Measurement 93 (2016) 232–242

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Implementations of the route planning scenarios for the autonomous robotic fish with the optimized propulsion mechanism

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ARTICLE INFO

Article history:
Received 9 September 2015
Received in revised form 4 March 2016
Accepted 5 July 2016
Available online 6 July 2016

Keywords:
Route planning
Parameter optimization
Robotic fish
Autonomous underwater vehicle
Biomimetic design
Dynamic model

ABSTRACT

Various human problems are tried to resolve with biomimetic design which imitate biological forms. A biomimetic Carangiform robotic fish provides great benefits with flexible maneuverability, high propulsion efficiency and less noisy considering classical rotary underwater vehicles. This paper presents a dynamic simulation model of the Carangiform robotic fish with flexible multi-joint propulsion mechanism considered as an artificial spine system for two swimming cases. In order to swim like a real fish, multi-joint propulsion mechanism assumed a series planar hinge joints which represent vertebras is adjusted by optimizing with a new searching method which provides precise values as direct search methods. The flapping frequency and the speed are proportional with the tail link lengths and angles of the joints. Thus, the optimization parameters are selected as end point coordinates of the joints and lengths of the each link to imitate the real traveling body wave. Two possible route planning scenarios for the robotic fish model inspired from the Carangiform motion are performed. These scenarios are summarized by two cases. Case 1 is the free swimming mode permits to go straight forward until it faces an obstacle. The fish decides to the turning direction by using decision-making process when it encounters an obstacle and finds the way to turn. In the Case 2, the fish proposes to reach the destination area along the shortest path. When faced with obstacles, it overcomes obstacles and tries to reach the target in the shortest way again.

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1. Introduction

As it is known that water has great importance for continuity of life. 71% of the Earth's surface is surrounded with seas and 99% of life on the Earth needs water [1]. Recently, marine environment and its exploration have been increasingly started to research. With this growing interest, rotary underwater vehicles have been widely started to use in many aquatic fields. After increasing of researches, undulation-based Autonomous Underwater Vehicles (AUVs) inspired by aquatic animals has started to be used instead of propeller-based AUV. These vehicles are frequently used in many aquatic applications. So that, bio-inspired AUVs (inspired from nature) become more and more popular and give great benefits in marine applications [1–7].

The study of underwater life has been a subject of interest to engineering of robotics. Researches take up further task to imitate swimmers and their locomotion ability to AUV mechanisms [7,8]. A bio-inspired approach in the AUVs indicates the appropriateness for the design of underwater vehicles both methods of locomotion and vehicle developing. Majority of conventional underwater vehicles used classic propellers for the thrust force. Based on the propeller locomotion showed that insufficient maneuverability, efficiency, and low power consumption [1,9]. Also, noises produced by propellers have negative acoustic effects on marine life and thus these have negative effects on researches. The bio-inspired AUVs are more maneuverable, quitter and more energy efficient. A bio-inspired AUV moves inconspicuously in water without creating ripples and eddies [1]. Therefore, bio-inspired AUVs have been widely used in such as underwater monitoring and exploration, detection of seabed pollution, observation of various underwater life, coast guards and military activities [2,10–14].

In nature, fish are the best swimmers with features of fast swimming, high maneuverability, low noise and low power consumption. Fish swim by bending their bodies and/or by using their fins and tails in the water [2–4]. As imitating the locomotion of real fish, bio-inspired AUVs can achieve higher performance from the classic rotary underwater vehicles. Their amazing swimming abilities draw attention of researchers to explore and learn principles of fish locomotion so as to develop or update the today's

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http://dx.doi.org/10.1016/j.measurement.2016.07.026
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marine technologies. Therefore, instead of the classic rotary propellers used in underwater vehicles, termed by robotic fish with undulation or oscillation movements to generate thrust force are preferred [1,15]. From the perspective of robotic research, a real fish is an optimal architecture to design and develop propulsion mechanisms for an AUV.

In recent years, many designs on robotic fish have been proposed in the literature. In 1990s, studies to build robotic fish brought out the first robotic fish named RoboTuna and RoboPike at MIT [10]. RoboTuna was designed with eight-link flexible thrust mechanism and a subsequent designed RoboPike focused on to study the drag reduction [2]. Draper Laboratory developed a novel design AUV, namely VCUUV, which could avoid the obstacles [10]. Additionally, some designs on robotic fish were developed by using smart materials [16,17] and specific structures to analyze the performance of submerging and ascending were designed [1]. In 2000s, most studies on robotic fish are performed to achieve optimal bio-inspired motion [2,6,7]. Today, a kind of Carangiform robotic fish, namely G9 (9. Generation) is designed by Hu and colleagues, which imitate the best swimming motion ever [15]. Apart from these prototype designs, intelligent control and optimization methods applied such as genetic algorithm to optimize robotic fish parameters [2], various path planning algorithms to apply assigned tasks [9], evolutionary optimization methods to obtain real fish performance [6,18], motion pattern generators to generate thrust force [19,20], fuzzy rule based and neural control laws to drive propulsion mechanism [21]. In this area, researches on robotic fish have still been continued to design novel prototypes, to develop novel control and optimization algorithms and to mimic a real fish motion [14].

To imitate biological features of a real fish in the bio-inspired AUVs, a suitable dynamic model must be derived and a numerical analysis for the designed mechanical architecture must be performed. The first problem to be answer is how to model a nonlinear biological fish body. For this, various dynamic models suggested to achieve an optimal model as Two-Dimensional (2-D) and Three-Dimensional (3-D) waving plate theory [2], Central Pattern Generator (CPG) [20,22,23], large-amplitude elongated body theory [18], kinematics and hydrodynamics analysis [10], Lagrange and Lagrange–Euler functions [24], and Newton–Euler methods [2,24]. Additionally, considering a real fish modeled by its musculature, the robotic fish consists of a series of vertebra motors from the central part of the fish body to tail. This precision musculoskeletal system still constitute challenge. To partly achieve fish-like motion, there are two kinds of design methods. The first is to model as a discrete body wave formed by multi-joint with multi-motor configuration [24]. The second one is to use smart materials such as Shape Memory Alloys (SMA) and Ionic Polymer Metal Composite (IPMC) [17]. However, this design is not completely imitate a real fish motion. Due to limitations of latter design, it is not generally preferred. Another problem is to fit each joint to the body traveling wave. Fitting the traveling wave of the fish body is one of the typical research for bio-inspired AUVs. There are two general proposed methods including end point location and intersection location [18]. In the end point location method, coordinates of the joint income on the body traveling wave and it can be calculated easily. But, this fitting method have not enough better performance because the error would be bigger [6,18]. Intersection location method is applied to the link length between two joint [18]. End point coordinates of the joint are determined by generating the minimum error between the body traveling wave and the circle drawn with radius of the link lengths. In this problem, another limitation is the link lengths. As a biologically feature of the real fish, the length of each link from nose to tail is getting smaller and smaller or a previous equals to following one. The derived solution method is to optimize the length of each link for the minimum error, which is named geometrically optimization of the envelop area [6]. In this solving method, specified limitations are determined as link lengths and minimum envelop areas. After all, the optimized multi-joint propulsion mechanism of the robotic fish has been developed according to the biological structure.

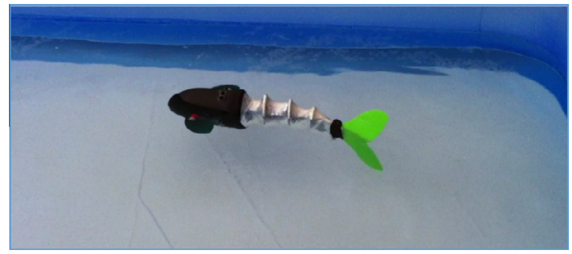

Fig. 1. The Carangiform robotic fish.

Another important issue is the route planning in the research of robotic fish [1]. To execute assigned tasks, the robotic fish needs to a trajectory or a set of target point. Also, it must carry out the task on the shortest route planning. Many kinds of algorithm have been developed for this problem such as various optimization methods [1,6,21] and vision based methods [12]. But these are limited due to complexity of the robotic fish dynamics [20,24]. Also, research costs are high and tests of the many proposed methods are difficult in the real time, therefore, testing the route algorithms in a simulation environment has obvious advantages.

The objective of this research is to design a dynamic simulation model of the Carangiform robotic fish with flexible multi-joint propulsion mechanism and perform avoiding obstacles in a swimming environment. Various route planning scenarios are implemented to find a suitable free swimming and to move from a start point to a target point with certain evaluation criteria. To achieve these tasks, the robotic fish can swim avoiding obstacles and move to the shortest path. Also, the length of each link for the minimum error is optimized and optimal joint angles are obtained. In this way, a bio-inspired robotic fish is designed, which can swim like a real fish and avoiding obstacles, and swimming environment is established. The motion of the robotic fish is performed in MATLAB/Simulink environment. Comparing simulation results, the proposed route planning algorithm is validated.

The designed robotic fish (Fig. 1) consists of two parts: an anterior rigid body and a flexible tail, which includes a four-joint propulsion mechanism. The flexible body consists of hinge joints actuated by servo motors. Motion control of the robotic fish primarily depends on the kinematics model of the tail joints.

The rest of this paper is organized as follows. Section 2 describes the robotic fish prototype. In Section 3, dynamic model of the robotic fish is given. Proposed optimization method and results are illustrated in Section 4. Implementations of the route planning scenarios are performed and the results for the proposed method are given in Section 5. Finally, conclusions are presented in Section 6.

2. System description

Before creation of the biomimetic robotic fish, it is necessary to make a design scheme of the whole system. To design an artificial biological system, which mimic a real fish, we have focused on fish-like motion mechanisms. For some limitations, motion of the robotic fish is analyzed only in two dimensions of the horizontal plane. Due to the steady swimming of the robot, vertical z plane can be neglected. So, the horizontal direction which refers to the fish body is x axis and the lateral direction is y axis. It should be noted that assumption of the planar motion is a hypothesis for

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