Magnetic Target Position Estimation Method Based on Prior Information

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Abstract. Aiming at the problem of detection and location of magnetic targets in water beach, the acoustic magnetic composite detection method is studied. After the sonar obtains the image of the suspicious object in the target area, the magnetic target recognition and location are realized by using the abnormal magnetic field distribution data near the target area measured by the shipborne magnetic sensor and the multi-sensor information fusion method. A target recognition and location method based on a priori information is proposed to solve the problem that the measurement results of magnetic sensor can not fully reflect the influence of ferromagnetic target on the surrounding magnetic field due to terrain constraints. In order to make up for this lack of information, taking the sonar measurement results as a priori information, the hypothesis test method is adopted to make full use of all the measurement results of different types of sensors to realize the recognition and positioning of magnetic targets.

1. Introduction
The ferromagnetic target in the geomagnetic field will affect the magnetic field distribution in its vicinity. Theoretically, the position of ferromagnetic target can be estimated by measuring the magnetic field distribution. In engineering practice, for the magnetic field measurement of underwater ferromagnetic target, it is necessary to carry magnetic sensor with the help of moving platform, and the movement of the platform will affect the measurement of the sensor; On the other hand, for the target close to the beach, the underwater platform, such as various measuring ships, cannot measure vertically above the target, and can only measure part of the magnetic field generated by the magnetic target [1-3].

Figure 1. Schematic diagram of motion path of magnetic sensor measurement carrier platform.
As shown in figure 1, the ship cannot measure along the path shown in AA' in the figure, so the "over the top" measurement data about the target cannot be obtained. It can only be measured along BB' path and its parallel path, so the measurement results must not reflect the full impact of ferromagnetic target on the surrounding magnetic field. In order to make up for this lack of information, it is necessary to take the sonar measurement results as a priori information and adopt the information fusion method in order to make full use of all the measurement results and realize the classification and positioning of targets.

2. Magnetic field generated by ferromagnetic target

In a small range, it can be considered that the geomagnetic field is an "invariant field". The existence of ferromagnetic targets will "disturb" the geomagnetic field. The magnetic induction vector generated by a single magnetic dipole in the surrounding space is [4]:

\[
\vec{B} = \frac{\mu}{4\pi} \left( \frac{3(\vec{m} \cdot \vec{r})\vec{r}}{r^5} - \vec{m} \right),
\]

where, \(\vec{m}\) represents the magnetic moment of the magnetic dipole, \(\vec{r}\) represents the vector diameter of the source point to the field point, and the direction of \(\vec{r}\) points from the center of the magnetic dipole to the calculated field point.

According to the above formula, the magnetic field distribution results shown in figure 2 can be obtained by simulating four independent ferromagnetic targets. In the area of x-axis [-20,20] m and y-axis [-20,20] m, there are four ferromagnetic targets, whose positions are: (5,15) m, (4,13) m, (3,12) m and (2,10) m. figure 2 (a) ~ (d) respectively show the magnetic field "disturbance" generated by a single target, and figure 2 (e) shows the results of the combined magnetic field "disturbance" of these targets.

If the distribution positions of ferromagnetic targets change, namely: (-5, -15) m, (4,13) m, (3,12) m, (2,10) m, the magnetic field distribution is shown in figure 3.

Comparing figure 2 and figure 3, it can be intuitively concluded that the distribution information of the joint magnetic field contains the information of the distribution of independent ferromagnetic targets. It is a kind of inversion problem to obtain the target distribution by measuring the joint magnetic field. Its analytical solution is affected by many factors, and it is difficult to draw a deterministic conclusion. At the same time, the actual constraints shown in figure 1 also pose a challenge to the measurement of the complete information of the joint magnetic field. On the premise...
that only part of the information of the joint magnetic field can be measured, how to estimate the position of the ferromagnetic target is the following problem to be discussed.

3. Influence of ship motion on measurement results of magnetic sensor

The constant magnetic field generated by the hard magnetic material of the carrier platform, the induced magnetic field generated by the soft magnetic material under the action of the geomagnetic field, and the eddy current field generated by cutting the geomagnetic field at the conductive part will interfere with the magnetic field measurement of the magnetometer, resulting in the vector superposition of the target signal magnetic field, geomagnetic field, platform related magnetic field and environmental magnetic field.

It is assumed that the ship's heading angle is within 0°~360°, and roll angle and trim angle have peak values of 5°, the error caused by the attitude angle error to the measured value of the magnetic sensor can be calculated, as shown in figure. 4.

4. Target classification and location fusion algorithm based on partial magnetic field measurement results and sonar sensor prior information

It can be seen from the above two sections that the magnetic sensor mounted on the moving platform is difficult to directly measure and obtain the target magnetic field distribution information, which is due to the interference of motion and limited to the special position of the target. Under such conditions, the information obtained by directly using the measurement results of the magnetic sensor is very limited. It is necessary to combine the measurement results of sonar sensor and adopt the method of signal decomposition to estimate some information related to the target from the complex magnetic field information obtained by magnetic sensor, so as to realize information fusion and target classification and positioning. The following describes the execution steps of this fusion process using simulation data.

![Figure 4. Influence of attitude angle error on magnetic field strength measurement error.](image)

The simulation scene is set as follows: in the measured environment, there are four objects suspected to be targets detected by sonar sensor. According to the principle of sonar detection, the positions of these four objects can be given. On this premise, it is hoped to further determine which of the above four objects are objects with ferromagnetic properties through the measurement data of the magnetic sensor, so as to classify the sonar measurement results.
In this process, the prior information used includes the following categories: first, the sonar detection results, including the size and position information of the object; The second is the prior knowledge of target characteristics, including the approximate range of target ferromagnetic characteristic parameters; The third is the calculation assumptions of magnetic field distribution, such as geomagnetic characteristics. The implicit information is that the targets detected by sonar include two categories: targets with ferromagnetic characteristics and targets without ferromagnetic characteristics. In the context of this study, it can be understood that the targets detected by sonar may be man-made obstacles (with ferromagnetic characteristics) or natural objects such as reefs. With the support of this prior information, the hypothesis test [5] method can be used to estimate which of the above targets have ferromagnetic properties.

If the four targets are all ferromagnetic targets, after their respective positions are known (measured by sonar), their respective magnetic field distribution can be calculated, as shown in figure 5; Their joint magnetic field distribution is shown in figure 6, and the measurement results of the joint magnetic field by the magnetic sensor are also shown in figure 6. It can be seen that it is difficult to directly distinguish the actual distribution of the combined magnetic field [6] from the measurement results of the magnetic sensor.

If target 3 does not have ferromagnetic characteristics, that is, only three of the four targets measured by sonar have ferromagnetic characteristics, the joint magnetic field distribution is shown in figure 7. Now, the problem to be solved can be described as "how to judge the number and position of ferromagnetic targets after obtaining the measured values of magnetic sensors and sonar measurement results".

![Figure 5. Schematic diagram of target magnetic field distribution.](image-url)
To solve the above problems, we first need to decompose the measured value obtained by the magnetic sensor, in order to decompose the signal with the lowest frequency from other high-frequency interference. The reason for this is that the target we want to judge is a stationary target. The magnetic field can be considered as a fixed and low-frequency signal during observation task span. Compared with the target magnetic field, the periodic variation magnetic field of the measured value caused by the platform motion is a high-frequency signal. The calculation results are shown in figure 8. (a) shows low frequency magnetic field distribution corresponding to measured values of three targets, (b) shows low frequency magnetic field distribution corresponding to three target theoretical values, (c) and (d) represents the corresponding situation of the four objectives.

As can be seen from figure 8, the measured values and their corresponding theoretical values have strong similarity. If the measured results are as shown in the first figure in figure 5, and the two theoretical values shown in Figure 5 can be calculated through the prior information, then by comparing the first figure and the two theoretical values, we can intuitively conclude that the
measured results tend to be consistent with the theoretical values in the upper right corner. In this way, we can compare the measured data with the prior information. The ferromagnetic target and its distribution are judged.

5. Conclusion
Aiming at the situation that the measuring ship cannot approach the target in the process of underwater magnetic target detection, this paper proposes target recognition and positioning method based on acoustic/magnetic fusion. The target in the area is measured by sonar sensor and the suspicious targets are marked. On this basis, some magnetic field information measured by magnetic sensor is used. The magnetic field theoretical calculation results closest to the measured values are sought by hypothesis test to find the distinguishing magnetic targets from multiple targets measured by sonar. The limitation of this method is that it is difficult to eliminate the inherent magnetic substances in the environment through the algorithm, which affects the accuracy of target recognition.

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