IJSES

International Journal of Scientific Engineering and Science

Volume 1, Issue 9, pp. 14-16, 2017.

ISSN (Online): 2456-7361

Calibration of Systematic Errors for Wheeled Mobile Robots

Bei Xuying, Ping Xueliang, Gao Wenyan

School of Mechanical Engineering, Jiangnan University Wuxi 214122 China

Abstract— *Odometry using encoder provides fundamental pose estimation for wheeled mobile robots. The error of odometry accumulates as the travel distance of robot increases. Calibrating the system parameters can reduce the error. The UMBmark method is widely used odometry calibration methods for wheeled mobile roborts. In accordance with the shortcomings of UMBmark method, a systematic error calibration method is proposed in this paper. The method considers the coupled effect of three main systematic errors. The experimental results show that the positioning accuracy of mobile robot can be improved by the proposed method.*

Keywords— *Wheeled mobile robot, localization, odometry, systematic error, calibration.*

I. Introduction

Localization is important for mobile robot, because accurate pose estimation is required for path planning and motion control [1]. Odometry using wheel encoders provides fundamental pose estimation for wheeled mobile robots. But the major drawback of odometry is the error accumulation as the robot's travel distance increases [2-3]. The sources of odometry error can be divided into two groups. One is the systematic error which is deterministic. Systematic error sources include unequal wheel diameters, uncertain of the effective wheelbase, misalignment, average of both wheel diameters differed from nominal diameter, limited encoder resolution and limited encoder sampling rate [4]. The other is nonsystematic error, which is stochastic. Nonsystematic error sources include travelling over uneven floors, slippery floors and fast turning [5]. Improved odometry can significantly reduce the operational costs associated with the installation and maintenance of sensors and landmarks [6-8]. Improved odometry also reduces the uncertainty of the estimated pose when the external sensors can not be used because of weather or environmental condition.

Despite the accumulation of odometry error, the calibration of systematic error is useful. The reduction of systematic errors directly contributes to the improvement of odometry accuracy. Studies related to odometry calibration have been conducted for many years. The UMBmark method [9-10] is a useful and widely used calibration scheme for wheeled mobile robots. In this method, the mobile robot is driven along a 4 meters square path in clockwise (CW) and counterclockwise (CCW) for five times. The wheel error and the wheelbase error can be calibrated by measuring the final position errors after the test run. The UMBmark method assumes that the wheel diameter error (E_d) and the wheelbase (E_b) error are independent, the scaling error (E_s) is a significant error and easy to be measured with an ordinary tape measure. The experimental results show this method can increase the accuracy of odometry effectively.

Studies show that the systematic error model of conventional UMBmark method is incomplete. In accordance with the shortcomings of UMBmark method, a new method of systematic error calibration is proposed in this paper. It considers the influence of the wheelbase error, the diameter error and the scaling error. The effectiveness and feasibility of the proposed method is verified by experiment.

II. New Calibration Method

Mobile robots use rubber tires to improve traction. But these tires are difficult to be manufactured exactly in the same diameter. This will cause substantial odometry errors. Denoting this error as E_d and defining it as:

$$E_d = \frac{D_R}{D_L} \tag{1}$$

where D_R and D_L are the actual wheel diameters.

Uncertain of the effective wheelbase is caused by the fact that rubber tires contact the floor not in a point, but rather in a contact area. Denoting this error as E_b and defining it as:

$$E_b = \frac{b_{actual}}{b_{nominal}} \tag{2}$$

where b_{actual} is the actual wheelbase of the robot, $b_{nominal}$ is the nominal wheelbase of the robot.

If the average of the actual wheel diameters D_a differs from the nominal diameter D_n, the robot will experience an additional odometry error, which is called scaling error E_s:

$$E_s = \frac{D_a}{D_n} \tag{3}$$

A. The Source of Linear Motion Error

The scaling error E_s includes the lateral displacement error and orientation error. The unidirectional square path includes four 90 degrees fixed-point rotation, the lateral displacement error can be compensated, so the effects of E_s on linear motion can be ignored [11].

In conclusion, only the wheel diameter error E_d has an effect on linear motion. It is the same as conventional UMBmark method. The unequal diameter of the wheels lead to an actual trajectory of linear mobile robot motion turning into an arc with a certain curvature. As shown in Fig. 1:

International Journal of Scientific Engineering and Science
Volume 1, Issue 9, pp. 14-16, 2017. ISSN (Online): 2456-7361

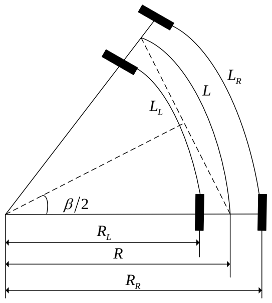

Fig. 1. The effects of E_d on linear motion.

B. *The Source of Fixed-Point Rotation Error*

1. *The effects of E_d on fixed-point rotation*

From section A, we know that the unequal diameter of the wheels lead to the actual trajectory turning into an arc with a certain curvature. It makes the mobile robot produce a certain orientation error before the fixed-point rotation, so the wheel diameter error E_d also has an effect on fixed-point rotation motion. Define α_d as an orientation error that caused by the wheel diameter error E_d. The decomposition diagram of fixed-point rotation after linear motion is shown in Fig. 2:

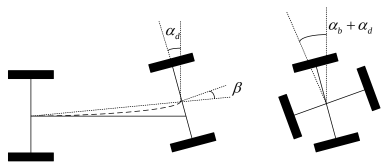

Fig. 2. Orientation error caused by two kinds of errors.

Where α_b is the orientation error caused by E_b, α_d and β satisfy the following relation [12]:

$$\alpha_d = \frac{\pi \cdot b_{nominal}}{4L} \cdot \beta \tag{4}$$

where $b_{nominal}$ is the nominal wheelbase of the mobile robot; L is the side length of the square path; β is the orientation error produced in the linear motion.

2. *The effects of E_s on fixed-point rotation*

The mobile robot rotates at a fixed point, the angular velocities of the wheels on the left and right sides are equal and opposite, so when the wheel diameter is unequal, the actual linear velocity of the wheel is in direct proportion to the actual diameter of the wheel. Because the linear velocity of the two wheels is unequal, the instantaneous center of velocity O' will not coincide with the center of the wheel axle O. Assuming that the actual diameter of right wheel is bigger than the actual diameter of left wheel, the rotation of the mobile robot is shown in Fig. 3:

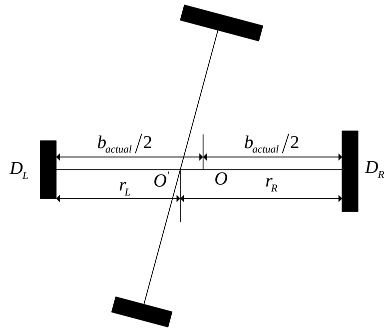

Fig. 3. The fixed-rotation with unequal diameters.

The actual rotation angle of the mobile robot is assumed to be τ, it can be deduced from Fig. 3:

$$\frac{D_R}{D_L} = \frac{r_R}{r_L} \tag{5}$$

where r_R and r_L are the distance from O to the right and left wheel.

Further deduction shows that the average of the actual diameter D_a, the average of the nominal diameter D_n, the actual rotation angle τ and the nominal rotation angle τ_n satisfy the following relations:

$$\frac{D_a}{D_n} = \frac{\tau}{\tau_n} \tag{6}$$

If $D_a \neq D_n$, then $\tau \neq \tau_n$. This is to say, error will occur when the average diameter of the wheel is unequal to the nominal diameter, it is defined as E_s, so the error caused by E_s can not be neglected for the fixed-point rotation motion. In this paper, the orientation error caused by E_s is defined as α_s:

$$\alpha_s = \tau - \tau_n \tag{7}$$

The orientation error caused by E_b is as follows:

$$\alpha_b = \alpha - (\alpha_d + \alpha_s) = \frac{x_{c.g.CW} + x_{c.g.CCW}}{-4L} \cdot \frac{180^\circ}{\pi} - \left[\frac{\pi \cdot b_{nominal}}{4L} \cdot \beta + (\tau - \tau_n)\right]$$

$$E_b = \frac{90^\circ}{90^\circ - \alpha_b} = \frac{90^\circ}{90^\circ - [\alpha - (\alpha_d + \alpha_s)]} \tag{8}$$

where $x_{c.g.CW}$ and $x_{c.g.CCW}$ are the abscissa of the center of gravity of each cluster as representative for the systematic odometry errors in CW and CCW directions. In conclusion, unequal wheel diameters, average of both wheel diameter differ from nominal diameter and uncertain about the effective wheelbase all have effects on the fixed-point rotation motion of mobile robot.

III. Experimental Verification and Result Analysis

In order to verify the feasibility and effectiveness of the improved calibration method of systematic errors. Experiments are carried out by using a self-developed JNPF-4WD mobile robot. The experimental equipment is shown in Fig. 4:

Fig. 4. The experimental equipment.

XOY is the global coordinate system of the experimental system, which is used to measure the absolute position of the mobile robot. The host computer controls the mobile robot to do square motion.

The mobile robot is driven along a 2 meters square path in clockwise (CW) and counterclockwise (CCW) for five times, and measure the absolute position error between the end point and the starting point. The UMBmark method and proposed method are used to calibrate the systematic parameters of mobile robot. The experimental results are shown in Fig. 5:

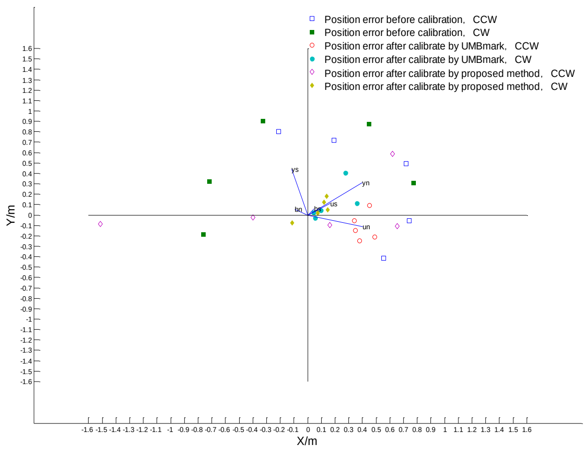

Fig. 5. The experimental results.

The absolute offsets of the two centers of gravity from the origin are denoted $r_{c.g.CW}$ and $r_{c.g.CCW}$:

$$r_{c.g.CW} = \sqrt{\left(x_{c.g.CW}\right)^2 + \left(y_{c.g.CW}\right)^2} \quad (9)$$

$$r_{c.g.CCW} = \sqrt{\left(x_{c.g.CCW}\right)^2 + \left(y_{c.g.CCW}\right)^2} \quad (10)$$

Literature [7] defines the larger value among $r_{c.g.CW}$ and $r_{c.g.CCW}$ as the measure of odometer accuracy for systematic errors:

$$E_{\max,syst} = \max\left(r_{c.g.CW}; r_{c.g.CCW}\right) \quad (11)$$

The measure of odometer accuracy for systematic errors before and after compensation are shown in table I:

TABLE I. The measure of odometer accuracy.

	$r_{c.g.CW}$	$r_{c.g.CCW}$	$E_{\max,syst}$	**Improvement**
Before compensation	0.4583	0.5043	0.5043	0
UMBmark method	0.2019	0.4175	0.2019	2.5-fold
Proposed method	0.0769	0.1099	0.1099	4.6-fold

The experimental results verify that accurate odometry calibration is improved remarkably by using the proposed method.

IV. Conclusion

This paper proposed an improved odometry calibration method. The method derives new calibration equations by considering the coupled effect of diameter errors, wheelbase errors and scaling errors. The proposed calibration experiments can be easily carried out in indoor environment and the experimental results show that the method provides more accurate calibration results than the conventional UMBmark method.

References

[1] M. Bashiri, H. Vatankhah, and S. Ghidary, "Hybrid adaptive differential evolution for mobile robot localization," *Intelligent Service Robotics*, vol. 5, issue 2, pp. 99-107, 2012.

[2] P. Y. Cheng and P. J. Chen, "Navigation of mobile robot by using D++ algorithm," *Intelligent Service Robotics*, vol. 5, issue 4, pp. 229-243, 2012.

[3] N. Ganganath and H. Leung, "Mobile robot localization using odometry and Kinect sensor," *IEEE International Conference on Robotics and Automation. Las Vegas*, pp. 91-94, 2012.

[4] S. Mondal, Y. Yun, and W. K. Chung. "Terminal iterative learning control for calibrating systematic odometry errors in mobile," *Robot*, vol. 26, issue 5, pp. 454-460, 2004.

[5] D. Jung, J. Seong, C.-bae Moon, J. Jin, and W. Chung. "Accurate calibration of systematic errors for car-like mobile robots using experimental orientation errors," *International Journal of Precision and Manufacturing*, vol. 17, issue 9, pp. 1113-1119, 2016.

[6] S. Thtun, W. Burgard, and D. Fox, *Probabilistic Robotics*, MIT Press, pp. 117-147, 2005.

[7] J. Borenstein and L. Feng, "Measurement and correction of systematic odometry errors in mobile robots," *IEEE Transactions on Robotics and Autmoation*, vol. 12, issue 6, pp. 869-880, 1996.

[8] R. Siegwart, I. R. Nourbakhsh, and D. Scaramuzza, *Introduction to Autonomous Mobile Robots*, MIT Press, pp. 265-367, 2011.

[9] W. Weihua, X. Youlun, and S. Ronglei, "Measurement and calibration of systematic errors of odometry," *Robot*, vol. 26, issue 5, pp. 454-460, 2004.

[10] C. Jung and W. Chung, "Accurate parameter estimation of systematic odometry errors for two-wheel differential mobile robots," *Journal of Mechanical Science and Instrumentation*, vol. 3, issue 3, pp. 268-272, 2012.

[11] K. Lee, C. Jung, and W. Chung. "Accurate calibration of kinematic parameters for two wheel differential mobile robots," *Journal of Mechanical Science and Technology*, vol. 25, issue 6, pp. 1603-1611, 2011.

[12] Z. Tie, C. Weihua, and M. Qiongxiong, "Calibration of systematic errors for mobile robots," *Journal of South China University of Technology*, vol. 42, issue 9, pp. 7-12, 2014.