International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 23, No. 3, September 2013, pp. 166–171

http://www.isope.org/publications

Depth Control for Robotic Dolphin Based on Fuzzy PID Control

Fei Shen, Zhiqiang Cao, Chao Zhou and De Xu
Institute of Automation, Chinese Academy of Sciences, Beijing, China

Nong Gu
Center for Intelligent Systems Research, Deakin University, Victoria, Australia

In this paper, the depth control for a robotic dolphin is considered. The structure of the robotic dolphin is firstly designed based on the analysis of stable conditions on the motions of biological fish and dolphins. Our pitching motion analysis indicates that the movement distance of balance weight can be employed for depth control. Considering the nonlinear model in depth control and the volume variation of the rubber skin due to water pressure, a fuzzy PID controller is proposed to realize the depth control. Fuzzy controller 1 is utilized to compensate for the big error with fast response. To eliminate steady-state error caused by buoyancy change, fuzzy controller 2 and an accumulator are activated by the intelligent switch when necessary. The experimental results verify the effectiveness of the proposed controller.

INTRODUCTION

Underwater biomimetic robotics, such as robotic fish and robotic dolphins, have received more and more attention in recent years. Compared to fish, dolphins are superior swimmers due to their horizontal caudal fins (flukes) along the longitudinal main bodies. It is observed that the propulsive efficiency of dolphins can reach up to 0.75–0.9 and the maximum swimming speed is over 11 m/s. Moreover, dolphins can also achieve excellent turning maneuverability in that they can rotate their bodies with an angular speed of 450 deg/s and with turning radii down to 11–17% of body length (BL) (Fish and Rohr, 1999).

These interesting features motivate many researchers to create dolphin-like robots, focusing on hydrodynamics analysis, mechatronic design and control schemes. These efforts include the two-joint robotic dolphin (Nakashima and Ono, 2002; Nakashima et al., 2006), the four-joint pneumatic robotic dolphin (Dogangil et al., 2005), the five-joint robotic dolphin with a pair of 2 degrees-of-freedom (DOF) pectoral fins as well as the robotic dolphin with a two-motor-driven scotch yoke mechanism (Yu et al., 2007; Yu et al., 2009), and our multi-link robotic dolphin with 3-DOF flippers (Shen et al., 2011). Some control schemes on propulsion, turning motion and loop-the-loop motion were developed for these prototypes (Nakashima et al., 2006; Yu et al., 2007; Shen et al., 2011). In addition, control algorithms for the pitching motion are of special interest as they can improve the maneuverability significantly. The pectoral fin method (Zhang et al., 2007; Liu et al., 2005) and the barycenter adjustment method (Zhou et al., 2006; Yu et al., 2011) were proposed for realizing the pitching motion. However, the research on depth control is relatively rare, especially for robotic dolphins. In fact, keeping the robotic dolphin at a certain depth to improve environmental adaptability has great potential applications. In this paper, we propose a new depth control method to address this problem.

From the engineering perspective, some guidelines to achieve stability of the robotic dolphin are firstly illustrated by taking advantage of biological fish and dolphins. The structure of the robotic dolphin with a barycenter adjustment mechanism is then designed to realize the pitching motion that is the foundation of depth control. Our pitching motion analysis indicates that one can employ the movement distance of balance weight to control the depth and the relationship between these two variables is nonlinear. This nonlinearity combined with the complexity of hydrodynamics make the model-based control method infeasible for the depth control. In this paper, fuzzy logic control is considered as it does not require an accurate model and *a priori* knowledge could be exploited to ensure reliability of the robotic dolphin. Currently, fuzzy control has been widely studied, including robust self-tuning fuzzy tracker (Fang et al., 2011) and formula-based fuzzy PI controller (Kumar et al., 2011). The challenges we face include the nonlinearity model of the robotic dolphin, periodic fluctuation of depth caused by the dorsal-ventral propulsive movement and the volume variation of the rubber skin due to water pressure. To address these challenges, a fuzzy PID depth controller is proposed in this paper. This controller employs fuzzy controller 1 to reduce the initial error with fast response. In addition, fuzzy controller 2 and an accumulator, which can be regarded as an integral controller, are used to eliminate steady-state error caused by volume variation. To avoid integration saturation that is easily caused by limited range of control variable, an intelligent switch is designed to activate fuzzy controller 2 when necessary.

THE STRUCTURE OF ROBOTIC DOLPHIN AND PITCHING MOTION ANALYSIS

The Stability Concerning Biological Fish and Dolphin

Some concepts about static stability are firstly introduced. Small turbulence may force an object to deviate from its balance position. As soon as the disturbance disappears, this object is static stable if it has the motional tendency of recovering its original balance position. Otherwise, it presents either static unstable if continuous deviations are observed, or neutral stable if the object stays at a new position after this disturbance.

Some observations about the stability of fish and dolphins are summarized as follows:

(1) Most bony fish are static unstable as their buoyancy centers are located below the gravity centers (Lauder and Madden, 2006).

Received November 8, 2012; revised manuscript received by the editors April 11, 2013. The original version was submitted directly to the Journal.

KEY WORDS: Robotic dolphin, depth control, barycenter adjustment, fuzzy PID control.