Summary of Research on Geomagnetic Navigation Technology

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Abstract. Summarizes the technical principles of geomagnetic matching navigation, expounds the navigation solution process of MAGCOM, SITAN and ICCP three main matching navigation algorithms, and discusses the application status of geomagnetic navigation technology from the three geographical environments of satellite, air and underwater. It points out the research prospects of geomagnetic matching navigation and provides reference for the research and development of geomagnetic navigation technology.

1. Introduction

The geomagnetic database is established by using the magnetic field signal of the target area collected by the geomagnetic sensor. Geomagnetic navigation is to use the established database for real-time matching to determine the final route. The realization of geomagnetic navigation mainly involves two technologies, namely geomagnetic filtering technology and geomagnetic matching technology. The collected magnetic field signals must contain external noise. Geomagnetic filtering technology refers to the use of suitable algorithms to process the collected magnetic field signals to obtain usable information [1][2][3][4]. Geomagnetic matching technology refers to the use of matching algorithms to match the real-time collected geomagnetic data with the pre-established database, within the allowable range of similarity, determine the magnetic field information with the highest degree of matching of the collected information, and select the navigation route [5][6] [7][8].

This article summarizes the technical principles of geomagnetic matching navigation, expounds the navigation solution process of three main matching navigation algorithms, and discusses the application status of geomagnetic navigation technology from the three geographical conditions of satellite, air and underwater, and points out the application of geomagnetic matching navigation. The research prospects provide references for the development of geomagnetic navigation technology.

2. Principles of Geomagnetic Navigation Technology

Geomagnetic matching algorithm is the core of geomagnetic navigation technology. The basic method of matching is to collect discrete geomagnetic data during the movement of the carrier, combine the data with the inertial navigation system, and find the closest motion curve in the appropriate area as the final match result.
MAGCOM (geomagnetic contour matching algorithm) has the advantage of being easy to implement and is widely used in engineering practice [9]. The algorithm uses the geomagnetic sensor to obtain the geomagnetic field data of the target area, uses the inertial navigation system and the geomagnetic reference map, through the matching calculation of the geomagnetic field information and the measurement sequence, and combines the correlation criterion to calculate the similarity of the two sets of information, and finally determines the best forward way.

The navigation process of MAGCOM is as follows: use the geomagnetic reference map and the inertial navigation system to determine the geomagnetic reference sequence, and determine the magnetic field data of each point through the geomagnetic reference sequence; use the magnetic field sensor to measure the geomagnetic data, extract the relevant feature quantities, and obtain the measurement sequence in real time. The real-time measurement sequence is compared with the reference sequence, and the appropriate algorithm is used to complete the similarity calculation and output the navigation position.

SITAN (Sandia Inertial Terrain Aided Navigation) is a terrain-assisted navigation system developed in the United States. It continuously processes SINS signals through Kalman filtering to obtain relatively pure magnetic field information to complete auxiliary geomagnetic navigation. The difference between the elevation information and the navigation depth is used as the relative distance of the aircraft, which is also the estimated value of the altitude. [10].

3. Application of Geomagnetic Navigation Technology
In recent years, the rapid development of microelectromechanical technology, artificial intelligence technology and magnetic detection technology has greatly promoted the research of geomagnetic navigation technology. Magnetic navigation technology has gradually attracted the attention of various countries in the field of navigation technology [11]. With its unique advantages, geomagnetic navigation technology has been widely used in three fields: satellite, air and underwater.

3.1. Application of Satellite Geomagnetic Navigation Technology
In 1989, Psiaki and others of Cornell University studied the feasibility and potential performance of two spacecraft magnetometer-based navigation methods [12] [13]. The data filtering results from the simulation of the true value model predict the accuracy of the method. The true value model includes random magnetometer noise, random star sensor attitude error and high spatial magnetic field uncertainty. For low altitudes (about 500 km) and large inclination (45 degrees or greater), the system has the highest accuracy. This study predicts that the accuracy of the position model is about 200 m, and the accuracy of the field model coefficients is 1 nT [14]. Wiegand used the actual spacecraft data of the BREM-SAT mission to develop an autonomous orbit determination system for low earth orbit spacecraft, and conducted simulation tests and inspections [15]. Mohammad introduced a navigation concept that applies to nanosatellites equipped only with magnetometers. It highlights the latest geomagnetic field models available and gives a brief overview of the magnetometers used in microsatellites and nanosatellites [16].

In 2000, the Chinese Academy of Sciences studied the study of geomagnetic navigation methods for near-Earth small satellites, using simulation experiments to verify the effectiveness of MAGSAT, and using measured data to further verify the feasibility of the navigation and positioning method [17]. It is shown in figure 1. In 2002, Wu Meiping proposed to apply the three-axis magnetometer to the positioning of satellite orbits, and simulated the experimental results, and the conclusions reached provided a theoretical basis for the application of geomagnetic navigation in satellites [18].
Zhao Minhua and others combined the radar altimeter and the geomagnetic navigation system to locate the satellite, and completed the simulation experiment using the measured data, the experimental effect is relatively ideal [19] [20] [21] [22]. In 2004, in order to study the matching reference map in a certain area, the 35th Institute of the Third Academy of Aerospace Science and Technology conducted the construction of the geomagnetic reference map in this area, and simulated the geomagnetic matching navigation accuracy of the area, which has a good navigation effect. Literature [24] proposed a new guidance law, which can not only control the impact time of the homing problem of the aircraft, but also control the impact angle.

3.2. Application of Aerial Geomagnetic Navigation Technology
J.F.Vasconcelos[25] [26] proposed to use the relevant information of two vectors of geomagnetism and gravity in order to correct the accumulated errors of low-precision navigation and positioning systems. Combining GPS to correct the position and speed information of the inertial navigation, greatly improve the navigation accuracy. Russia has made considerable progress in geomagnetic air navigation and positioning. It is shown in figure 2[27] [28]. Yang Xu extended the geomagnetic field model and proposed using the filter state to replace the uncertainty of the magnetic field model, and correcting the Gaussian coefficient of the model when filtering the magnetic field data. The simulation results show that the navigation and positioning effect has been significantly improved [29] [30]. The description of the integrated navigation system uses the relevant principles of actual coordinate determination to determine the best navigation by finding the best fit between the geomagnetic profile measured on board during the flight and the corresponding profile stored on the ship’s map. The problem of accurate measurement of EMF on airplanes [31]. In 2007, France used geomagnetic navigation technology to complete precision guidance, simulations and actual launch experiments conducted theoretical and actual verification of this technology, and completed a live ammunition launch [32].

Literature [33] studied the navigation method that combines inertial navigation and geomagnetic navigation, using Kalman filter and extended Kalman filter method to process the data, the results show that the data processing effect of Kalman filter method is significantly better than extended Kalman
filter. The literature [34] [35] established a simulation study on the application of geomagnetic navigation in missiles based on the global geomagnetic field model. Aiming at the impact of model repetition on accuracy, it pointed out that autonomous navigation has a higher effect on the initial and mid-stage guidance of cruise missiles. The precision. Literature [36] [37] modeled the geomagnetic field in a certain area based on the geomagnetic field model, simulated the research process of geomagnetic navigation, and achieved high navigation accuracy. Kong Yanan et al. established a similarity criterion for geomagnetic matching, took Hausdorff distance as an evaluation index, and completed physical experiments using measured data [38]. In 2019, in order to improve the positioning accuracy of the inertial/geomagnetic integrated navigation algorithm, Xiusheng Duan et al. proposed an integrated navigation method based on a matching strategy and hierarchical filtering. Simulation and physical experiments verify the feasibility and effectiveness of the algorithm. Compared with the integrated filtering algorithm that directly uses the error equation of the inertial navigation system as the state equation, the layered filtering algorithm can achieve higher positioning accuracy [39].

3.3. Application of underwater geomagnetic navigation technology
Inspired by the experimental work of geomagnetic field-assisted navigation for aquatic animals, we focus on the application of the inertial system to the earth's geomagnetic and sounding field maps to navigate the AUV [40]. In 2010, Since the AUV described here is designed to obtain magnetic field measurements, the second advantage is particularly important. In simulation and experimental testing, the proposed EKF understands the calibration deviation of the magnetic heading sensor and improves the heading estimation in the presence of magnetic interference [41]. It is shown in figure 3. It is allowed to fly in all directions at the actual possible turning speed. The digital elevation model (DEM) of the flight area with a resolution of 30m is used. The proposed method is based on searching and matching the terrain elevation value under the UAV in the DEM, and using simulation technology to test its accuracy and performance. The entire algorithm uses a series of elevation values with a predetermined length (ie, longitudinal section). During the flight, a series of terrain elevations measured by radar and barometric altimeter will be searched in a small neighborhood of the corresponding contour set [42]. In 2015, Meng W et al. proposed a magnetic gradient-assisted navigation based on adaptive SLAM [43].

![Figure 3. AUV magnetic navigation system in America](image)

4. Research prospects
As a new and very advantageous navigation method, geomagnetic matching navigation shows great application potential. In recent years, it has shown an important development direction of integrated navigation with inertial navigation, satellite navigation and other technologies. Its development direction can be summarized as the following aspects:

(1) In-depth study of the error correction of the geomagnetic navigation module itself. The measured geomagnetic data includes a variety of interference components. When the geomagnetic data is preprocessed, the compensation and elimination of geomagnetic anomalies can be studied, and better correction methods can be studied to correct the errors of the geomagnetic navigation module itself, which can improve the accuracy of geomagnetic information sampling.

(2) Improve real-time solution efficiency. Algorithm matching takes a long time. Consider incorporating new algorithms into the geomagnetic matching problem. Before the trajectory is matched,
the possible matching trajectories are stored in the computer to shorten the matching time in the real-time matching process.

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