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Research article

Underwater terrain-aided navigation system based on combination matching algorithm

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ABSTRACT

Considering that the terrain-aided navigation (TAN) system based on iterated closest contour point (ICCP) algorithm diverges easily when the indicative track of strapdown inertial navigation system (SINS) is large, Kalman filter is adopted in the traditional ICCP algorithm, difference between matching result and SINS output is used as the measurement of Kalman filter, then the cumulative error of the SINS is corrected in time by filter feedback correction, and the indicative track used in ICCP is improved. The mathematic model of the autonomous underwater vehicle (AUV) integrated into the navigation system and the observation model of TAN is built. Proper matching point number is designated by comparing the simulation results of matching time and matching precision. Simulation experiments are carried out according to the ICCP algorithm and the mathematic model. It can be concluded from the simulation experiments that the navigation accuracy and stability are improved with the proposed combinational algorithm in case that proper matching point number is engaged. It will be shown that the integrated navigation system is effective in prohibiting the divergence of the indicative track and can meet the requirements of underwater, long-term and high precision of the navigation system for autonomous underwater vehicles.

As the basic navigation system for Autonomous underwater vehicles (AUVs), a primary drawback of the strapdown inertial navigation system (SINS) is the time-accumulating error, which necessitates frequent revisions and calibrations of the navigation on a long voyage. Terrain-aided navigation (TAN) system has been applied to correct the drifting errors of the SINS and has become a new research direction in underwater integrated navigation technology [1–4].

Originating from 1950s, TAN has been studied as a reliable method for assisting SINS in aerocraft area. Research on underwater terrain navigation is much later than in aerocraft area, because its applications of underwater is more difficult than in air and land navigation systems due to the special underwater environment [5–9]. For example: due to the sediment effect for thousands of years, underwater terrain is flatter than land, which provides less various navigation information than land; due to the influence of sea condition, environmental noise, velocity gradient, sediment thickness and etc., the accuracy of underwater terrain measurement is poorer than land measurement in magnitude, and high-precision underwater terrain map is difficult to get. In order to improve the precision of TAN and make full use of the features of topographic information, artificial intelligence algorithm is proposed for the modeling of bathymetric terrain and integrated into the path planning algorithm [10–18]. In order to lower the cost of the underwater navigation system and improve the precision, scholars and experts of different countries always solve the problems through improving the core technology of terrain matching algorithm by using image processing techniques [19–24]. During the past six decades, the most frequently used matching algorithms of TAN are roughly classified into two different types: correlation matching and application of a filter. For correlation matching, the Terrain Contour Matching (TERCOM) algorithm and iterated closest contour point (ICCP) algorithm have been mostly studied which acquires rigorous precision on sensor error, and the system

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reliability decreases when the sensor error increases [25]. For the filter method, the Sandia Inertial Terrain-Aided Navigation (SITAN) method is basically based on Kalman filter [26,27] which demands linearization of the terrain data, since the terrain data is highly nonlinear. No matter which algorithm is chosen, the approach is to search for the optimal matched point for the true position of the AUV, centering on the probable position indicated by the SINS.

In this paper, the ICCP navigation algorithm is mainly studied, which originates from the iterative closest point (ICP) algorithm of image registration problem, Behzad K.P. first applied it in the underwater vehicle navigation. Liu did an intensive study of ICCP in the application to underwater terrain matching. To solve the problem of local convergence and bad real-time, Zhang Tao improved the algorithm by the mutative chaotic optimization algorithm and Zhang Hongmei gave out pre-translation simplified ICCP algorithm. The ICCP navigation algorithm should precisely know the starting point of the matching track to obtain high precision. To solve this problem, Wang and Yuan proposed to use TERCOM algorithms as the initial alignment for ICCP, but the nature of TERCOM using MSD operator is a way of least squares estimation with not taking the disadvantage–the statistical characteristics of random variables into consideration. She introduced a new combinational seabed terrain matching algorithm based on PDAF and ICCP to meet the AUV mobile navigation [28–33].

ICCP algorithm implements iterative closest contour point registration is based on rigid rotation and transformation of the SINS directed path. Because the speed of AUV is always slow and the matching cycles are usually longer, and also with the increase of route length, the accumulative SINS position error cannot be ignored in the matching section. To reduce the accumulative SINS error affection on the ICCP algorithm precision, this paper adopts a combination matching algorithm based on ICCP and Kalman filter in the terrain-aided inertial navigation system (TAINS). This paper is organized as follows: in the introduction section, a review of previous research is presented, and the proposed algorithm is given. Section 1 describes the principle of the integrated navigation system TAINS. In section 2, ICCP algorithm is introduced in detail. In Section 3, the influence of SINS error and the sampling points number on matching result is analyzed, and the combination algorithm is given. Mathematical models of TAINS are given in Section 4. To validate the proposed algorithm, simulations are shown in Section 5 while Section 6 presents the conclusion [34–36].

1. Principles of TAINS

The TAINS is composed of an inertial navigation system, underwater depth measurement module, digitally stored terrain maps, terrain matching algorithm, computer and electronic circuitry. The inertial navigation system consists of three accelerometers, and three gyroscopes can give the acceleration and angular velocity at frequency of 100 Hz. The pose, position and velocity information of the AUV are gained via navigation calculation. The terrain matching algorithm used underwater depth measurements, digitally stored terrain maps and SINS outputs to generate position estimates of AUV. The outputs of TAN were then used as observed value of the Kalman filter to bound SINS position errors and get more precise indicative track for ICCP algorithm. Therefore, TAINS is an adequate solution to provide underwater navigation system which has superior performance in comparison with the traditional underwater navigation system. The block diagram of TAINS for the AUV is shown in Fig. 1.

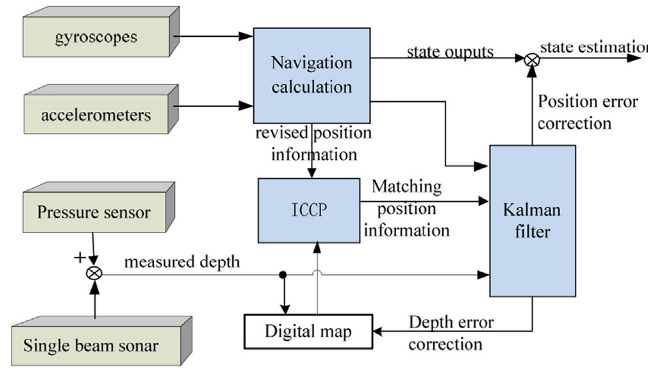

Fig. 1. Block diagram of TAINS.

2. ICCP algorithm

Terrain-aided navigation module installed in the AUV is able to provide location information intermittently when it moves into the matching-suitable areas where the navigation information of underwater terrain is abundant enough. The theme of ICCP algorithm is to connect the measured depth along the trajectory into line, and then match it with the preferred underwater digital map respectively. The main idea of ICCP algorithm is shown in Fig. 2. The track composed of the points $\{P'_1 \cdots P'_{Np}\}$ is the real-time measured depth sequences of AUV, Np is the number of matching points. $\{P_1 \cdots P_{Np}\}$ is the indicative track given by SINS. In addition, $\{C_1 \cdots C_{Np}\}$ is the local measured contour and each contour corresponds to a contour line of digital map. The purpose of ICCP algorithm is the following certain guidelines to let $\{P_1 \cdots P_{Np}\}$ close to $\{C_1 \cdots C_{Np}\}$ and determine the current position of underwater vehicles. The concrete steps of ICCP algorithm are as follows:

Step 1: Extracting the contour C_i on the priori topographic map according to the measured depth. Firstly, identifying an area centered on the sequence P_i, three times error of SINS for side length. Secondly building a two-dimensional matrix with terrain information of the identified area, after that the elevation of any point (*posn, posm*) in the area can be obtained via bilinear interpolation algorithm. The bilinear interpolation algorithm diagram is shown in Fig. 3.

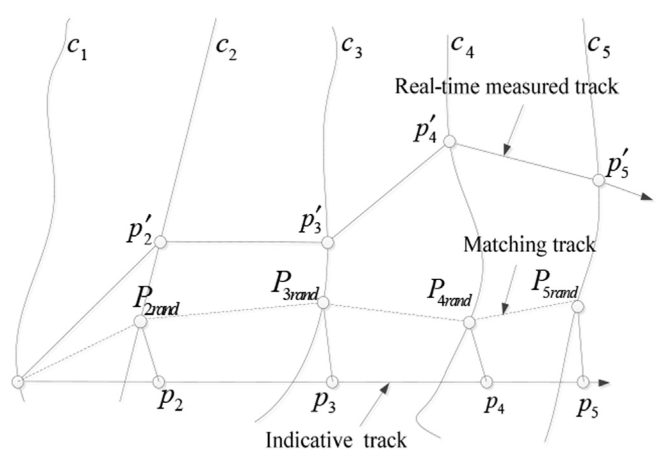

Fig. 2. Principle of ICCP algorithm.

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