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ScienceDirect
Journal of Bionic Engineering 12 (2015) 37–46

A School of Robotic Fish for Mariculture Monitoring in the Sea Coast

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Abstract

This paper presents a multi-agent robotic fish system used for mariculture monitoring. Autonomous robotic fish is designed to swim underwater to collect marine information such as water temperature and pollution level. Each robotic fish has 5 degrees of freedom for controlling its depth and speed by mimicking a sea carp. Its bionic body design enables it to have high swimming efficiency and less disturbance to the surrounding sea lives. Several onboard sensors are equipped for autonomous 3D navigation tasks such as path planning, obstacle avoidance and depth maintenance. A robotic buoy floating on the water surface is deployed as a control hub to communicate with individual robots, which in turn form a multi-agent system to monitor and cover a large scale sea coast cooperatively. Both laboratory experiments and field testing have been conducted to verify the feasibility and performance of the proposed multi-agent system.

Keywords: robotic fish, mariculture monitoring, multi-agent system, pollution detection, sea coast

doi: 10.1016/S1672-6529(14)60098-6

1 Introduction

Mariculture is a specialized branch of aquaculture involving the cultivation of marine organisms for food and other products in the open ocean, an enclosed section of the ocean, or in tanks, ponds or reserves that are filled with seawater. An example is the farming of marine fish, including finfish, shellfish and seaweed in saltwater ponds. Fig. 1 demonstrates the concept of mariculture proposed by East-sea Fisheries Research Institute.

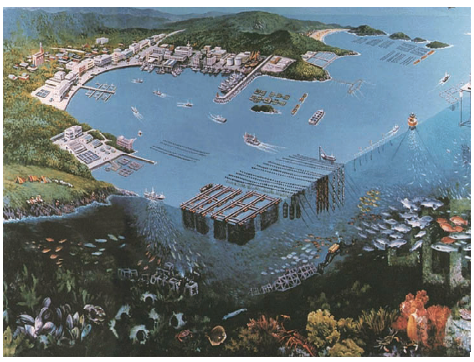

Fig. 1 Concept of mariculture (East-sea Fisheries Research Institute).

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Monitoring mariculture around sea coast is an important and challenging task due to the complex geography of sea bed, ocean currents and human activities. Difficulties in information exchange, management, and energy supply could happen as well. The classical way of using floating sensor devices has the problems of uncontrollable locations and sparse sensing points. Recently, multi-robot systems started to be applied to solve these problems. A typical multi-robot system consists of a number of self-controlled robots which can collect data independently within a dedicated area. A central control unit can combine the data from individual robots to cover a large area which otherwise cannot be accomplished by a single robot.

Multi-robot systems have been deployed in many real world applications such as manufacturing, as well as search and rescue operations[1]. It has been proved that multi-robot systems can reinforce and extend the robot ability in space, time and functionality under uncertain and dynamic environments[2]. However, mariculture environments are extremely difficult for any robots to conduct efficient and consistent jobs since the robots have to be well waterproofed and strong enough against huge water pressure. In addition, the distribution of jobs among multiple robots to accomplish should take the function of each robot into a careful consideration[3].

Up to now, unmanned underwater robots have been widely used for the purpose of the marine exploration, surveillance, and environmental monitoring. However, their driving efficiencies are limited by rotary-propellers, *i.e*. below 70%, and they are very noisy and not friendly to sea animals. Moreover, their turning radii are relatively big and evading speeds are considerably slow. These weakness are the major obstacles for traditional underwater vehicles to perform mariculture monitoring[4,5]. In contrast to rotary propellers, robot fish applies an undulatory tail movement for propulsion and maneuvering[6]. The undulatory tail motion is less noisy, more efficient, and more maneuverable (turning radius is 1/10 of Body Length (BL) contrast to 10 times of body length of a conventional ship[7]). So robotic fish is a good solution for this problem, which can be effectively deployed in the mariculture monitoring operations and other similar applications[8–10].

Many robotic fishes have been developed worldwide for the last two decades. Streitlien *et al*. compared the performance between a tuna-like robot tail fin and a traditional propeller in 1994, and found that the fins are more efficient method to proceed in the water[11]. The fins of robotic fish could repulse the water more than the square of propeller's blade, as a result its energy efficiency reached 87% (the propeller is 70%)[12]. Jalbert *et al*. applied Shape Memory Alloy (SMA) to produce a robot lamprey[13] which aimed to provide mine countermeasures. Guo *et al*. developed a micro robotic fish using ICPF actuators[14]. Yu *et al*. developed a biomimetic robotic fish and a motion control algorithm for a group of robotic fish using overhead vision system[15]. Liu *et al*. produced three energy-efficient multi-joint fish robots to mimic carp fish, which were daily operated at London Aquarium to the public for over 2 years[16]. Kato *et al*. produced a robot Blackbass[17] in order to study the propulsion characteristics of pectoral fins. Recently, Chen *et al*. developed an ionic polymer-metal composite caudal fin for robotic fish[18]. Klein *et al*. controlled a group of robotic fish via a underwater wireless network[19]. Polverino *et al*. deployed a robotic fish to lead live fish away from oil spills[20]. Liao *et al*. proposed a wire-driven flapping propulsor which can have a maximal cruise speed of 0.288 $BL\cdot s^{-1}$ [21].

In this paper, we propose a complete new solution of a multi-robot system for monitoring mariculture. A versatile robotic fish, "Ichthus V5.5", has been designed for high efficient swimming and high maneuverability. A number of sensors are equipped for monitoring water temperature, electric conductivity and pH (hydrogen ion concentration) value of the water. The developed robotic fish has the abilities to control its posture, navigate autonomously in a 3D space and to monitor the water quality. A robotic buoy floating on the water surface is deployed as a control hub to communicate with individual robotic fish, which in turn form a multi-agent system to monitor and cover a large scale sea coast cooperatively. Petri net theory is applied for the multi-agent control.

The rest of the paper is organized as follows. Section **2** introduces the design of the robotic fish, including its kinematics and onboard sensors. In section **3**, a multi-agent control system is proposed for coordinating a school of robotic fish in mariculture monitoring and management. Some experimental results are presented in section **4** to show the feasibility and performance of the proposed system. Finally, a brief conclusion and future work are given in section **5**.

2 Robotic fish design and its kinematics

2.1 Bio-inspired underwater robot "Ichthus V5.5"

The fish robot deployed in this research is named as 'Ichthus-V5.5' (Ichthus in short), which is developed at Bio-inspired Robot Engineering Laboratory in Korea Institute of Technology (KITECH). Its shape looks like a trout fish, with a dimension of 500 mm × 146 mm × 170 mm (length × width × height). Its weight is about 4.7 kg (Including buoyancy adjustment weights).

As shown in Fig. 2, 'Ichthus' has three joints in the body and the tail to mimic the swimming movements of a real carp fish. It can be characterized with its sufficient underwater DOFs and durability resulted from its high swimming speed and quick turning. It has a low center of gravity, with underwater specific gravity close to 1, in order to maintain a stable posture in the water. It can realize flexible up and down movements using its side fins. The platform is in a modular structure, *i.e*, a drive part, a sensor part, a communication part, a control part. Therefore, it is easy to assemble, repair and replacement.

On each joint, the servo motors are connected to the body frame of the robot. Therefore, by using the servo