Analysis and Research on Error-Eliminating Odometry Localization Methods (Postprint)

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Abstract

Omnidirectional mobile platforms can execute linear motion in any direction without prior rotational movement and can simultaneously perform rotational motion during linear travel, exhibiting superior maneuverability and obstacle avoidance capabilities. This paper presents an error-eliminating odometry positioning system based on the NI myRIO-1900 controller. Building upon traditional encoder- and gyroscope-based odometry positioning, infrared sensors and ultrasonic sensors are incorporated. Through mean filtering and correction, the platform' s pose is accurately measured, and accumulated errors are periodically reset to zero, achieving the elimination of cumulative error. This method has been applied to the Mobile Robot category of the 2017 WorldSkills Competition, where the competition platform demonstrated excellent motion control performance, meeting the requirements for high-speed and precise motion control. The error-eliminating odometry positioning scheme proposed in this paper offers high cost-effectiveness, strong practicality, precise control, and broad application prospects.

Full Text

Preamble

An Analysis and Research on Error-Elimination Odometer Positioning Methods

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Abstract:

Omni-directional mobile platforms exhibit excellent maneuverability and obstacle avoidance capabilities, as they can move linearly in any direction without prior rotation and can simultaneously execute rotational motion while translating. This paper introduces an error-elimination odometer positioning system based on the NI myRIO-1900 controller. Building upon traditional odometer positioning that relies primarily on encoders and gyroscopes, the system incorporates infrared and ultrasonic sensors. Through mean filtering and periodic correction, the platform's posture is measured accurately, and cumulative errors are periodically cleared to achieve error elimination. This method was successfully applied in the Mobile Robotics category of the 2017 WorldSkills Competition, demonstrating effective motion control that satisfies high-speed, high-precision requirements. The proposed error-elimination odometer positioning solution offers high cost-effectiveness, strong practicality, and precise control.

Keywords: PWM, closed-loop control, error elimination, platform positioning, motion navigation

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1 Introduction

Mobile robots are increasingly deployed across diverse fields including planetary exploration, power line inspection, healthcare, industrial manufacturing, national defense, and public services [1-3]. Precise platform localization constitutes a fundamental prerequisite for robots to accomplish designated tasks [4]. Omni-directional wheeled mobile platforms can rotate, translate, and adjust posture accurately at any 360° angle within a plane, making them suitable for navigating narrow spaces or complex paths. Localization methods for omni-directional platforms include navigation beacon positioning, map matching, GPS, BeiDou, visual tracking, and odometry [5-9]. Each approach presents distinct characteristics: navigation beacon positioning requires pre-installed markers in the environment, incurring high initial costs; map matching offers high precision but demands prior knowledge of the environment map, involves substantial computational overhead, requires large storage capacity, and cannot adapt to dynamic environments; GPS and BeiDou systems provide low positioning accuracy and may fail indoors [10]; visual tracking achieves relatively high precision but suffers from poor real-time performance and target loss due to occlusion [11]; odometry using inertial sensors [12-13] suffers from error accumulation [14-15]. The error-elimination odometer positioning method can periodically calibrate the mobile platform' s posture to eliminate cumulative errors while achieving comprehensive omni-directional motion capabilities.

2.1 Kinematic Model of Omni-Directional Platform

The omni-directional mobile platform [16-17] consists of three omni-directional wheels uniformly distributed at 120° intervals, as shown in [Figure 1: see original paper]. The platform has no non-holonomic constraints, enabling linear motion in any direction without prior rotation and simultaneous rotational motion during translation, thereby offering exceptional maneuverability.

The kinematic simplified model is illustrated in [Figure 2: see original paper], where XOY represents the world coordinate system and xoy denotes the platform coordinate system. The angle between these two coordinate systems is Φ. The three wheels are labeled i, j, and k, with linear velocities Vi, Vj, and Vk, respectively. The platform' s rotational angular velocity is , and the distance from each wheel to the platform center O is R.

In the platform coordinate system, the platform' s linear velocities along the two coordinate axes are vx and vy. The relationship between vx, vy, and Vi, Vj, Vk is given by:

$$\begin{bmatrix} v_x \\ v_y \\ \omega \end{bmatrix} = \mathbf{J} \begin{bmatrix} V_i \\ V_j \\ V_k \end{bmatrix}$$

where **J** represents the Jacobian transformation matrix.

In the world coordinate system, the platform' s linear velocities along the two axes are VX and VY. The transformation between VX, VY, and vx, vy, follows the rotation matrix:

$$\begin{bmatrix} V_X \\ V_Y \\ \omega \end{bmatrix} = \begin{bmatrix} \cos\Phi & -\sin\Phi & 0 \\ \sin\Phi & \cos\Phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} v_x \\ v_y \\ \omega \end{bmatrix}$$

The relationship between the robot' s current posture (x , y ,) and initial posture (x , y ,) is:

$$\begin{bmatrix} x_1 \\ y_1 \\ \theta_1 \end{bmatrix} = \begin{bmatrix} x_0 \\ y_0 \\ \theta_0 \end{bmatrix} + \int_0^{\Delta t} \begin{bmatrix} V_X(t) \\ V_Y(t) \\ \omega(t) \end{bmatrix} dt$$

where Δt is the robot' s operation time, and xi, yi, i (i = 0,1) represent the x-coordinate, y-coordinate, and angular orientation of the mobile platform' s posture, respectively.

2.2 Odometer Positioning Analysis

Odometer positioning calculates the mobile platform' s current posture based on changes in inertial sensor data relative to the initial state. This relative positioning method estimates the platform' s motion trajectory according to its kinematic model without requiring environmental information, offering self-adaptation advantages. However, error accumulation emerges as the trajectory progresses. Systematic errors arising from wheel diameter variations, wheelbase differences, and installation inaccuracies exhibit regular patterns, while non-systematic errors caused by wheel slippage, locking, and discontinuous wheel-ground contact during motion possess uncertain characteristics.

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3 Error-Elimination Odometer Positioning System Design

Traditional odometer methods employing motor encoders and gyroscopes suffer from error accumulation. The error-elimination odometer system utilizes the NI myRIO-1900 controller and augments traditional systems with ultrasonic and infrared distance sensors in hardware, while incorporating posture calibration subroutines in software. The system periodically calibrates the mobile platform' s posture, clearing cumulative errors caused by installation inaccuracies and discontinuous wheel-ground contact before resuming predetermined tasks. The hardware architecture is shown in [Figure 3: see original paper].

3.1 Hardware Circuit Design

The primary electrical components of the omni-directional mobile platform are listed in . Infrared and ultrasonic sensors are combined to measure the platform' s orthogonal coordinates. The system wiring diagram is shown in [Figure 4: see original paper], with sensor wiring detailed in [Figure 5: see original paper].

The platform' s locomotion structure employs three DC geared motors requiring bidirectional operation, driven by H-bridge PWM. The A4973 H-bridge PWM driver chip features built-in PWM current control with fast and slow decay modes, a 1.5A drive current, and comprehensive protection functions including overcurrent and undervoltage protection. The motor driver circuit is shown in [Figure 6: see original paper], where the PWM1 signal originates from the myRIO-1900 controller interface B/DIO8 (PWM0). M1+ and M1- connect to DC motor #1, AO1 sets the motor current limit protection point, and SENSE1 reports motor current to the myRIO-1900 controller. The normal drive current path (forward rotation), PWM current control fast decay path, and slow decay path are illustrated in [Figure 7: see original paper].

3.2 Software Design

The omni-directional mobile platform control program is implemented in LabVIEW 2015 using a modular design approach. Primary modules include gyroscope data acquisition and positioning calculation, motor speed acquisition and closed-loop control, and infrared/ultrasonic sensor data acquisition with posture calibration.

The myRIO-1900 controller obtains the platform' s current rotation angle through gyroscope data acquisition and determines its orthogonal coordinates by sampling encoder values from three motors, thereby deriving the platform' s posture, coordinates, and velocity. Motion navigation calculates compensation distance and speed based on current and target coordinates, implementing platform X-axis and Y-axis linear motion through speed and position loop control using PID algorithms. The platform periodically collects infrared and ultrasonic sensor data to calibrate X-axis and Y-axis positions. The data acquisition flowcharts for infrared and ultrasonic sensors are shown in [Figure 8: see original paper], with posture calibration schematic and flowchart illustrated in [Figure 9: see original paper] and [Figure 10: see original paper], respectively.

4 Experimental Results

Three actual distances of 100mm, 200mm, and 300mm were measured (labeled Distance 1, 2, 3) using the "Analog Input" VI to read infrared sensor data. As shown in [Figure 11a: see original paper], raw measurements exhibited deviation ranges of 12.36-15.21mm with 2.85mm fluctuation. After mean filtering, deviations reduced to 9.23-10.54mm with 1.31mm fluctuation [Figure 11b: see original paper]. The filtered deviations remained essentially constant with reduced data fluctuation. Applying deviation correction during platform position calibration yielded measurement errors of ±0.66mm.

The myRIO-1900 controller' s I/O data was acquired via FPGA. Using the same three distances, measurements via LabVIEW Real-Time (RT) module querying the FPGA showed deviations of 21.35–24.28mm with 2.93mm fluctuation [Figure 12a: see original paper]. Direct FPGA I/O reading reduced deviations to 6.34–8.26mm with 1.92mm fluctuation [Figure 12b: see original paper]. Direct FPGA access significantly decreased deviation and fluctuation; after deviation correction and mean filtering, measurement error was ±0.96mm. The large fluctuations and deviations during RT-FPGA queries occurred because ultrasonic sensor trigger and read times caused digital signal loss and delay.

Applying the aforementioned infrared and ultrasonic sensor algorithms to the omni-directional platform, multiple 10m forward linear motion tests revealed an average cumulative error of ±50mm over 10m, which remains acceptable for mobile platform target management tasks. To enhance precision, the platform followed the path shown in [Figure 13: see original paper] with posture calibration and error clearing at points A, B, C, D, and E. The relationship between platform posture error and travel distance is plotted in [Figure 14: see original paper]. The error curve divides into four segments, with error accumulating during forward motion in each segment. The third segment exhibited maximum cumulative error of 22mm. Error clearing occurred at points A, B, C, and D. The stepwise error increases (highlighted in red) resulted from wheel slippage during platform turning.

5 Conclusion

This paper proposes an improved odometer positioning method that integrates infrared and ultrasonic sensors with traditional encoder- and gyroscope-based odometry. Through mean filtering and correction, the system accurately measures platform orthogonal coordinates and posture while periodically clearing cumulative errors. In October 2017, a mobile robot implementing this method competed in the WorldSkills Mobile Robotics category, demonstrating reliable motion control performance [18,19] that satisfied competition positioning requirements.

The method is suitable for fixed-site, periodic cyclic applications such as power line inspection [20], medical services, and warehouse management. The proposed improved odometer positioning method represents a low-cost robot localization solution with high cost-effectiveness and practicality, offering significant value for promotion in omni-directional mobile robot positioning and navigation control.

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Note: Figure translations are in progress. See original paper for figures.