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Tracking UUV based on interacting multiple model unscented particle filter with multi-sensor information fusion

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ABSTRACT

For complexity and variability of obtaining UUV (Unmanned underwater vehicle) underwater movement information by acoustic sensors in underwater environment, a novel Least Square Interacting Multiple Model Unscented Particle Filter (LSIMMUPF) algorithms based Multi-sensor information fusion is proposed to solve the problem of tracking UUV. In order to realize the information fusion of Pitching Angle and Azimuth Angle from sensors, Least Square (LS) is used to pretreat the angles measurement; Moreover, the Interacting Multiple Model Unscented Particle Filter was combined the advantages of automatically adjusting filter bandwidth of Interacting Multiple Model and processing nonlinear non-Gaussian of Particle Filter to process the information pretreated, and the UKF was adopted to generate the important density function and the residual resampling was used to alleviate particle degradation phenomenon. Finally, to verify the performance of the proposed algorithm, a typical simulation is performed. Simulation results show that the proposed algorithm has good accuracy performance, which can satisfy the requirements for UUV.

1. Introduction

With the development and utilization of marine resource, UUV (Unmanned underwater vehicle) has been widely used for various underwater missions. To accomplish the tasks, one of the many difficult problems associated with UUV is the issue of tracking, how to accurately track and obtain motion information of UUV has become the focus of research and development in the world [1,2].

UUV as an underwater vehicle generally has multiple motion models underwater in order to perform specific tasks. So, to effectively describe the process of UUV motion state changes, tracking system modeling usually has multiple models. The Interacting Multiple Model (IMM) algorithm is a target tracking algorithm that uses a fixed model set and mode transition probabilities has already been adopted to describe the motion mode [3]. The subfiltering of IMM generally used the Kalman Filter (KF) [4], Extended Kalman Filter (EKF) [5], and Unscented Kamlan Filter (UKF) [6]. Because the three filtering methods were based on the assumption of Linear-Gaussian model, so these methods can bring biggish error variance under the condition of Nonlinear-Non-Gaussian. To solve the Nonlinear-Non-Gaussian target tracking, Particle Filter (PF) was proposed to obtain the optimal estimate target motion results by using the weighted random sample set of state space to approximate the posterior probability density function [7]. And IMM Particle Filter (Interacting Multiple Model Particle Filtering, IMMPF) algorithm was put forward [8], which replace the subfiltering of IMM with PF to improve the strongly nonlinear effect on tracking accuracy.

However, with the increasing complexity of the marine environment, underwater tracking are often subject to a variety of factors such as marine organisms, reverberation noise and unrelated noise. So, the Gaussian state of noise can not meet the underwater movement, and there is a large error between measurement value and the real value because of the above uncertainty factors [9]. Therefore, comprehensive utilization of multi-sensor has become one of research hotspots in the field of multi-source information fusion, how to make use of multi-sensor measurement data to realize the complex system state estimation is of great significance [10].

In light of these problems, the Least Square Interacting Multiple Model Unscented Particle Filter (LSIMMUPF) algorithm is proposed for tracking the UUV in this paper. The remainder of this paper is organized as follows. Section 2 presents the theoretical analysis and

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system description. Section 3 proposes the Multi-Sensor information fusion based on LS. Section 4 introduces performance analysis of IMM and PF. Section 5 is devoted to design the IMMUPF algorithm. Section 6 describes the experimental simulation. Finally, the conclusions of the study are given in Section 7.

2. Theoretical analysis and system description

Basic function of passive sensor is to measure angle information including Azimuth Angle and Pitching Angle, the Azimuth angle contains the target position information in the horizontal direction, and Pitching angle contains target depth information. In the research of UUV tracking, the relationship between sensor and UUV can be abstracted and shown in Fig. 1.

In the UUV tracking system, the discreted state and observation equation can be described as

$$X(k+1) = F(k)X(k) + G(k)W(k) \tag{1}$$

$$Z(k) = H(k)X(k) + V(k) \tag{2}$$

where $X(k) = [x_k, y_k, z_k, x_k^{\cdot}, y_k^{\cdot}, z_k^{\cdot}]^T$ is the motion state at time k, which is composed of the relative position and velocity of the UUV in the three-dimensional underwater space, $F(k)$ is the state transition matrix which can describe state accurately, $G(k)$ is the noise input matrix, $Z(k)$ is the observation matrix, $H(k)$ is the measurement matrix, the overall process noise $W(k)$ is zero-mean white Gaussian noise with covariance Q, $V(k)$ is the measurement noise with zero-mean white Gaussian covariance R, both $W(k)$ and $V(k)$ are assumed to be uncorrelated.

In the Cartesian coordinate system, Azimuth Angle and Pitching Angle are defined

$$\begin{bmatrix} \beta(k) \\ \alpha(k) \end{bmatrix} = \begin{bmatrix} \tan^{-1}(x(k)/y(k)) \\ \tan^{-1}(z(k)/\sqrt{x(k)^2 + y(k)^2}) \end{bmatrix} \tag{3}$$

Considering after launching, navigable depth of UUV dose not change significantly, so navigable depth $Z(k)$ is assumed a constant. Azimuth Angle and Pitching Angle can be measured and converted in the x, y-axis. Then, the Eq. (3) can be converted and defined as

$$Z(k) = \begin{bmatrix} x(k) \\ y(k) \end{bmatrix} = \begin{bmatrix} \dfrac{z(k)}{\tan(\alpha(k))\sqrt{1+\tan^2(\beta(k))}} \\ \dfrac{z(k)\tan(\beta(k))}{\tan(\alpha(k))\sqrt{1+\tan^2(\beta(k))}} \end{bmatrix} + V(k) \tag{4}$$

where $V(k) = [v_\beta(k), v_\alpha(k)]^T$ is the measurement noise, and $R = \text{diag}\left\{\sigma_\beta, \sigma_\alpha\right\}$ is covariance matrix.

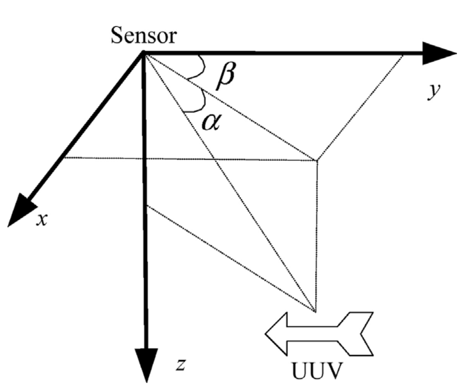

Fig. 1. Relationship position between sensor and UUV.

3. Multi-sensor information fusion based on LS

Multiple-sensor information fusion can obtain the UUV underwater movement information with the high efficiency and credibility, which can achieve a wide range of coverage in time and space. The overall structure of Multi-Sensor information fusion based on LS is described briefly as follows.

As shown in Fig. 2, a position line can be determined by Azimuth Angle and Pitching Angle though i-th sensor station. Multiple position lines are measured by multi-sensor to join at one point, which is the UUV position. However, these position lines can not be positioned at a point because of the presence of observational errors. Then, LS is proposed and applied to estimate position of the UUV at point T as shown in Fig. 3, which considers the least sum of distance between position estimate point and these position lines [3,4].

The (x_i, y_i, z_i) is the sensor coordinate, (x_T, y_T, z_T) is the UUV coordinate, L_i denotes ith position lines, A_i denotes the foot of perpendicular from estimated target to position line, N is the number of sensors, $i = 1, 2, \ldots, n$.

The equation of ith position line is written as

$$(x - x_i)/l_i = (y - y_i)/m_i = (z - z_i)/n_i \tag{5}$$

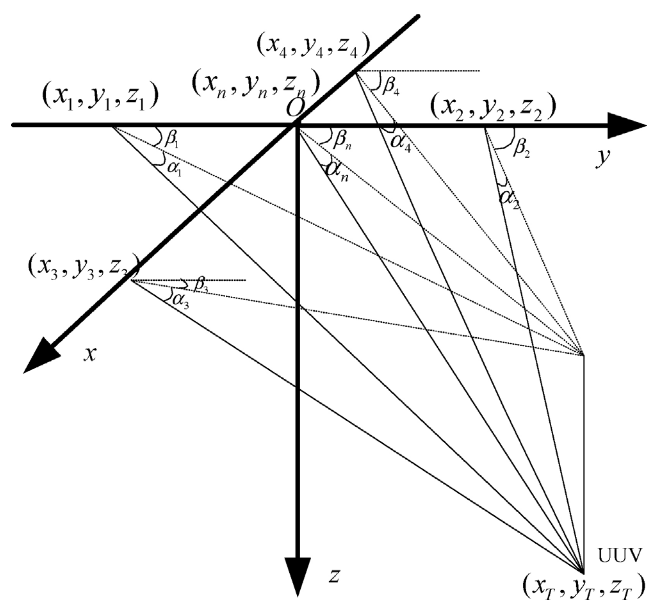

Fig. 2. Geometric relationship of UUV and sensor.

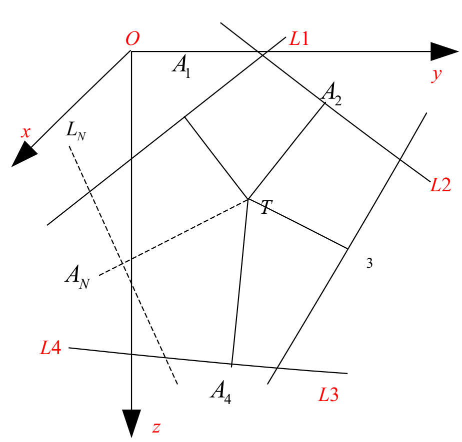

Fig. 3. Multi-sensor information fusion based on LS.