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Simultaneous localization and mapping method for geomagnetic aided navigation

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ABSTRACT

In this paper, a geomagnetic correcting navigation method is developed inspired by the simultaneous localization and mapping method, which can greatly improve the positioning precision, and helps to improve the mapping accuracy. The geomagnetic characteristic information on navigation path was analyzed during the navigation. The error models of simultaneous localization and mapping method combined with inertial navigation system were described to help developing Kalman filter. Simulations based on the actual geomagnetic reference map have been performed for the validation of the proposed algorithm. The method's feasibility is further demonstrated by analysis of optimal segment length using Monte Carlo simulation.

1. Introduction

Geomagnetic aided navigation (GAN) is an essential technique for flight vehicle navigation in some environments where positioning system such as GPS (global positioning system) are not available. It has a bright future due to its advantages of passive, all-time, all-weather, all-terrain, low weight, no accumulative error and so on [1,2]. In recent years, using geomagnetic information to assistant Inertial Navigation System (INS) has become a hot topic in the research area of navigation. The basic principle of Geomagnetic Aided Inertial Navigation System is to utilize geomagnetic matching algorithm to compare the geomagnetic measure sequence with the stored geomagnetic map for matching [3,4]. Then the matching results are used to update the INS to bound inertial errors.

As for GAN, matching precision depends on not only geomagnetic matching algorithms but also the precision of geomagnetic prior knowledge [5,6]. But typical environments cannot provide precise geomagnetic map about the carrier working environments. Moreover, in the flight, the carrier itself may also lacks of precise location information. So, is it possible to allow the carrier to detect geomagnetic signals under uncertain condition of its own location, to build a map based on geomagnetic characteristics and measurements, and then use the same map to compute the carrier's location?

This is known as a simultaneous localization and mapping (SLAM) problem, and various efficient SLAM techniques for solving the problem have been proposed from the 90 s of last century [7,8]. Experiments show that so long as the map features and the relative position of the carrier can be measured, combined with a certain filtering algorithm, the problem can be achieved [9,10]. However, due to the particularity of geomagnetic navigation, only the geomagnetic information of the current position can be obtained at one time, and the geomagnetic value at other positions cannot be detected remotely [11]. It is clear that traditional SLAM method is difficult to apply to geomagnetic navigation.

This paper presents a navigation method suitable for geomagnetic navigation draws on the basic idea of SLAM method. The priori geomagnetic map is pre-processed with path analysis and feature extraction during the navigation. Then, the proposed method

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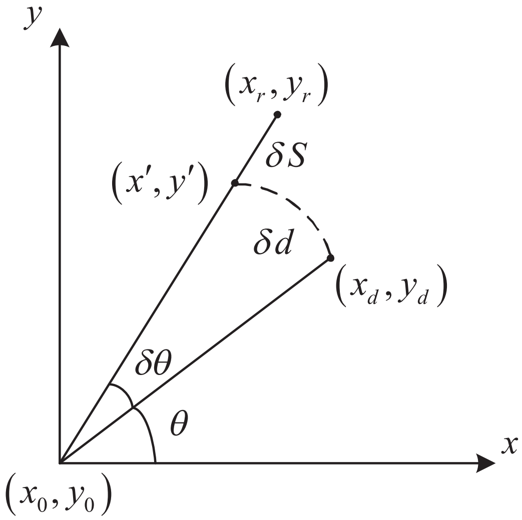

Fig. 1. Diagram of INS trace.

combines the INS output with the corresponding feature information in the priori map as the system state vector. Along with the geomagnetic measurement of each point on the motion path, the Kalman filter is built to realize the purpose of simultaneously correcting the priori geomagnetic map and the carrier its own state of motion.

2. Problem description

In the two-dimensional plane, motion equations of carrier can be expressed as follows

$$\begin{cases} x_d = x_0 + v\cos\theta \\ y_d = y_0 + v\sin\theta \end{cases} \tag{1}$$

where (x_d, y_d) is the desired location corresponds to a pair of latitude and longitude coordinate (λ, ϕ), the system input determined by velocity v and heading angle θ.

However, the positioning error of INS accumulates along with time, so the real location of the carrier (x_r, y_r) can be represented as shown below.

$$\begin{cases} x_r = x_0 + (v + \delta v)\cos(\theta + \delta\theta) \\ y_r = y_0 + (v + \delta v)\sin(\theta + \delta\theta) \end{cases} \tag{2}$$

where δv denotes the errors of velocity (and accelerometer), $\delta\theta$ denotes the errors of heading (and gyroscope). The illustration of INS movement trace is shown in Fig. 1.

In Fig. 1, (x', y') is the predicted position which has the same length of movement trace with (x_r, y_r) in the desired path. δS denotes the error of travel distance between (x', y') and (x_r, y_r), and δd denotes the error of heading distance between (x_d, y_d) and (x', y').

Recent years, there are two typical ways to achieve geomagnetic navigation, geomagnetic matching and geomagnetic filtering [12]. Whether it is matching the geomagnetic measurements with the reference map, or providing corrections to the state vector based on the actual magnetometer measurements, both of them are evaluated with the employment of real geomagnetic field data. Since the positioning error of INS accumulates along with time, these real measurements of geomagnetic field cannot correspond to their real positions. Therefore, these measurements are generally only used to positioning the carrier's location during the navigation.

In this paper, by extracting the feature of the desired position according to the priori geomagnetic map, the trace of carrier can be corrected to the real position, so that the geomagnetic map can be updated with the actual geomagnetic measurements.

3. Analysis of the priori geomagnetic map

Geomagnetic field data is stored in computers in the form of grids and describes the space variation of geomagnetic field. When the carrier passes through the reference area of the geomagnetic field, the carried magnetometer gathers a set of geomagnetic measurements. B_r denotes the measurement of geomagnetic field of coordinate (x_r, y_r). B_d denotes the geomagnetic value of the desired location (x_d, y_d) derived from the priori map. The purpose of this paper is to correct the desired location (x_d, y_d) to the real location (x_r, y_r), with the actual values of the geomagnetic measurements corresponding to the corrected positions.

In the navigation process, take no account of the error of heading angle in this part, i.e., $\delta\theta = 0$. So (x_r, y_r) is coincide with (x', y'). See Fig. 2.

Take the travel distance S as the horizontal axis, and the geomagnetic field value B as the vertical axis. Compare the geomagnetic