

A Vision-Based Path Planning and Following System for a Miniature Robotic Fish

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Abstract—Most existing path following algorithms for middle- or large-sized underwater vehicles minimize yaw difference of the control object. Breaking the canonical manner, this paper presents a vision-based path planning and following system for miniature robotic fish. As for path planning, the proposed system finds a gird path based on the AStar algorithm and selects a series of target points in the grid path. By connecting these points in order, a curve path can be planned. In terms of path following, the proposed system forgoes to give a specific yaw and only uses a global camera. It obtains coordinates of the robotic fish in real time by KCF tracking algorithm to calculate an approximate motion vector. A PID controller is employed to drive the difference angle between the motion vector and the target vector (the vector from the robotic fish to the target point) to zero. By swimming to target points one by one, the robotic fish can move to the terminus following the planned path. Finally, aquatic experiments are conducted to verify the effectiveness of the vision-based path planning and following system. The results reveal that the developed system can generate a safe and smooth path, and the robotic fish can follow the path with acceptable deviation.

I. INTRODUCTION

Underwater vehicles have received more attention with ever-growing requirements of underwater tasks, e.g., underwater exploration, search, and rescue. For better underwater operation, two problems need to be solved, i.e., path planning and path following. To these ends, some methods were proposed. Garau *et al.* used an Astar search procedure to optimal paths on ocean environments while considering the more realistic and applied case of constant thrust power navigation [1]. Warren *et al.* used artificial potential fields to plan the path which is fast but apt to plunge into local minimum [2]. Petillot *et al.* employed a well-proven nonlinear search (sequential quadratic programming) which is

less affected by local minima than classical methods using potential fields [3]. Sugihara *et al.* proposed a genetic algorithm for path planning in 3D space for underwater robotic vehicles [4]. Wang *et al.* proposed a path tracking controller based on nonlinear iterative sliding mode incremental feedback [5]. Xing *et al.* addressed a 3D path following control problem for underactuated autonomous underwater vehicle subject to both internal and external uncertainties [6]. Liu *et al.* used sliding mode fuzzy control to control a dolphin robot to follow a predefined path [7].

As a biologically-inspired underwater vehicle, the robotic fish has advantages on high maneuverability, low disturbance, and high swimming efficiency [8]-[11], so they were also applied to the underwater tasks [12]. But conventionally, most control methods are designed for middle- or large-sized robotic fish because they have sufficient space for motors and sensors. Some methods (e.g., sliding mode control method) promote the robotic fish to follow path by minimizing the yaw difference. It means that a sensor needs to be arranged in the robotic fish to measure the yaw, but some small-sized robotic fish cannot be equipped with the sensor. For instance, Chen *et al.* developed a magnetically driven miniature robotic fish that only had 70 mm in length [13]. Therefore, for this kind of miniature robot, we cannot use the yaw difference for direction control.

In this paper, a vision-based path planning and following system for miniature robotic fish is developed. As for the path planning, we first rasterize the global image, and then apply the Astar algorithm to find a gird path. By selecting a series of target points and connect them, a curve path can be planned finally. Moreover, a path following algorithm is proposed using visual information. In particular, KCF tracking algorithm is employed to obtain the coordinates of the robotic fish in real time, and then the approximate motion vector of the robotic fish can be calculated at each timestamp. Sequentially, the vector from the robotic fish to the target point is calculated as target vector. We use a PID controller to minimize the difference angle between the motion vector and target vector, and then the robotic fish can swim to the target point. After passing all target points in order, the robotic fish can reach the terminus. This path following algorithm directly controls the motion mode of the robotic fish, instead of generating a desired yaw motion. Thus, our proposed method is suited to miniature robots without inner sensors. Through extensive aquatic experiments, the effectiveness of the proposed system has been confirmed, and we achieve a safe and smooth path planning for the miniature robotic fish and succeed in promoting the robotic fish to follow the path with acceptable deviation.

*This work was supported in part by the National Natural Science Foundation of China under Grant 61725305, Grant 61573226, and Grant 61633017, and in part by the Key Project of Frontier Science Research of Chinese Academy of Sciences (Grant No. QYZDJ-SSW-JSC004).

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