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Research on fuzzy control of path tracking for underwater vehicle based on genetic algorithm optimization

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ABSTRACT

The path tracking problem of underwater robots in different working conditions is studied. According to the analysis of the control model for underwater robots, a path tracking method for underwater robots based on a line-of-sight method is proposed. Based on the fuzzy control algorithm, a fuzzy controller is designed, which is further optimized by a genetic algorithm. The fuzzy control method developed is applied to the path tracking of a self-made underwater vehicle, and tested by both simulation and experiment. Results show that with the path control method based on the fuzzy controller optimized by the genetic algorithm ensures that the vehicle sails along the expected path. Also, the system shows strong robustness.

1. Introduction

The environment in the ocean is complex, with predictable factors such as submarine topography, and also with many unpredictable factors such as currents and waves, marine creatures, etc. These factors are likely to affect the working of underwater robots (Xuezhi, 2010; Prabhakar and Buckham, 2005), especially for tasks with accuracy requirements. Therefore, studying on the control system for underwater robots is critical for the efficient work of robots under water (Healey and Lienard, 1993). And the motion control technique is important for realizing the required motion and achieving a stable driving condition of the underwater vehicles, which is essential for underwater tasks with accuracy requirements (Mamdani and Assilian, 1975).

At present, the commonly used methods for navigation control of underwater vehicles mainly include PID control, adaptive control, synovial control, fuzzy control and neural network control at home and abroad (Shaocheng, 2005). As an important control method, fuzzy control has the most prominent advantage that is not only dependent on the precise mathematical model of the control system, but also can effectively control the nonlinear system. It has strong robustness and anti-interference ability. The disadvantage is that it is difficult to ensure that the control system has good stability and sensitivity (Debitetto, 1994). And genetic algorithm has fast and random search capabilities.

In this paper, based on the characteristics of fuzzy control and the advantages of genetic algorithm, a novel fuzzy controller is designed for the path tracking control of underwater machines. The motion control (i.e. path tracking) method for a self-made prototype of underwater vehicle "Sea Dog" is developed with a fuzzy controller that is optimized by genetic algorithm, which is tested by both simulation and experiment.

2. Design of the path tracking controller based on the fuzzy theory

"Sea Dog" is different from ordinary ROV which uses a three-tier frame design (Huhman and Neri, 2012; Lygouras et al., 1998). Two features are as follows: (1) its center of gravity coincides with the origin of the motion coordinate system; (2) taking into account the simplification of modeling, the up and down, the front and back and the upper and lower of the vehicle as approximately symmetrical. In order to facilitate the description of the motion of the vehicle, The coordinate origin O of the coordinate system can be taken at any point on the vehicle. The axis X is consistent with the main symmetry axis of the vehicle. The axis Y is consistent with the auxiliary axis of symmetry of the vehicle. The axis Z points to the bottom of underwater robot. The coordinate system selection is shown in Fig. 1.

The path tracking control for the underwater vehicle "Sea Dog" is a mixed path tracking control which considers the movement in both the horizontal plane and the vertical plane (Jing Zheng and Xu, 2007). In the control process, when the coordinates of the target location and the current location are given, the expected heading and pitch angles at the expected velocity of the vehicle are obtained according to the path solver, in which the calculation method on special error is adopted. Then, the

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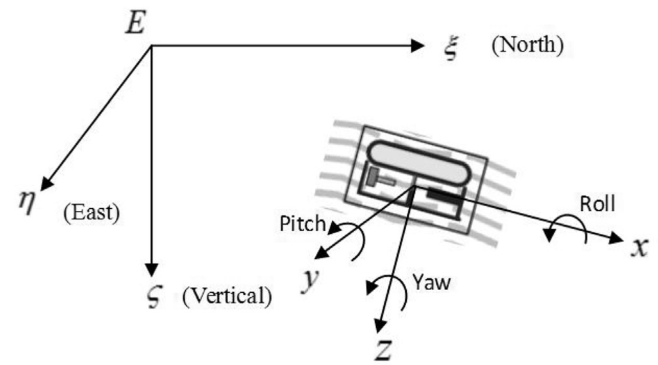

Fig. 1. Ground coordinate system and kinematic coordinate system diagram.

fuzzy controller eliminates the error between the practical and the expected heading angle, velocity, and pitch, receptively, thereby indirectly makes the vehicle approach the expected path. The fuzzy controller section forms an accurate control system for the tracking of the curved path in space. By the fuzzy algorithm, the corresponding ration speed of the propeller can be obtained to adjust the motion of the vehicle. The diagram of the control system is shown in Fig. 2.

Fig. 3 shows the diagram horizontal path tracking of the vehicle. Here we take the horizontal path tracking as an example. As shown in Fig. 2, the red curve is the expected path of the vehicle, O is the starting point, A is the current position of the vehicle, and B is the target position. The coordinates of point A and B are set as (x_a, y_a) and (x_b, y_b), respectively. As a result, the expected sailing direction in segment AB is

$$\psi_d = \tan^{-1}((y - y_d)/(x - x_d)) \tag{1}$$

The distance of the vehicle form the expected path, i.e., tracking error, $d = |AD|$, can be expressed as.

$$d = |AO| \cdot \sin\left(\left(\arctan\frac{y_b}{x_b}\right) - \left(\arctan\frac{y_a}{x_a}\right)\right) \tag{2}$$

The traveling distance, L, is defined as the distance between the vehicle position A and the line that is perpendicular to the line OB through the target point B as the target reference line (represents an interface). The positive direction of L is defined as the direction from O to B. L is used to determine whether the vehicle enters the next segment, and is related to the position of point B (Zhuang, 2000). L can be obtained by the follow equation:

$$L = S_{AB} \cdot COS\left(\arctan\frac{x_b}{x_a} - \psi_d\right) \tag{3}$$

During horizontal path tracking, we divide the given curved path into several segments. As shown in Fig. 3, point B is the target point for the vehicle in the current segment. According to the current position of vehicle, the controller determines the segment that the vehicle is currently in, and consequently determines the target point for the vehicle in the current segment. In this way, the vehicle quickly enters the control state of path tracking (Yi and Heng, 2002; Liu, 2009; Xing, 2010). The detailed solution is as follows: starting from the previous segment, according to Eqs. (1)–(3), the distance, L, in Fig. 3 is determined to check whether it is less than 0, that is to say, whether the target point has been passed. If it has been passed, L for the next target point is checked. When L is larger than 0, the segment is determined as the current segment for the vehicle.

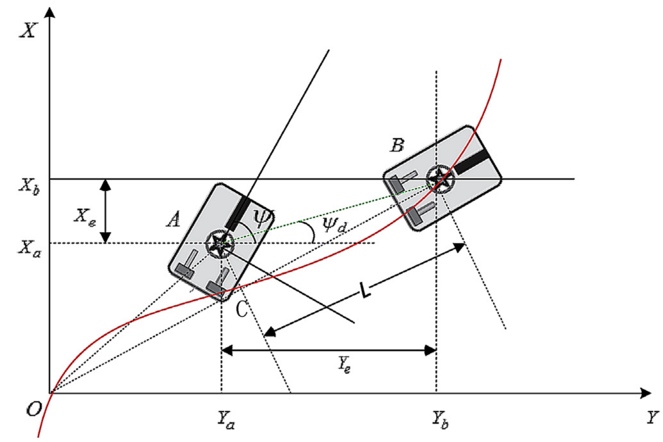

Fig. 3. Diagram of horizontal path tracking of the vehicle.

The fuzzy controller of horizontal path tracking is a two-dimensional fuzzy controller. The inputs are the heading angle deviation and heading angle deviation rate. The corresponding subordinate function is shown in Fig. 4.

There are 49 fuzzy rules for heading angle adjustment according to the practical experience, which are shown in Table 1. The weighted average method is adopt for defuzzification.

3. The fuzzy controller optimized by genetic algorithm

The performance of the fuzzy logic controller depends on whether a high-performance subordinate function and reasonable fuzzy rules are used. The subordinate function is basically determined by the trial-and-error method in practice, which is cumbersome and lack of adaptability (Maji et al., 2016). The control rules and subordinate functions of the fuzzy controller are affected by some subjective factors, which have a great influence on the performance of the fuzzy controller (Zhang et al., 2004). The genetic algorithm is introduced in the design of the fuzzy controller, which optimize the subordinate function and fuzzy control

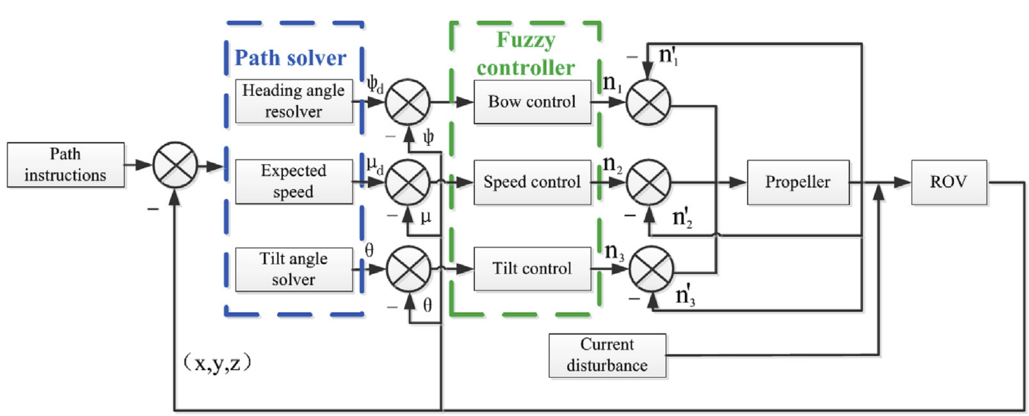

Fig. 2. Diagram of a control system.