi.org/10.1016/j.measurement.2022.112418

Ostanin, M., Zaitsev, S., Sabirova, A., & Klimchik, A. (2022). Interactive Industrial Robot Programming based on Mixed Reality and Full Hand Tracking. *IFAC-PapersOnLine*, *55*(10), 2791-2796. https://doi.org/https://doi.org/10.1016/j.ifacol.2022.10.153

Sun, Y., Wang, X., Lin, Q., Shan, J., Jia, S., & Ye, W. (2023). A high-accuracy positioning method for mobile robotic grasping with monocular vision and long-distance deviation. *Measurement*, *215*, 112829. https://doi.org/https://doi.org/10.1016/j.measurement.2023.112829

Suryaprakash, M., Gomathi Prabha, M., Yuvaraja, M., & Rishi Revanth, R. V. (2021). Improvement of overall equipment effectiveness of machining centre using tpm. *Materials Today: Proceedings*, *46*, 9348-9353. https://doi.org/https://doi.org/10.1016/j.matpr.2020.02.820

Suwoyo, H., Abdurohman, A., Li, Y., Adriansyah, A., Tian, Y., & Ibnu Hajar, M. H. (2022). The Role of Block Particles Swarm Optimization to Enhance The PID-WFR Algorithm. *International Journal of Engineering Continuity*, *1*(1), 9-23. https://doi.org/10.58291/ijec.v1i1.37

Suwoyo, H., & Harris Kristanto, F. (2022). Performance of a Wall-Following Robot Controlled by a PID-BA using Bat Algorithm Approach. *International Journal of Engineering Continuity*, *1*(1), 56-71. https://doi.org/10.58291/ijec.v1i1.39

Suwoyo, H., Hidayat, T., & Jia-nan, F. (2022). A Transformable Wheel-Legged Mobile Robot. *International Journal of Engineering Continuity*, *2*(1), 27-39. https://doi.org/10.58291/ijec.v2i1.80

Tai, T. S., & Yeung, C. H. (2022). Adaptive strategies for route selection en-route in transportation networks. *Chinese Journal of Physics*, *77*, 712-720. https://doi.org/https://doi.org/10.1016/j.cjph.2021.07.024

Tan, S., Yang, J., & Ding, H. (2023). A prediction and compensation method of robot tracking error considering pose-dependent load decomposition. *Robotics and Computer-Integrated Manufacturing*, *80*, 102476. https://doi.org/https://doi.org/10.1016/j.rcim.2022.102476

Yu, Z., Yuan, J., Li, Y., Yuan, C., & Deng, S. (2023). A path planning algorithm for mobile robot based on water flow potential field method and beetle antennae search algorithm. *Computers and Electrical Engineering*, *109*, 108730. https://doi.org/https://doi.org/10.1016/j.compeleceng.2023.108730

Zhang, D., Luo, R., Yin, Y.-b., & Zou, S.-l. (2023). Multi-objective path planning for mobile robot in nuclear accident environment based on improved ant colony optimization with modified A∗. *Nuclear Engineering and Technology*, *55*(5), 1838-1854. https://doi.org/https://doi.org/10.1016/j.net.2023.02.005

Zhang, J., Lou, Z., & Fan, K.-C. (2023). Accuracy improvement of a 3D passive laser tracker for the calibration of industrial robots. *Robotics and Computer-Integrated Manufacturing*, *81*, 102487. https://doi.org/https://doi.org/10.1016/j.rcim.2022.102487

Zhang, Z., Xiao, J., Liu, H., & Huang, T. (2022). Base placement optimization of a mobile hybrid machining robot by stiffness analysis considering reachability and nonsingularity constraints. *Chinese Journal of Aeronautics*. https://doi.org/https://doi.org/10.1016/j.cja.2022.12.014