Research on trajectory correction model of dual magnetic navigation differential mobile robot

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Abstract. In order to improve the pose accuracy of magnetic navigation mobile robot, differential driving mobile robot is taken as the research object. The kinematics and deviation model are analyzed by means of double magnetic strip sensor navigation. The kinematic model is built in SIMULINK, and a fuzzy controller with double input and single output is designed through MATLAB, and the motion process is simulated and analyzed. The feasibility of the kinematic model is verified and the fuzzy rectifying controller designed in this paper has good rectifying control performance and response characteristics.

1. Introduction
In recent years, factories all over the world have shown an intelligent trend, and mobile robots need to be able to accurately locate in some tasks such as production line docking, material handling[1], stacking and inspection. The positioning of mobile robot includes two parts: position and attitude. Position requirements mobile robot can accurately reach the specified location[2]; The attitude of mobile robot requires the accuracy of tracking navigation, and the mobile robot will produce two deviations in the tracking process, which are the left and right position deviation and the Angle deviation of the trajectory[3]. The single-magnetic strip sensor navigation method used by traditional mobile robots can only detect its left and right position deviation relative to the track, but not the Angle deviation formed between it and the track, and its navigation accuracy has been unable to meet the actual production requirements[4]. At present, inertial measurement devices such as gyroscopes are mostly used to detect the posture of mobile robots [5]. However, because the data collected by inertial measurement units will be calculated by integration principle, a large integration error will be generated over time, resulting in the situation that the accuracy will diverge over time, so the inertial measurement units have poor navigation accuracy in the long term. Aiming at this problem, this paper proposes a new method of double magnetic navigation to improve the posture accuracy of mobile robot.

2. Differential model of mobile robot
The differential kinematic model of the mobile robot is shown in Figure 1, where the front two wheels are the driving wheels and the back two wheels are the universal wheels, and the center of the two driving wheels is the geometric center. Here, $L$ represents the driving wheel pitch, $R$ represents the motion radius, $O$ represents the motion instantaneous center, $O$ represents the geometric center of the two driving wheels, $V$ represents the forward speed of the mobile robot, $\theta$ represents the rotation
Angle of the mobile robot, $\omega$ represents the rotation angular speed of the mobile robot, $V_l$ and $V_r$ respectively represents the speed of the driving left and right wheels.

![Figure 1. Differential motion model of mobile robot](image)

By analyzing the kinematics of the mobile robot, the differential equation as shown in Formula (1) can be obtained.

$$\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{\theta}
\end{bmatrix} =
\begin{bmatrix}
\cos\theta & 0 \\
\sin\theta & 0 \\
0 & 1
\end{bmatrix} \begin{bmatrix}
V_l \\
V_r
\end{bmatrix}
$$

(1)

Set the rotational speed and wheel radius of the left and right wheels of the mobile robot as $\omega_l$, $\omega_r$ and $r$ respectively, and substitute them into Formula (1) to obtain the differential model of the mobile robot, as shown in Formula (2).

$$\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{\theta}
\end{bmatrix} =
\begin{bmatrix}
\frac{r}{2} \cos\theta & \frac{r}{2} \cos\theta \\
\frac{r}{2} \sin\theta & \frac{r}{2} \sin\theta \\
\frac{r}{L} & \frac{r}{L}
\end{bmatrix} \begin{bmatrix}
\omega_l \\
\omega_r
\end{bmatrix}
$$

(2)

3. Analysis of deviation model of mobile robot

The magnetic navigation deviation model of mobile robot designed in this paper is shown in Figure 2. The deviation of mobile robot can be divided into four cases: a, b, c and d. According to the position signal output by the magnetic navigation sensor, the deviation distance $e_1$ and $e_2$ from the midpoint of each magnetic navigation sensor to the center of the magnetic strip can be measured. The Angle deviation $\theta$ is caused by the rotational angular velocity of the mobile robot and can be calculated by the position deviation of the two magnetic navigation sensors. The Angle deviation and position deviation are determined by the speed of the left and right driving wheels. Only adjusting the speed of the left and right driving wheels can eliminate the position deviation and Angle deviation in the driving process of mobile robot, so as to achieve control effect.
Figure 2. Magnetic navigation deviation model

Here: Angular deviation $\theta_a$ of mobile robot in state a can be calculated by formula (3).

$$\tan \theta_a = \frac{e_1 - (e_2)}{d}$$  \hspace{1cm} (3)

The angular deviation $\theta_b$ of the mobile robot in state b can be calculated by formula (4).

$$-\tan \theta_b = \frac{-e_1 - e_2}{d}$$  \hspace{1cm} (4)

The angular deviation $\theta_c$ of the mobile robot in state c can be calculated by formula (5).

$$\tan \theta_c = \frac{-e_1 - (e_2)}{d}$$  \hspace{1cm} (5)

The angular deviation $\theta_d$ of the mobile robot in state d can be calculated by formula (4).

$$-\tan \theta_d = \frac{e_1 - e_2}{d}$$  \hspace{1cm} (6)

Assuming that the Angle deviation $\theta$ and distance deviation $e_1$ and $e_2$ of the mobile robot are positive in the left-biased direction and negative in the right-biased direction, the Angle deviation of the mobile robot can be expressed by formula (7).

$$\tan \theta = \frac{e_1 - e_2}{d}$$  \hspace{1cm} (7)

The position deviation of a magnetic navigation sensor and the calculated Angle deviation can be used as the control quantity of the correction of the mobile robot navigation deviation. In the tiny time period $\Delta t$, the mobile robot has a deviation during driving, and its motion deviation equation can be expressed by formula (8).

$$\begin{align*}
\Delta e &= e_1 = \left(\frac{\omega_r + \omega_l}{2}\right) r \sin \Delta \theta \Delta t \\
\Delta \theta &= \frac{(\omega_r - \omega_l)}{L} r \Delta t
\end{align*}$$  \hspace{1cm} (8)

Through Laplace transform, the deviation equation of mobile robot can be expressed by formula (9).

$$\begin{align*}
\hat{e}(s) &= \frac{(\omega_r + \omega_l)}{2s} r \sin \Delta \theta \\
\hat{\theta}(s) &= \frac{(\omega_r - \omega_l)}{Ls} r \Delta t
\end{align*}$$  \hspace{1cm} (9)
4. The simulation analysis
A fuzzy controller with double input and single output is designed to simulate the fuzzy controller with the input of position deviation and Angle deviation, and the output of which is the wheel speed difference of two driving wheels.

The position deviation of the input variable is $e$, and the domain is [-0.075, 0.075]. The fuzzy subset is divided into \{NB, NM, NS, ZO, PS, PM, PB\}, respectively representing the mobile robot relative to the Central Line of the magnetic strip \{extreme right deviation, right deviation, slightly right deviation, just, slightly left deviation, left deviation, extreme left deviation\}.

The Angle deviation of input variable is $\theta$, and the domain is [-$\pi$/10, $\pi$/10]. The fuzzy subset is divided into \{NB, NM, NS, ZO, PS, PM, PB\}, which respectively represent \{large left corner, small left corner, small left corner, small left corner, small left corner, zero corner, small right corner, small right corner, large right corner\}.

The theoretical domain of the speed difference $\Delta \omega$ between the two driving wheels of the output variable is [-8,8], and 9 subsets are defined to cover the output values, which are \{left extreme speed, left fast speed, left medium speed, left slow speed, no speed difference, right slow speed, right medium speed, right fast speed, right extreme speed\} corresponding to the fuzzy subset \{NB, NM, NS, NU, ZO, PU, PS, PM, PB\}.

A dual-input single-output fuzzy controller is designed in the fuzzy control toolbox of MATLAB. Its input and output characteristic surface is shown in Figure 3.

![Figure 3. Dual-input single-output fuzzy controller](image)

The model shown in Figure 4 is built in MATLAB Simulink and simulated.

![Figure 4. Correction model of fuzzy control for differential mobile robot](image)
In the simulation process, the mobile robot keeps uniform speed by default, and the initial speed of the two driving wheels is set as 0.6m/s, the wheelbase is set as L=0.5m, the initial position deviation is set as 0.01m, and the Angle deviation is set as π/60. The simulation figure is as follows:

![Simulation results of position deviation and Angle deviation](image)

Figure 5. Simulation results of position deviation and Angle deviation

According to Figure 5, when there is a large deviation at the beginning, the position and Angle deviation can be corrected in a relatively short time under the action of fuzzy control, so that it can quickly return to the predetermined track and continue driving. The deflection Angle $\theta$ starts to decrease from the initial $\pi/60$, and the speed of change can be seen that it is fast at the initial stage and tends to be stable at about 1.7s. The position deviation $e$ decreased from 0.01 and leveled off at about 1.3s. It is proved that the designed mobile robot control system has good control function for correcting deviation and attitude adjustment.

5. Conclusion
This paper proposes a navigation method based on double magnetic navigation. Through the detailed analysis of the four deviations of the magnetic navigation deviation model of mobile robot, a clear mathematical model is established. The correctness of the kinematic model and the good performance of the controller are proved by simulation analysis, which provides a theoretical basis for the realization of navigation correction and attitude adjustment of mobile robot.

References
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