Design of Electromagnetic Navigation System for Inspection Robot

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Abstract. Aiming at the steering control accuracy problem of electromagnetic navigation inspection robot, a steering control strategy based on the sensor weighted data fusion is proposed. In order to accurately calculate the steering angle of inspection robot, the eight sensors symmetrical distributed on the mechanical mechanism are used for signal detection, the deviating position between the navigation line and inspection robot is obtained after weighted data fusion, the weighted coefficient calculation process and location of steering angle relationship curve are given. This scheme is very suitable for application on the microcontroller because of the low computational complexity and easy control in program.

Introduction

With unmanned substation of step by step, the scene of the PV power plant inspection robot will become a trend. Because of the inspection robot trajectory is relatively fixed, so the electromagnetic navigation is a kind of low cost, high reliability of navigation [1,2]. In electromagnetic navigation early research, mainly composed of the position and direction detection [3], with the growing popularity of the application, the technology gradually turned to free-space field positioning and navigation applications [4,5]. The electromagnetic navigation technology has good development prospect because of its practicability.

In order to ensure the electromagnetic navigation robot along a predetermined orbit and reliable operation, the magnetic field signal detection and steering control solenoid are an electromagnetic rail navigation robotics research focus. Electromagnetic sensor IIR filter can effectively improve the linearity of the sensor data [6], steering servo control based on fuzzy control algorithm can improve the dynamic performance of the smart car [7], some experts had completed the electromagnetic robot navigation steering control by way of a robot positioning solution [8].

In order to get the inspection robot’s deviation from the navigation line distance, and assure the accuracy of the steering control of the inspection robot. On the basis of the existing electromagnetic navigation theory, the scheme using eight inductance sensors for signal detection, which were set up in the mechanical structure symmetrically, and calculated the inspection robot steering angle accurately by the weighted data fusion algorithm. Finally, the effect test was implemented in the inspection robot device and the test data was presented.

Detection Principle and Sensor Layout

Principle of Magnetic Field Detection

Based on the classical electromagnetic theory of Maxwell, magnetic fields are created when the alternating electric current flows. So we can lay the wires adding in a 20 KHz frequency alternating current signal in the wheeled robot pathway, and the magnetic field can used as the wheeled robot navigation signals. The signal of magnetic field can be detected by the inductor, and the wire magnetic induction strength calculation diagram is shown in Figure 1. The magnetic induction intensity of point P which is capital r from the wire can be deduced as follow based on the Biot-Savart law.
\[
B = \int_{\theta_2}^{\theta_1} \frac{\mu_0 I}{4\pi r} \sin \theta d\theta 
\]

(1)

For infinitely long conductor, parameter \( \theta_1 \) can be approximately considered as 0, and parameter \( \theta_2 \) can be approximately considered as \( \pi \), so the magnetic induction intensity can be approximate as in

\[
B = \frac{\mu_0 I}{4\pi r} 
\]

(2)

When the axis of the inductance coil is horizontal, the vertical distance between the electromagnetic induction coil and the ground is \( h \), the horizontal distance is \( x \), so the induced electromotive force can be derived as shown as follow[9]:

\[
E = \frac{h}{x^2 + h^2} 
\]

(3)

**Sensor Layout**

The trends the induced electromotive force is shown as Figure 2 with the horizontal distance change and the vertical distance \( h \) is fixed. According to the trends in Figure 2, the relationships tend to be linear between the induced electromotive force and offset distance when the horizontal offset distance within 4 centimeters. In order to improve the degree of linear sensor output, there are eight sensors set in the support with sensors spaced 3 centimeters apart in the layout.

**Signal Acquisition and Processing**

**Signal Detection and Acquisition**

The inductive sensor is PK type and the inductance value is 10mH, it has better ability in magnetic field detection. The frequency selective circuits make use of LC circuits, and the amplification is 20 through the filter and amplifying circuit. The sensors detection circuit principle diagram is shown in Figure 3.

**Signal Filter Processing**

Due to the inductance characteristic and the subsequent processing circuit characteristic being inconsistent, the different sensors have different output although at the same height and same location, this problem will lead to subsequent steering control error unless it was handled. So the first
thing is normalization of the output of the sensors, the normalization can ensure the sensor’s output values only associate with offset instead of the processing circuit, the normalization formula is shown as follow:

\[
VL_i = \frac{ad_i - \min}{\max - \min} \times 100
\]

where \( VL_i \) is the normalized value of sensor \( i \), \( ad_i \) is the value of sensor \( i \) after AD converter, \( \max \) is the calibrated maximum, \( \min \) is the calibrated minimal.

\[
\begin{align*}
\text{Figure 3. Sensor detection circuit principle diagram.}
\end{align*}
\]

**Data Fusion Algorithm**

**Support Matrix**

Data fusion technology is a comprehensive data processing technique, which can comprehensively processes the information on multi-source, multi-type and multi-level [10, 11]. N sensors were used to measured the same parameter for different azimuth, \( x_i(k) \) and \( x_j(k) \) are measurements of the sensor \( i \) and the sensor \( j \) both in the moment \( k \), the large difference between the two measurement shows that the support degree of the sensor’s measurement is low. On the contrary, the support degree is high. For uniform quantization process, the support function in moment \( k \) can be shown as follow by using the membership function in the fuzzy set theory\[12\].

\[
s_{ij}(k) = \frac{2 \arccot(|x_i(k) - x_j(k)|)}{\pi}
\]

(5)

In order to measure the mutual support between the sensor’s measurements, the support matrix of the sensor’s data can be structured by \( s_{ij}(k) \) in moment \( K \).

\[
S^{(k)}_n = \begin{bmatrix}
1 & s_{12}(k) & \cdots & s_{1n}(k) \\
s_{21}(k) & 1 & \cdots & s_{2n}(k) \\
\vdots & \vdots & \ddots & \vdots \\
s_{n1}(k) & s_{n2}(k) & \cdots & 1
\end{bmatrix}
\]

(6)

**Weighted Data Fusion**

To make the measurement results more accurate, the need for multiple sensors data fusion, the \( w_i(k) \) is
the weighting factor of the measurement data $x_i(k)$ of sensor $i$ in the time $k$, so we can use $w_i(k)$ and $x_i(k)$ weighted sum, while the weighting coefficients $w_i(k)$ is defined as in

$$\sum_{i=1}^{n} w_i(k) = 1, \quad 0 \leq w_i(k) \leq 1$$

(7)

So the expression of multiple sensors data fusion at time $k$ can be shown as follow, the use of different weighted coefficients ensure the data fusion result more accurate.

$$\hat{x}_k = \sum_{i=1}^{n} w_i(k)x_i(k)$$

(8)

**Determine the Weight Coefficient**

Figure 4 shows the block diagram of the layout of the sensor, eight sensors are distributed symmetrically, the distances of the right four sensors to the car centerline are L1, L2, L3, L4 respectively, the vertical distance from the servo to board is D, and the maximum steering angle of the servo is $\pm 57^\circ$. So the weighting coefficients can be set according to the off-center position distance L. Since the sensor symmetrically distributed, so that the sensor S1 and S8 from the center to the circuit board are L4, the weighting factors can be calculated by the angle which is calculated by arctangent, the relationship of the mechanical parameters and weighted coefficient is shown in Table 1.

![Diagram of sensor layout](image)

**Table 1. Mechanical parameters and weighting coefficient corresponding to relational.**

| Sensor number |
|---------------|-----------------|-----------------|-----------------|-----------------|
| 1,8           | 129             | 145             | 57              | 0.404           |
| 2,7           | 98              | 145             | 40              | 0.306           |
| 3,6           | 67              | 145             | 10              | 0.202           |
| 4,5           | 26.1            | 145             | 0               | 0.064           |
The Experimental Data and Result Analysis

In order to verify the feasibility of the program, the zero point value is the output value of the sensor, where the sensor is located directly above the signal line, and read sensor’s output after left and right translation of the sensors. The measurement data of the eight sensors were recorded sequentially, and fuse the data after the normalization. the position-steering angle curve shown in Figure 5, according to the data curve, the fused position-steering curve and the actual position-steering curve are consistent, the results show that the measuring errors of the steering angle meet the accuracy requirements by the way of weighted data fusion.

Conclusions

In the paper, the electromagnetic navigation system of inspection robot is designed based on the principle of electromagnetic detection. In order to guarantee to the precision of steering control, the weighted coefficient is set and computed by the mechanical structure, data fusion adopts the weighting fusion algorithm. This scheme can accurately calculate the turning angle of robot by the distance bias of the robot, and system error was analyzed by the position-steering angle curve after weighted data fusion. The test results show that the system achieves the accurate testing of the robot’s steering angle, the predicted value relative error in 5%, meets the demand from control.

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