2022-04-20

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http://hdl.handle.net/10026.1/19514

10.1109/control55989.2022.9781455
2022 UKACC 13th International Conference on Control (CONTROL)
IEEE

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***Abstract*—This paper focuses on the development and vision-based object tracking control of a fish robot. Its efficiency towards target tracking is demonstrated in a water tank. Inspired by the maneuvering and stability of Tuna fish, the fish robot is designed by a single actuator located at the rare part of the fish body. The precise maneuverability characteristics of the fish robot is achieved by the motion of a caudal fin. A servo-motor is involved to control the oscillation of the caudal fin. A vision-sensor is integrated into fish robot to gain information related to Cartesian coordinates of the targeted object by implementing a color-based filtering algorithm. An object tracking algorithm is designed which performs the decision-making task for the fish robot while identifying and following the targeted object. The locomotion of the fish robot in various directions is tested experimentally by achieving effective performance of the proposed targeted object following task.**

*Keywords—**Fish robot, autonomous underwater vehicles, vision-sensor, target tracking***

I. Introduction

Bionic underwater robots have become significantly one of the hot research topics in the past few years. Autonomous underwater vehicles (AUVs) emulate the propulsion mechanism of a real fish. However, compared with traditional propeller-driven AUV technology, fish-like robots have great advantages that include greater efficiency, high-level agility and station-keeping ability [1]. Moreover, robotic fish has shown superior swimming performance [2]. Recent research work on bio-inspired technology proves that robotic fish offers advanced features such as swimming speed, real-time sensing and artificial intelligence over various marine species. For instance, a vision-based robotic fish is attracting the attention of the researchers, because of some better aspects in the context of object detection and tracking [3], and [4]. Such kind of robotic fish is being utilized for deep-sea exploration, observation and military underwater applications. The maneuverability of the robotic fish is categorized into anguilliform, carangiform and thunniform: (i) By waving the entire body (ii) wave the posterior body (iii) undulation by caudal fin.

In this literature, various fish-inspired robots have been proposed. For instance, in [5], researchers have presented a multi-link robotic fish that has locomotion of type anguilliform. The robotic fish consists of cylindrical-shaped rigid body with a conical head and a trapezoid caudal fin. The forward and backward movements of the robotic fish are achieved by three servo-motors used as electric actuators. A central-spine mechanism has designed in [6] to acquire the maneuverability of the Koi fish. The robotic fish mimics the carangiform locomotion by using caudal fin actuated by single servo-motor. The authors of [7], have designed a biomimetic robotic fish prototype with thunniform locomotion. Experimental results are obtained by the rotational motion of the servo-motor for tail fin to observe the swimming speed.

In the aquatic environment, the number of vision-based robot applications involve target identification and following. The target can be identified by adopting various sensors like, sonar, infrared or visionary sensors. Visionary sensors offer diverse technology as they provide information that includes the color and dimension of the targeted object. The authors of [8], designed the first embedded vision-guided target following robotic fish. The robotic fish equipped with on–board CMOS camera that allows to capture images, however, to improve image quality, a Camshift algorithm for image processing is needed. A vision-based bionic robotic fish has been developed in which visual information gathered through a camera then processed with ARM11 processor in [9]. A vision-based robotic fish is developed in [10] to navigate the target of interest in the underwater environment by implementing various robust vision algorithms.

Although the simple camera is considered as to add vision ability in the robotic fish, it has certain limitations related to huge data processing, computational complexity and resources. Pixy vision-sensors can be used to resolve problem of huge data processing. Pixy implements a color-based filtering algorithm which can process an entire 640×400 image frame in every 1/50th of a second besides providing desired information to microcontroller [11].

In this paper, we have developed a cost effective, vision-based, fish robot to identify and track an underwater object. This fish robot is feasible and capable of tracking the targeted object and drive towards it by considering a Pixy vision-sensor.

The rest of this paper is structured as follows. Section II introduces the mechanical and electrical design of the fish robot prototype and propulsive mechanism is proposed in Section III. Section IV addresses the object tracking algorithm while the experiments with the fish robot are conducted in Section V. Finally, we conclude the paper in Section VI.

II. MECHATRONIC DESIGN OF FISH ROBOT PROTOTYPE

The fish robot consists of two parts, a rigid hull and a caudal fin. The core structure of the body of the fish robot is very lightweight, waterproof hull. First, the technical drawings of the fish model are designed in the SolidWorks environment. The shape of the middle part of the hull is cylindrical, and the front part having conical rounded mouth-shape to reduce the drag force while driving. The material selection is a critical step towards the structural design of the fish robot, for this study as the material should exhibit different parameters for an efficient performance in underwater environments. For the production of the current prototype, a high-density 1.75mm Polylactic Acid (PLA) material is used by the 3D printer to design fish's body. To block water flow inside the hull, epoxy resin is coated on the inner and outer surface of the hull. The waterproof hull secures all the internal power while additionally offering space for electronic components and weights. The weights are required in order to reach a neutral buoyancy.

The fish robot can endow an intelligent autonomy in aquatic environments. Thus, it is equipped with a microcontroller, navigation sensors, HD wireless camera, power supply, wireless remote control relay and a Bluetooth module for the interface with a personal computer. The caudal fin is actuated by DC servo-motor which is screwed in the rear part of the main body and fixed to the caudal peduncle of a caudal fin. However, the pectoral fins are fixed in order to achieve stable locomotion of the fish robot along a horizontal plane. We set waterproof property when the vision-sensor is installed inside the mouth position with a transparent hemisphere glued to the front part of the hull. A waterproof ultrasonic sensor is fixed at the bottom surface of the hull inside a square box. The Lipo battery (5000 mAh) is employed to operate all the electronic components for nearly an hour. Meanwhile, a waterproof toggle switch is utilized to ON and OFF the battery. The photograph of the developed fish robot prototype is presented in Fig.1.

Fig. 1. Developed prototype fish robot

In order to control the functionality of the fish robot an Arduino Nano board is adopted. A vision-sensor named Pixy CMUcam5 performs an "eye-like" function to differentiate various colored objects. In general, hue (color) and saturation (color purity) techniques allow vision-sensor for color estimation and classification of each RGB pixel aiming to extract desired content form the captured image. Pixy, in fact, comes with a unique attribute of detecting seven color signatures simultaneously. The microcontroller is used to receive data from the vision-sensor via the gray ribbon cable with In Circuit Serial Programming (ICSP) interface. The transfer rate of the Pixy is 1Mbit/sec and the data is transmitted in blocks containing different characteristics about the Cartesian coordinates, width and height of the target of interest with respect to the sensor's position. Regarding to the obstacle avoidance strategy, a low-cost waterproof ultrasonic sensor is opted. Obstacle avoidance mechanism operates at a programmed distance to change the direction of fish robot. The microcontroller is specialized for performing decision making tasks based on the received information and then generates Pulse Width Modulation (PWM) signal. Servo-motor receives these signals to control the oscillation patterns of the caudal fin. A Bluetooth device is installed in fish body to carry out duplex communication with the personal computer. We have mounted a Go-Pro 1080 HD camera to capture surroundings. The camera can be operated wirelessly with Go-Pro App to access the stored data. Moreover, the fish robot can be operated wirelessly at any time by activating the remote control relay. The hardware control framework of the fish robot is illustrated in Fig. 2 while the Table I presents the technical key characteristics of the fish robot.

TABLE I. TECHNICAL KEY CHARACTERISTIC OF THE FISH ROBOT

Items	***Characteristics***
Body Dimension (L×W×H)	415 mm×280 mm×150 mm
Actuator mode	DC servo-motor
Navigation sensors	Pixy CMUcam5, Ultrasonic sensors
Programming	ICSP
Power supply	11.1 V, 5000 mAh
Mode of operation	Autonomous/BT mode

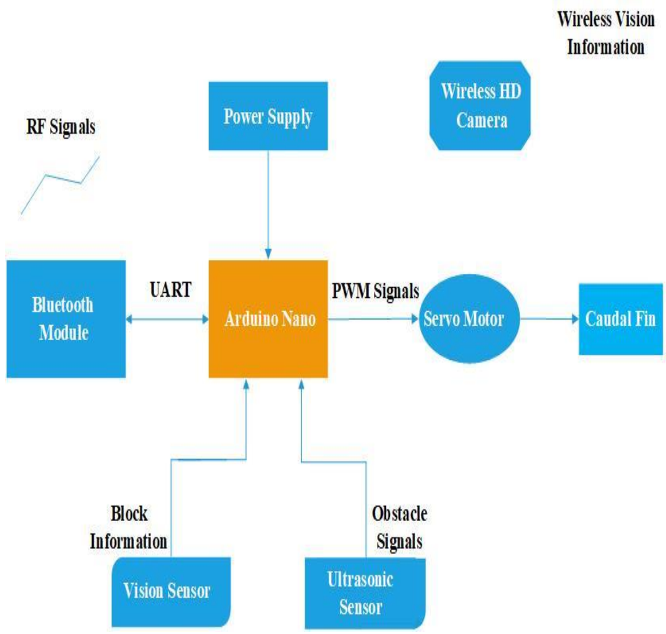


Fig. 2. Hardware control framework of the fish robot

III. PROPULSIVE MECHANISM

As stated above, a DC servo-motor is used to control the propulsion of the underwater fish robot. For this purpose, we preferred to incorporate HS-646WP servo-motor due to its promising waterproofing feature. The angular range of the rotation of a servo-motor is from 0° to 180°. The main structure of fish is designed based on propulsion mechanism as discussed in previous section. Behavioral analysis of several fish species exhibit different swimming models. We followed the propulsion model of Tuna after a detailed literature review for adequate model selection. Research insights that the lateral motion is related to caudal peduncle and caudal fin. The turning and propelling characteristics of fish robot have three degrees of freedom (DOFs) linked to the caudal fin. The precise control of the oscillatory motion of the caudal fin is achieved through a common closed-loop control. A perfectly rounded square shaped caudal fin having a low aspect-ratio is designed in order to facilitate better locomotion through adequate thrust force. Aspect-ratio plays a vital role to calibrate the shape of the caudal fin.

Numerical expressions of Aspect-ratio is shown in (1):

$$AR = \frac{L^2}{S} \tag{1}$$

Where L and S represent the span length and surface area of the caudal fin respectively. The precise multi-directional maneuverability of the fish robot is achieved by actuating the caudal fin appropriately.

IV. OBJECT TRACKING ALGORITHM

In order to accomplish underwater tasks autonomously, the fish robot must efficiently of detecting obstacles in the path promptly, make an immediate and adequate decision to bypass these obstacles by adopting an optimal path [12].

The navigation framework for object detection and tracking is attained by Pixy CMUcam5 vision-sensor along with the ultrasonic sensor. The vision-sensor, in fact, solely does not provide the data regarding the distance to the object from the fish robot, but read the information like color and dimension of the target of interest. Therefore, to obtain data regarding the distance to an object, an ultrasonic sensor is needed. The entire process of object detection and tracking algorithm for fish robot is illustrated in Fig. 3. This algorithm is programmed in the microcontroller. In short, this program allows fish robot to detect object based on the hue and saturation techniques of the image. If the target of interest comes in front of the fish robot, the vision-sensor estimates the x-position of the target of interest and the fish robot will change its position accordingly. On the other hand, if there is no object, the ultrasonic sensor will operate and the fish robot will start to move straight. If there is any obstacle facing the ultrasonic sensor, the fish robot will bypass it and turns to right.

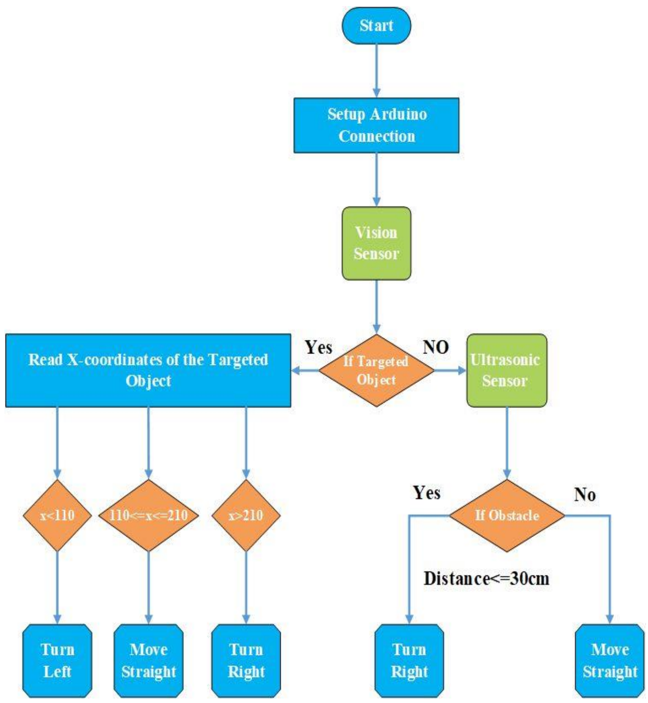
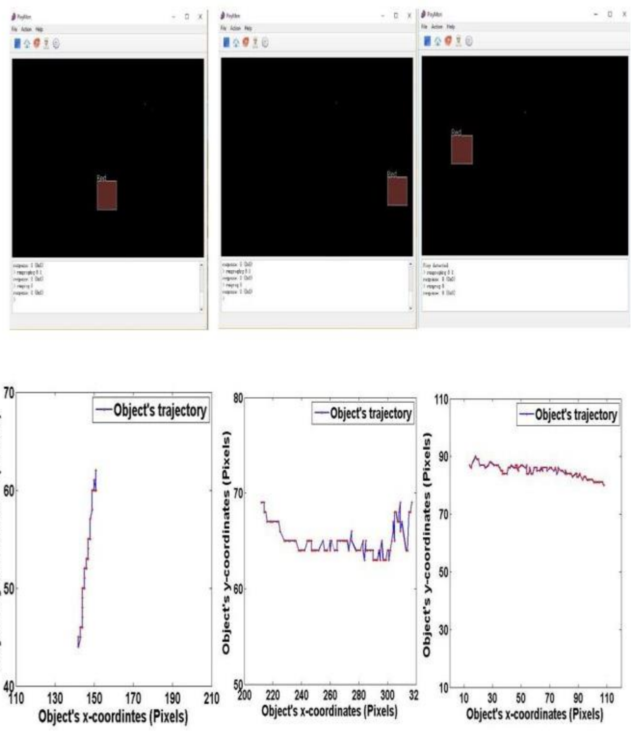


Fig. 3. Object tracking algorithm follow chat

V. EXPERIMENTAL RESULTS

The primary experiments with the fish robot are carried out in the water tank. First, a simple test is executed to determine the fish robot's ability to detect the movements of target object (a golf-sized red ball) placed underwater. The fish robot is connected to a personal computer wirelessly using Bluetooth module throughout the operation while PixyMon tool displays the image as the sensor detects the target of interest. The x and y-coordinates of the center of the target of interest in the vision-sensor lens are from 0 to 319 and 0 to 199 pixels respectively. If the x-coordinates of the target are from 110 to 210, the target is at the central position of the fish robot. In addition, x-coordinates are from 211 to 319 and 0 to 109 shows that the object lies at the right and left side of the fish robot respectively. Several movements of the target object and corresponding x and y-coordinates with respect to the fish robot are shown in Fig.4. Linear movement of the target object in the direction of fish nose is displayed in Fig.4a. It states that the position of the target object remains at the center while ranging its x-coordinates between 141 and 152 and y-coordinates between 44 and 63. Similarly, right and left movement of the target object from the central position is illustrated in Fig.4b and 4c respectively. The changes in x and y-coordinates can be noticed clearly. It is also shown that practical aspects such as non-uniform motion is causing a slightly change in the y-coordinates of the target object.



(a) (b) (c)

Fig. 4. Object position and corresponding Cartesian coordinates with respect to the fish robot (a) moving straight (b) moving right (c) moving left

The next experiment is conducted to analyze the robustness of the fish robot towards swimming performance while tracking the targeted object. The targeted object is chosen to be a small red toy fish which is controlled with human support. The propulsive power is mainly provided by the caudal fin to move the fish robot in forward, right and left directions. As the fish robot recognizes the targeted object, it begins to track the position of the target. The fish robot keeps track the targeted object as well as maintaining a distance within a specific range. However, underwater circumstances and the idiosyncrasies of the targeted object's motions have a considerable impact with respect to the distance fluctuations between the fish robot and the targeted object to some extent rather than to retain at a specific value. The distance between the fish robot and the targeted object along with x-coordinates of the targeted object while tracking as shown in Fig. 5.

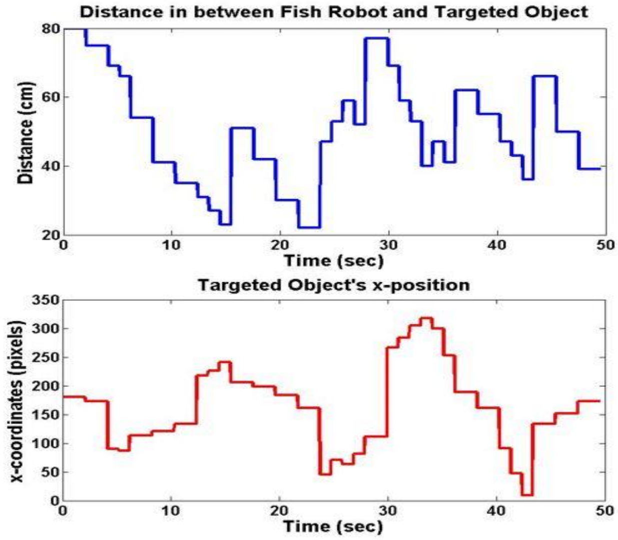


Fig. 5. Distance between the fish robot and targeted object

The object tracking and locomotion control closed-loop algorithm is applied to accurately track the position and orientation of the moving target object. When the x-coordinates of the targeted object are at the front position of the fish robot, the oscillatory motion of the caudal fin is from 0° to 180° and consequently, the locomotion of the fish robot towards forward. As the targeted object moves towards right or left position with respect to the fish robot, the caudal fin oscillates from 0° to 90° or 90° to 180° to turn the fish robot, right or left respectively. Fig. 6 shows the locomotion of the caudal fin of the fish robot with respect to the x-coordinates of the targeted object.

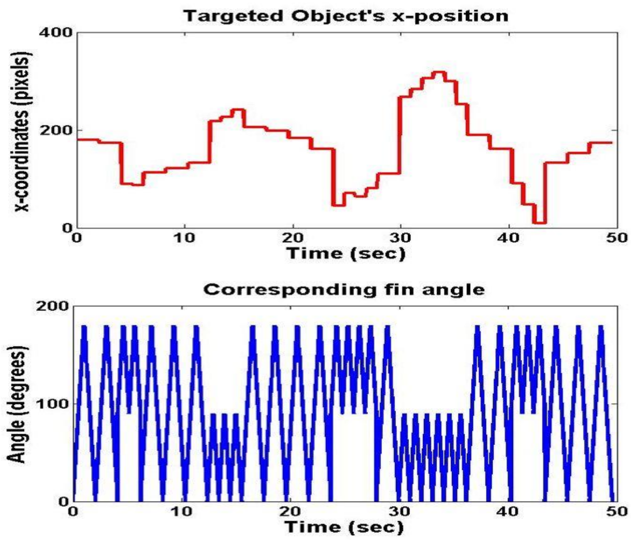


Fig. 6. Locomotion of the fish robot regarding to targeted object's x-position

Originally, the targeted object is in front of the fish robot, consequently, the caudal fin oscillates from 0° to 180° to get the fish robot motion in a required forward direction. After a while, the targeted object takes a left turn, the oscillatory motion of the caudal fin of the fish robot also changes to move towards left. Likewise, when the targeted object move towards the right side, the fin oscillation adjusts itself to move the fish robot in a required right direction.

VI. Conclusion

In this study, a fish robot has been developed for underwater tasks like object detection and tracking autonomously. Simple closed-loop control system is developed in order to realize the precise oscillatory motion of the caudal fin. The object detection is addressed with color hue and saturation techniques. A vision-based object tracking algorithm has been implemented to track the path of the targeted object in real-time. A combination of the vision and ultrasonic sensor has been considered for data collection from the environment.

In this paper, we examined the position and movements of the targeted object in different directions. The primary goals and objective of this research work have been achieved successfully as the maneuverability of the fish robot to detect and track a small red toy fish at varying speed and in different directions is developed effectively. In our future work we plan to increase the maneuvering abilities of our robotic fish by adding components for upward and downward maneuverability. Moreover, more sophisticated control algorithms will be implemented in order to deal with uncertainties in the environment and sensor noise.

Acknowledgement

The authors like to acknowledge the Royal Society International Exchange grant number IEC\NSFC\170405 for this work.

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