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Course and Depth Control for a Biomimetic Underwater Vehicle - RobCutt-I

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This paper presents the design and fabrication of a new type of Biomimetic Underwater Vehicle (BUV) inspired by cuttlefish: the RobCutt-I. The RobCutt-I has good maneuverability and can perform multiple motion modes, especially submerging or surfacing vertically in the water. A course controller and a depth controller for the RobCutt-I were proposed based on the Active Disturbance Rejection Control (ADRC) technique. Experiments conducted on the RobCutt-I prototype validated the feasibility and effectiveness of the mechanism and control system. Simulations and experiments conducted on the RobCutt-I prototype showed that both the course controller and depth controller give better performance than the PID controller.

INTRODUCTION

Autonomous Underwater Vehicles (AUVs) have been used as an operation tool in many fields of marine activity such as submarine rescue, oil and gas survey, scientific research, and military application. Motivated by an interest in designing an agile and environmentally friendly AUV, many researchers and engineers have been dedicated to designing a Biomimetic Underwater Vehicle (BUV), which utilizes an undulatory fin for propulsion because the undulatory fin offers several advantages such as low acoustic noise, low disturbance of the surrounding environment, and great maneuverability.

In recent years, many BUVs with undulatory fins have been designed (Low, 2009; Zhou et al., 2010; Curet et al., 2011; Shang et al., 2012; Rahman et al., 2013). Some of these BUVs can swim only on the water surface, while others have three-dimensional locomotion ability. However, the heave speed is usually small because heave motion is often obtained by changing the center of gravity or adjusting the angle of attack of a dedicated caudal fin. The above methods need auxiliary mechanisms except for the undulatory fins and increase the complexity to a certain extent. Therefore, it is of great significance to design a new BUV that has better maneuverability.

For a practical BUV working in the 3D underwater space, its course and depth are two basic factors for navigation or operation in a fixed location. Hence, the course and depth should be precisely controlled so that the BUV can complete its task successfully. To our knowledge, however, few studies have presented an approach to precisely control the course or depth (Xie et al., 2011). Therefore, robust and precise course and depth controllers need to be designed to improve the operability of the BUV.

In view of the aforementioned issues, this paper focuses on two aspects. The first one is to design a new type of BUV, the RobCutt-I, based on our previously designed BUV (Wei et al., 2013). Compared to the previous designs by other research groups, the main contributions and differences of the RobCutt-I are: (1) the RobCutt-I can swim freely in 3D underwater space, relying solely on its two flexible long fins, while the previous designs require additional mechanisms such as a buoyancy tank or tail rudders to achieve heave motion; and (2) the RobCutt-I can submerge or surface quickly and vertically in water, which increases the maneuverability. In contrast, the previous designs can submerge or surface only slowly, and they need a relatively long time to change depth or have to march at the same time.

The second aspect is to propose methods to precisely control the course and depth of the RobCutt-I. The course controller and depth controller are designed based on the Active Disturbance Rejection Control (ADRC) technique (Gao, 2003; Han, 2009). The basic idea of this control method is to estimate the general disturbances, including external disturbances, and model uncertainties in real time by the use of an Extended State Observer (ESO) and then dynamically compensate them in the control signal.

In this paper, the mechanism design and control system of the RobCutt-I, the RobCutt-I prototype, and its mathematical model are introduced. A course controller and a depth controller are then proposed based on the ADRC technique discussed in the following section. Simulations of the model of the RobCutt-I and experiments conducted on the RobCutt-I prototype are then presented. The conclusions of this study are lastly presented.

OVERVIEW OF THE ROBCUTT-I

The RobCutt-I presented in this paper is a bio-inspired mechatronic system. The mechanism and control system are introduced briefly in this section. We then fabricated a prototype based on the mechanism design and control system. The mathematical model of the RobCutt-I is lastly presented in this section.

Mechanism Design of the RobCutt-I

Inspired by cuttlefish that employ rajiform locomotion for pelagic locomotion, maneuvering, and other behaviors, the RobCutt-I was designed to imitate the unique propulsion mode. Figure 1a shows the 3D CAD model of the RobCutt-I. The RobCutt-I is composed of a main body and two flexible long fins mounted on both sides of the main body. While most of the existing BUVs using rajiform locomotion for propulsion have a wide and flat body structure, which makes it hard for them to submerge or surface vertically, a tube-like main body and two hemispherical covers are adopted in the RobCutt-I mechanism design. Furthermore, the RobCutt-I has bilateral symmetry and fore/aft symmetry, and the center of gravity is set to below the center of buoyancy, which guarantees that the

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KEY WORDS: Biomimetic underwater vehicle (BUV), undulating fin, Active Disturbance Rejection Control (ADRC), course control, depth control.