물고기 로봇 추적 제어 구현

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Implementation of Fish Robot Tracking-Control Methods

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요 약

This paper researches a way of detecting fish robots moving in an aquarium. The fish robot was designed and developed for interactions with humans in aquariums. It was studied merely to detect a moving object in an aquarium because we need to find the positions of moving fish robots. The intention is to recognize the location of robotic fish using an image processing technique and a video camera. This method is used to obtain the velocity for each pixel in an image, and assumes a constant velocity in each video frame to obtain positions of fish robots by comparing sequential video frames. By using this positional data, we compute the distance between fish robots using a mathematical expression, and determine which fish robot is leading and which one is lagging. Then, the lead robot will wait for the lagging robot until it reaches the lead robot. The process runs continuously. This system is exhibited in the Busan Science Museum, satisfying a performance test of this algorithm.

1. Introduction

Recently developed bio-inspired robotic fish are imitating various aspects of nature. “People have been trying to copy nature for a very long time,” says Jerry Pratt, a research scientist at the Institute for Human and Machine Cognition in the United States. Often, engineers get ideas from biological systems, and are inspired to make new biomimetic robots.
Our research is exhibited in the Busan Science Museum, controls the positions of robotic fish, and it is a new underwater world concept that interact with people. This manuscript is mainly concerned with detecting and tracking the positions of robotic fish using different algorithms, such as a boundary algorithm, an optical flow algorithm, and a color segment algorithm. Then, we analyze the performance of the three algorithms and adopt a suitable algorithm for this system. Finally, we track the motion of robotic fish using various tracking algorithms, like stop-zone tracking control based on the manual position command that decides when to stop robotic fish. Color-mark tracking control is based on color, and when we place any color mark near the aquarium walls, robotic fish recognizes color and stop after reaching the color mark; when the color mark is removed, the robotic fish will swim again. Lead-lag tracking control is based on the leading and lagging positions of robotic fish; when the distance between the leading and lagging robotic fish is high, the lead robotic fish will stop until the lagging robotic fish reaches it.[1~8]

2. Design of Robotic Fish

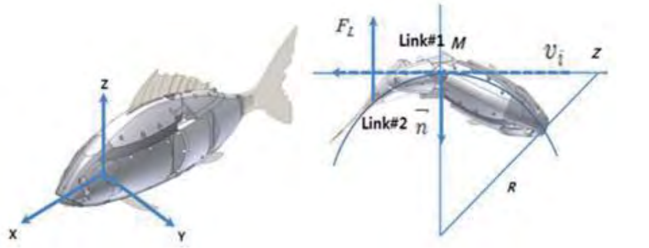
Robotic fish are researched for aquariums to realize biomimetic fish. This robot mainly consists of the head, a first-stage body, a second-stage body, and the tail, all connected through joints and the design parameters shown in Table 1. The body was designed through analysis of biological fish swimming in order to maximize the momentum of the robotic fish.

<Table 1> Parameters of the Robotic Fish

Component	Length	Width	Height
Head	70	72	110
1st Body	180	90	175
2nd Body	82	80	150
Tail	190	70	180

In addition to this, a control system consists of three position sensitive detectors (PSDs), two DC motors, a weight moving unit, and an RF modem. The PSD sensors are attached to the head and are used to detect obstacles in the aquarium; when the robotic fish hits a boundary, a signal is sent to the AVR(Micom) to control it. The DC motors are used to make the robotic fish flexible enough to swim in the aquarium, are connected to the first-stage body and the second-stage body, and operate with sensor data from the micom. The weight moving unit is also a battery, which is used to balance the robotic fish when it goes up and down. Finally, the RF modem is used to control the swimming of the robotic fish manually.

The robotic fish's dynamic force is determined during instantaneous swimming; the forces acting on it are thrust (the forward direction is the x-axis), water resistance (the reverse direction is the y-axis), and gravity (the vertical direction is the z-axis), as shown in Figure 1(a). When the robotic fish is swimming, the force acting on the body is the gravitational force acting opposite to fluid propulsion of the robotic fish, lifting the body as shown in Figure 1(b).



(a) (b)

(Figure 1) The acting axes of the fish robot, (b) The lift and swimming rotation in the aquarium.

We present the mathematical modeling of the buoyancy force acting on the fish in the aquatic environment as expressed in the fixed coordinate system $[\hat{x}_i, \hat{y}_i, \hat{z}_i]$, and the swimming equation of the robotic fish is a continuous function with a discrete function for the kinematic streamer model through the proposed light hill analysis. In order to control the tracking speed, the speed of the motor highly depends on the torque value, TL. It can improve the performance from the speed of the motor by using a proportional feedback controller.

3. Comparing the Detecting of an Object using python

3.1 The boundary algoritghm

This is the first approach to find the position and detect the object boundary; there are four primary stages to follow, namely, filtering, enhancement, detection, and localization. To detect the edge of a robotic fish, we used edge detectors (such as Roberts, Sobel, and Prewitt) to localize the edge of the object. In this algorithm, these procedures are image processing that can distinguish objects and detect boundaries. This algorithm was developed using edge detectors to detect the boundary of an object. The Sobel operator is very similar to the Prewitt operator. It is also a derivative mask, and is used for edge detection. Like the Prewitt operator, the Sobel operator is also used to detect two kinds of edges in an image: the vertical direction and the horizontal direction.

(1) Roberts Operator: The Roberts edge operator computes a simple approximation of the gradient magnitude of the pixels of an image, as shown in equation (2):

$$\left(\frac{\partial f}{\partial x}+\frac{\partial f}{\partial y}\right)^2+\left(\frac{\partial f}{\partial x}-\frac{\partial f}{\partial y}\right)^2 \quad (2)$$

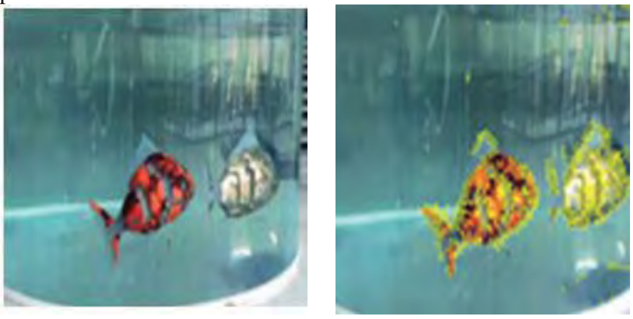
where $\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}$ represents the gradient operator, in which f is the function and x and y are the pixels.

(2) Prewitt Operator: The Prewitt operator introduced 3x3 gradient operators by using the pixel numbering convention. The Prewitt operator's square root edge gradient is shown in equation (3), where k=1. In this formulation, the row and column gradients are normalized to provide unit-gain, positive- and negative-weighted averages about a separated edge position.

$$G(j,k)=\left[\left[G_R(j,k)\right]^2+\left[G_C(j,k)\right]^2\right]^{1/2} \quad (3)$$

$G(j,k)$ is the spatial gradient amplitude, $G_R(j,k)$ is the row gradient: $G_R(j,k)=\frac{1}{K+2}\left[(A_2+KA_3+A_4)-(A_0+kA_7+A_6)\right]$; and $G_C(j,k)=\frac{1}{K+2}\left[(A_0+KA_1+A_2)-(A_6+kA_5+A_4)\right]$ $G_C(j,k)$ is the column gradient.

(3) Sobel Operator: The Sobel operator edge detector differs from the Prewitt edge detector in that the values of the north, south, east, and west pixels are doubled when the value of k=2. It can be expressed in equation (3); k is the constant, and A0, A1, A2, A3, A4, A5, and A6 are the neighborhood pixels.



(a) (b)

(Figure 2) (a) The original video (b) detecting the fish by the optical flow.

3.2 The color segment algorithm

Detection of an object is foremost, but it depends on the object and the environment. An object can be detected either by its shape or color. Color is essential for computer vision; it is an attractive feature because of its simplicity for object positions.

The hue–saturation–value (HSV) color space belongs to the group of hue-oriented color-coordinate systems. This type of color model closely emulates models of human color perception. While in other color models, such as red–green–blue (RGB), an image is treated as an additive result of three base colors, in the three channels of HSV, hue gives a measure of the spectral composition of a color, saturation gives the proportion of pure light in the dominant wavelength (which indicates how far a color is from a gray of equal brightness), and value gives the brightness relative to the brightness of a similarly illuminated white color. These correspond to the intuitive appeal of tint, shade, and tone. HSV is widely used to make a comparison of colors, because H is almost independent light variations. The color space conversion code to convert between RGB and HSV in OpenCV using cvtColor is COLOR_BGR2HSV, COLOR_RGB2HSV, COLOR_HSV2BGR, and COLOR_HSV2RGB. In this case, it is worth noting that if the source image format is eight-bit or 16-bit, cvtColor first converts it to floating-point format, scaling the values between 0 and 1. After that, the transformations are computed from equations (6) and (7):

$$V=max(R,G,B)$$

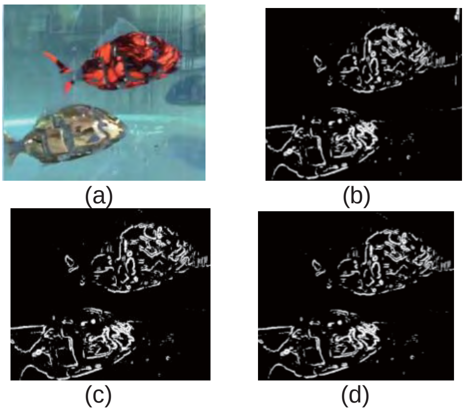
$$S = \begin{cases} \dfrac{V - min(R,G,B)}{V} & if\ V \neq 0 \\ 0 & otherwise \end{cases} \qquad (6)$$

$$H = \begin{cases} \dfrac{60(G-B)}{V - min(R,G,B)} & if\ V = R \\ 120 + \dfrac{60(B-R)}{V - min(R,G,B)} & if\ V = G \\ 240 + \dfrac{60(R-G)}{V - min(R,G,B)} & if\ V = B \end{cases} \qquad (7)$$

If $H<0$, then $H = H + 360$. Finally, the values are reconverted to the destination.

3.3 Comparison of object-detecting algorithms

The experimental results from various algorithms, such as the boundary algorithm, the optical flow algorithm, and the color segment algorithm, are shown in figures 2, 3, and 4. Figure 3(a) shows the original object source directly covered from a side-view camera, and Figure 3(b) shows Roberts edge-detecting of robotic fish. This edge operator has a large mask used to reduce noise in the image.
Figure 3(c) shows the edges from detecting the robotic fish using the Sobel edge detector. Figure 3(d) shows the edges from detecting the robotic fish using the Prewitt edge detector. These results are also similar to the Sobel edge operator, but the main difference between these two edge-detecting operators is the weight of the mask or kernel. Finally, when comparing the three edge detectors, Roberts, Sobel, and Prewitt detectors give similar results.



(Figure 3): (a) The original video, (b) detecting the fish by using Roberts edge detector, (c) detecting the fish by using the Sobel edge detector, and (d) detecting the fish by using the Prewitt edge detector.

Figure 4(a) shows robotic fish covered by the camera and figures 4(b), 4(c), 4(d), and 4(e) are variously colored robotic fish detected by using the color mark segment algorithm. Finally, the color segment algorithm is suited to this system for tracking robotic fish in an aquarium.

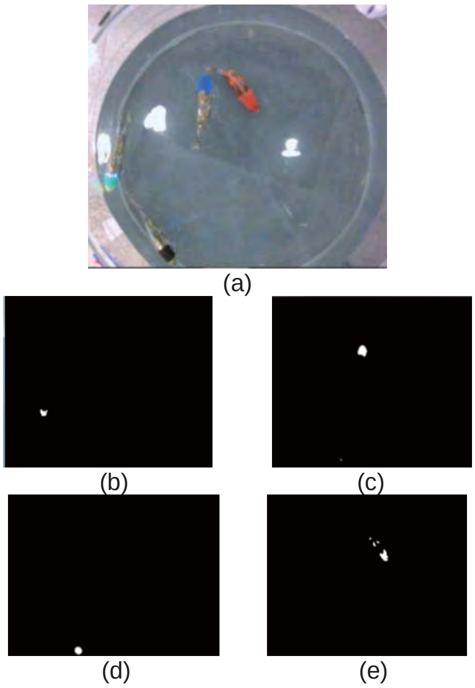
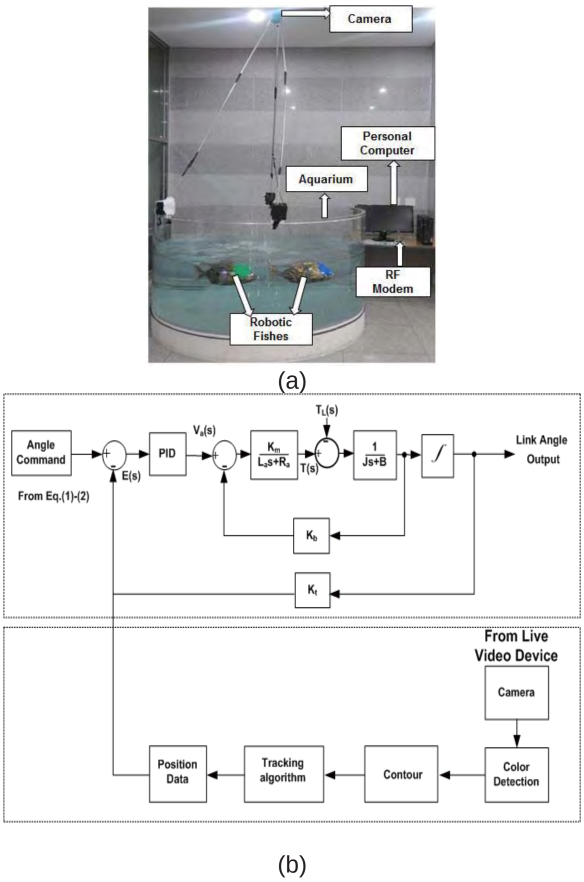


Figure 4 (a) The original video, (b) a green fish, (c) a blue fish, (d) a black fish, and (e) a red fish.



(Figure 5) (a) The experimental result of robotic fish in the aquarium, and (b) the proposed robotic fish tracking position control system.

4. Conclusion

In this paper, the designed fish robot mimics biological swimming fish because the performance of the fish robot is excellent. To find positions, we have to detect the moving objects that are fish robots in the aquarium. In this, we used an optical flow algorithm to detect the positions of moving objects in an aquarium. The designed fish robot uses a Python model to display the coordinates of the fish robot and to analyze the positions of the fish robots, as shown above. We detected the results of the fish robots by using a boundary filter, and detected a green rectangle surrounding the objects along with motion vectors that can be formed by using the optical flow algorithm. By using this positional data, we compute the distances between fish robots using a mathematical expression, and determine which fish robot is leading and which fish robot is lagging. Then, the lead fish robot will wait for the lagging fish robot until the lagging fish robot reaches the lead fish robot. When the distance between them becomes zero, the fish robots move parallel to each other until the distance between them becomes long again; then, the lead fish robot will again wait for the lagging fish robot. This method uses the Python image processing model for tracking and detecting the fish robots. Finally, we compared the performance of lead–lag control from the optical flow algorithm, and confirmed excellent performance in field tests, such as filtering images, enhancing them, detecting objects, determining motion vectors, localizing the boundaries, and finally, achieving lead–lag control of the fish robots. This satisfied the performance test of this algorithm. The system performance as shown in Figure 6 is very good and attracts visitors to the Busan Science Museum.

(Figure 6) Robot fish tracking control system in Busan National Science Museum.

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