IEIE Transactions on Smart Processing and Computing

Robot Fish Tracking Control using an Optical Flow Object-detecting Algorithm

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Received September 21, 2016; Revised October 31, 2016; Accepted November 19, 2016; Published December 30, 2016

* *Regular Paper*

* *Extended from a Conference: Preliminary results of this paper were presented at the ITC-CSCC 2016. This paper has been accepted by the editorial board through the regular review process that confirms the original contribution.*

***Abstract*:** This paper realizes control of the motion of a swimming robot fish in order to implement an underwater robot fish aquarium. And it implements positional control of a two-axis trajectory path of the robot fish in the aquarium. The performance of the robot was verified though certified field tests. It provided excellent performance in driving force, durability, and water resistance in experimental results. It can control robot motion, that is, it recognizes an object by using an optical flow object-detecting algorithm, which uses a video camera rather than image-detecting sensors inside the robot fish. It is possible to find the robot's position and control the motion of the robot fish using a radio frequency (RF) modem controlled via personal computer. This paper proposes realization of robot fish motion-tracking control using the optical flow object-detecting algorithm. It was verified via performance tests of lead-lag action control of robot fish in the aquarium.

***Keywords*:** Robot fish control, Object detecting, Optical flow algorithm, Aquarium robot system, Lead-lag control, Motion tracking control

1. Introduction

The design of robots is often inspired by nature; recently developed bio-inspired robots have imitated various aspects of their live counterparts. Robotic dynamics is a new sub-category of bio-inspired design. It is about learning concepts from nature and applying them to the design of real-world engineered systems. More specifically, this field is about making robots that are inspired by biological systems [1, 2].

The researched robot fish inspired from the biological systems (that is natural Korean fish called it as DOMI). DOMI is first version of research and this research started from the year 2007. Firstly, we have approached with wired link mechanism, this approach held between 2007 to 2008, in this mechanism, robot fish body operated by the servo motor and this wire having multiple links and these links are connected with wire, when the servo motor rotated parallel to the robot fish body, the servo motor connected to the wire. When the motor is rotating clock wise and counter clock wise directions, then, these links are moving left and right. In this scenario, these links are also placed parallel to the robot fish body, when the motor is rotating the clockwise and counter clockwise directions with respect to links, links rotating the left and right directions. So that, this mechanism is called as the wired link mechanism. In this method, fish robot could be performed only two directions such as left and right, and also, the design of the fish robot is not satisfied because of this robot fish was not mimic the DOMI. So that, after, one year, we have approached the direct link DC motor mechanism held between 2008 to 2012, in this mechanism, DC motor is directly connected to the links of the body, when DC motor is rotating the clockwise and counter clockwise directions, links of the body are moving linear motion because of rotary motion is converted into the linear motion like left and right directions of the robot fish. In this method, the robot fish could be performed only two directions such as left and right directions, but could not be performed the up and down directions, and also, not mimic the DOMI. So that, we have approached the moving central weight mechanism, this method has started research held between the year 2010 to 2012. In this method, we have approached the sliding mechanism and generally, it is also known as the balancing mechanism. This mecha-nism balances the robot fish and places the

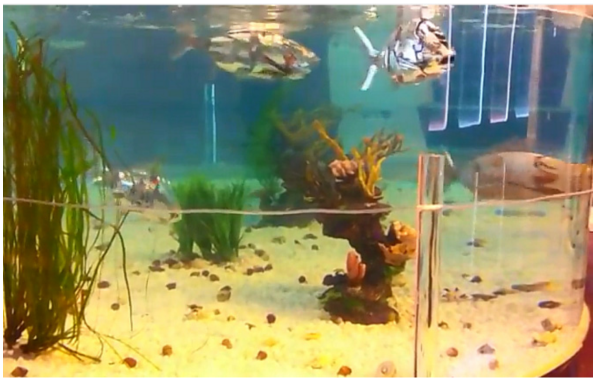


Fig. 1. The exhibited robot fish at YEOSU Marine expo 2012.

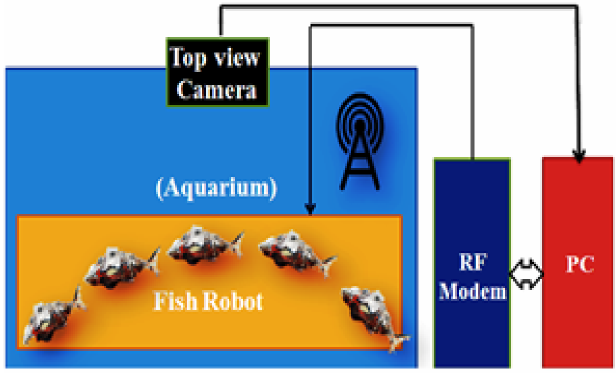


Fig. 2. The aquarium robot fish world to control the robot fish.

central position of the robot fish, when the slide is moving forward, the head of the robot fish moves down, then fish body goes to the bottom of the aquarium and slide is moving back-ward, the head of the fish robot moves up, then robot fish goes to the top of the aquarium. This method has satisfied both design and swimming performance such as left, right, up and down directions, and also perfectly mimic the DOMI. We have developed this robot fish to entertain the people, (especially children) using robot fish along with holographic methods. The design of a robot fish has patent [1] and also published an articles [3, 4] entitled as "Design of Autonomous Biomimetic Robotic Fish with Swimming Artificial Intelligence" and "Development of Autonomous Biomimetic Ornamental Aquarium Fish Robotic" and also, exhibited robot fish in the international YEOSU Marine expo, 2012 as shown in Fig. 1. Finally, We have extremely interested on gathering a robot fishes at one place and segregate from that place.

In this paper, a robot fish is researched, designed, and developed for an aquarium robot system. The proposed aquarium consists of robot fish, a personal computer (PC), a camera, and a radio frequency (RF) modem, as shown in Fig. 2. The robot fish model was analyzed to maximize the momentum of the robot, and the body of a robot was designed through analysis of biological swimming and presented robot fish consists of the head, a first-stage body, a second-stage body, and a tail, which are connected through two-point drive joints in the robot, applying an approximate method of a streamer model that utilizes techniques to mimic biological fish [3, 4]. The swimming robot fish has three operating modes: manual, autonomous and control modes. In manual mode, the robot fish's swimming is operated by using an RF transceiver through command. In autonomous mode, the robot is controlled through a microcontroller unit. It consists of two servo motors and three position sensitive detector (PSD) sensors in the forehead of the robot fish to detect obstacles. An air bladder in the head is used for movement methods, and a communication port receives data. In control mode, the robot is controlled through a commands like left, right, up, and down through program. An aquarium robot world was designed using the robot fish to realize the robot aquarium requires coordinated position data, from research about robot fish using boundary detecting, color weight, and comparing image data algorithms [10-12].

This paper has proposes to design the robot fish aquarium to establish communications between the robot fish and the PC. In order to detect the robot fish and for position-tracking control of the robot fish using an optical flow object-detecting algorithm, from the PC,control the robot's motion, recognizing objects by using a video camera without any other object-detecting sensors inside the robot fish. It is possible to find the position and control the motion of the robot fish using an RF modem controlled from the PC.

This paper proposes to realize the robot fish tracking control using an optical flow object–detecting algorithm. It was verified the performance tests for the designed robot fish aquarium.

2. Modeling of the Robot Fish

The designed robot fish was researched and developed for an underwater robot-system aquarium. The presented robot fish consists of the head, first-stage body, second-stage body, and a tail connected through two-point drive joints. Because the robot needs to maximize momentum, the body of the robot was designed through analysis of swimming by biological fish. Also applied was kinematics analysis of robot fish swimming algorithms, which is basically Light-hill dynamics. The center of gravity for the robot fish is transferred to one-axis sliding, and it is possible to submerge and raise the robot with the weight-moving unit.

In addition to this configuration, the entire robot fish con-trol system was designed to apply an artificial intelligence algorithm and apply an AVR microcontroller in order to mimic biological control of the robot. AVR is one of the first microcontroller families to use on-chip flash memory for program storage which was developed by Atmel. The AVR micom is heart of the control system and mainly it consists of the RF modem, three PSD sensors, two servo motors, and a weight-moving unit. The RF modem is used to control the behavior of the robot fish in manual mode. PSD sensors are used to detect obstacles in the aquarium, and servo motors operate with the sensor data. The weight-moving unit is used to balance the swimming motion of the robot fish using a sliding method

Table 1. The parameters of the designed robot fish (unit: mm).

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

and a communication port designed for a data acquisition unit.

It functions as the streamer position control algorithm for autonomous mode and manual mode using the servo motors. Each robot fish body was manufactured through an assembly device configured like an optimized inner area-design robot. The robot dynamic force is determined by instantaneous swimming, and the robot specifications are shown in Table 1.

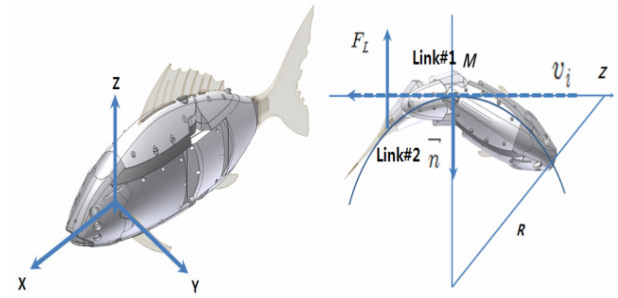
$$\vec{F}_i = -\frac{1}{2}\rho_{water}\begin{bmatrix}(C_{d\hat{x}_i}L_iH_i + C_{f\hat{x}_i}(H_i+L_i)W_i)v_{\hat{x}_i}\left|v_{\hat{x}_i}\right| \\ (C_{d\hat{y}_i}L_iW_i + C_{f\hat{y}_i}(L_i+W_i)H_i)v_{\hat{y}_i}\left|v_{\hat{y}_i}\right| \\ (C_{d\hat{z}_i}W_iH_i + C_{f\hat{z}_i}(W_i+H_i)L_i)v_{\hat{z}_i}\left|v_{\hat{z}_i}\right|\end{bmatrix} - \begin{bmatrix}0 \\ \rho_{water}L_iH_iW_ig \\ 0\end{bmatrix} \quad (1)$$

where $v_{\hat{x}_i}$, $v_{\hat{y}_i}$, $v_{\hat{z}_i}$: i^{th} body-fixed coordinate system, $\hat{x}_i, \hat{y}_i, \hat{z}_i$: axis speed, W_i, L_i, H_i : i^{th} width, length and height of the body, ρ_{water} : density of the water, g :gravitational force, $\vec{F}_i$: force acting on the body by water, $C_{d\hat{x}_i}, C_{d\hat{y}_i}, C_{d\hat{z}_i}$: drag coefficients and $C_{f\hat{x}_i}, C_{f\hat{y}_i}, C_{f\hat{z}_i}$: friction coefficients for each body-fixed coordinate system $\left[\hat{x}_i, \hat{y}_i, \hat{z}_i\right]$.

The forces acting on the robot fish are thrust (the forward direction is the x-axis), water resistance (the reverse dire-ction is the y-axis), and gravity (the vertical direction is the z-axis) as shown in Fig. 3(a). Buoyancy acting on the fish in the aquatic environment is expressed as the force acting on fluid propulsion to the fixed coordinate system $\left[\hat{x}_i, \hat{y}_i, \hat{z}_i\right]$ of the robot fish, which is shown in Eq. (1) [5]: When the robot fish is swimming, the force acting on the robot is the gravitational force acting opposite to the fluid propulsion of the robot fish, and it lifts the robot fish body as shown in Fig. 3(b). The driving force can be obtained with Eqs. (2) and (3) by the Lagrangian function [6]:

$$\begin{aligned} L &= T - V \\ &= \sum_i \frac{1}{2} m_i^2 v_i^2 + \sum_i \frac{1}{2} I_i^2 w_i^2 - E_p \end{aligned} \quad (2)$$

where L : lagrangian function, T : total kinetic energy of the system , V : potential energy of the system, m_i: mass of the i^{th} link, v_i :velocity of the i^{th} link , I_i : moment of inertia of the i^{th} link , w_i : angular velocity of the i^{th} link and E_p : potential energy, and:



(a) (b)

Fig. 3. Motion control of the robot fish.

$$\vec{F}_R = \frac{d}{dt}\frac{\partial L}{\partial \dot{q}} - \frac{\partial L}{\partial q} \quad (3)$$

where $\vec{F}_R$: propulsive force of the body, L : lagrangian function, q : joint variable and $\dot{q}$ is the first derivative of the joint variable.

So finally, the force acting on the robot fish is equal to the addition of relative force acting on the body, the initial force acting on the body, and the weight acting on the body as shown in Eq. (4):

$$\vec{F} = \vec{F}_R + \vec{F}_i + w \quad (4)$$

where $W = m\vec{g}$, m is the mass of the body, $\vec{g}$ is the gravita-tional force acting on the robot , W is the weight acting on the robot, $\vec{F}_L$ is the total force acting on the robot, $\vec{F}_R$ is the propulsive force, $\vec{F}_i$ is force acting on the robot by water.

The swimming form of the robot fish is a continuous fun-ction with a discrete function for the kinematic streamer model through the proposed analysis by Light-hill, which is equal to Eq. (5) [5, 7, 8]:

$$\begin{aligned} y_i(x,t) &= \left(C_1x + C_2x^2\right)\sin\left(kx - 2\pi ft\right) \\ &= \left(C_1x + C_2x^2\right)\sin\left(kx - \frac{2\pi}{M}i\right) \end{aligned} \quad (5)$$

where $y_i(x,t)$ is the transverse displacement of the bio-mimetic fish robot along the x-axis at time t, x is the axial displacement of the body (head and tail), C_1 and C_2 are the linear coefficient and the quadratic coefficient of the body wave amplitude envelope of fish robot respectively, k is multiples of the body wave number, ω is the body wave frequency of the biomimetic fish robot and f is the propelling frequency.

Error is defined in Eq. (6),which is the traveling wave approximation using the three joints, and the joint angle can be approximated with Eq. (7) by a sine wave having the same frequency, like a traveling wave:

$$error = \sum_{i=0}^{n-1}\int_{x_s}^{x_{end}}\left|g(x) - f(x)\right| \quad (6)$$

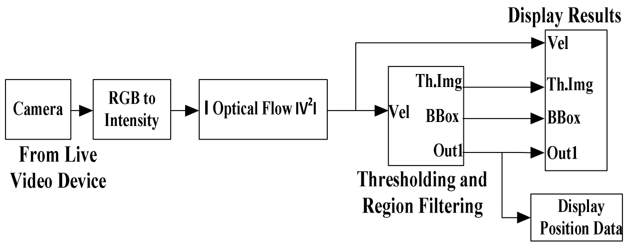


Fig. 4. The proposed optical flow algorithm model for detecting the position of robot fish.

where *g(x)* is the function of travelling wave of joint angle 2 and *f(x)* is the function of travelling wave of joint angle 3.

$$\theta_i = a_i \sin\left(2\pi ft + p_i\right) \quad (7)$$

where θ_i is the joint angle, a_i is the amplitude, f is the frequency, t is the time and p_i is the phase difference between the heaving and pitching motions.

In order to swim up and down, the robot is designed to move back and forth around the center of gravity estimation point using a sliding-weight center-point method, which is like the gravity principle in bio-inspired robot fish.

3. Robot Fish Tracking Control using Optical Flow-Detecting Algorithm

3.1 Detecting the Position of the Robot Fish

The Simulink model for detecting robot fish is shown in Fig. 4. The process in Simulink starts from live video and ends with a display of robot fish data. It consists of live video, RGB to intensity, optical flow, thresholding and filtering, and two-axis position data blocks. The camera is installed at the top of the robot fish aquarium, and it captures the swimming motion of the robot fish. Here, this step is very important, because the original video is converted into grayscale by using RGB to gray. Then, applied optical flow will detect the motion vectors of the robot fish throughout the body as well as boundary filtering of the robot fish, and it finds the position of the robot fish in two axes. Actually, the process of estimating the motion between two frames is called optical flow. Mainly, optical flow is used to analyze the motion of the video sequences [9, 10]. Consider the pixels in frame (n-1) as having (x,y) coordi-nates with motion vectors (u,v) at time $(t-1)$, and the pixel position changes after time (t) in frame (n), that is, $(x+u,\ y+v)$. So, assume the intensity of two images is the same, that is, expressed in Eq. (8):

$$I_2\left(x+u, y+v\right) = I_1\left(x, y\right) \quad (8)$$

The above equation can be expressed with time as shown in Eq. (9):

$$I_2\left(x+u, y+v, t+1\right) = I_1\left(x, y, t\right) \quad (9)$$

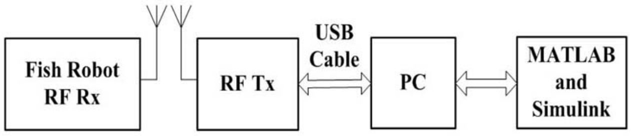


Fig. 5. Block diagram of the RF link to the robot fish.

Eq. (9) becomes, after applying a Taylor series to the left-hand side:

$$\frac{dI}{dx}u + \frac{dI}{dy}v + \frac{dI}{dt} + I\left(x, y, t\right) = I\left(x, y, t\right) \quad (10)$$

Solving Eq. (10) gives Eq. (11):

$$\frac{dI}{dx}u + \frac{dI}{dy}v = -\frac{dI}{dt} \quad (11)$$

where $\frac{dI}{dx} = f_x, \frac{dI}{dy} = f_y, \frac{dI}{dt} = f_t$, so Eq. (11) becomes Eq. (12):

$$f_x u + f_y v = -f_t \quad (12)$$

Eq. (12) is called the standard equation of optical flow. This is used to detect motion from the frames in the video, and can get the motion vectors on the object, as shown in the experimental results in Fig. 9(d). The two axes can be displayed on the two-axis data display on the PC in table format in the display block. These experimental results are shown in Fig. 9 [11-14].

3.2 Robot Fish Control using the RF Modem

The robot fish operates in three modes: manual mode, automatic mode, and control mode. In automatic mode, it is controlled using built-in sensors of robots through path-search optimization in the aquarium. Before controlling the robot fish, it has to be set to manual mode. Then, control the robot fish using commands (like left, right, straight, up, and down) in the control mode to provide motion directions to the robot fish. This control was done by using Simulink and MATLAB. The robot fish and PC are connected via wireless communications through the RF modem. The RF modem and PC are connected through a USB cable and establish serial communications, as shown in Fig. 5, and the robot fish is controlled in the water tank. The water in the tank is not salty and low in depth. So, a high frequency is used with a 5V DC power supply, and the radio frequency signal can pass via serial communications protocol. To catch this radio signal, a whip antenna is used to transmit the signal, and it covers more than 1.5 m. Also, it controls three joints and the bladder device via the RF transceiver in manual mode, which is shown in the PC through the camera.

3.3 The Proposed Robot Fish Tracking-Control System

It is important to control the tracking speed, so the speed of the motor is highly dependent on the value of torque, T_L. It can improve the speed performance of the motor by using a proportional feedback controller. The controller is compos-ed of a sensor to determine the speed and an amplifier with gain K (proportional control) in the configuration of the robot fish. The speed at the motor shaft is sensed by the potentiometer with gain K_t, and proportional-integral-deri-vative (PID) control can be expressed in Eq. (13):

$$\mathrm{PID}(s) = K_p + K_d s + \frac{K_i}{s} \tag{13}$$

where K_p is the proportional gain, K_d is the differential gain, and K_i is the integral gain.

The input to the control system is converted from voltage V_{in} to speed ω_{in} using potentiometer gain K_t. Hence, assum-ing $L_a = 0$ gives Eq. (14):

$$\omega(s) = \frac{K_m / R_a J}{s + \left(\frac{R_a B + K_b K_m}{R_a J}\right)} V_a(s) \tag{14}$$

where $\omega(s)$ is the speed of the robot fish, K_m is motor gain, R_a is armature resistance, J is the moment of motor inertia, B is the viscous friction coefficient of the motor shaft, K_b is the gain of back emf, L_a is armature inductance, T_L is external load torque considered as a disturbance, and $V_a(s)$ is the applied voltage.

In order to control link angle, the Simulink model to control the link body of the robot fish is shown in Fig. 6. In this, the first block is the dynamic motion of the robot fish, and the remaining blocks are the model used to control the link angle of the robot fish. The link angle output (LAO) is expressed in Eq. (15):

$$\mathrm{LAO} = \frac{s^2 K_m K_d + s K_t K_p + K_i K_m}{s^3 R_a J + s^2 (K_m K_b + R_a B + K_m K_t K_d) + s(K_m K_t K_p) + K_m K_t K_i} \tag{15}$$

where K_m is motor gain, K_d is the differential gain, K_i is the integral gain, K_p is the proportional gain, J is the moment of motor inertia, K_b is the gain of back emf, K_t is the angle signal gain, R_a is armature resistance, B is the viscous friction coefficient of the motor shaft, L_a is armat-ure inductance, T_L is external load torque considered as disturbance, and $V_a(s)$ is the applied voltage.

The link angle command is produced from Eqs. (5)-(7) and the error $E(s)$ is calculated by subtracting the angle command to the feedback link angle signal that is defined by the integral processing of the link potentiometer output signal. The error is compensated by the PID controller and converted to the drive signal of the DC motor. External disturbance torque T_L is compensated by feedback from the motor speed, and it realizes the control of the link angle, just like a fish. The control of the robot fish can be monito-red through the live video, which is connected to the live video-device (that is, the camera) and it detects the bound-ary of the robot fish, which can be displayed in the display block.

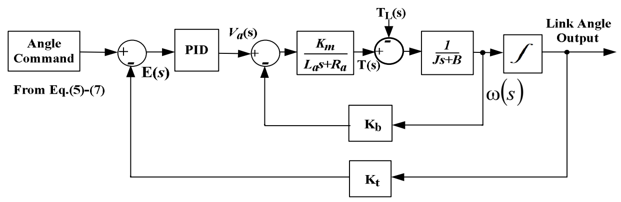


Fig. 6. The link angle control of the robot fish.

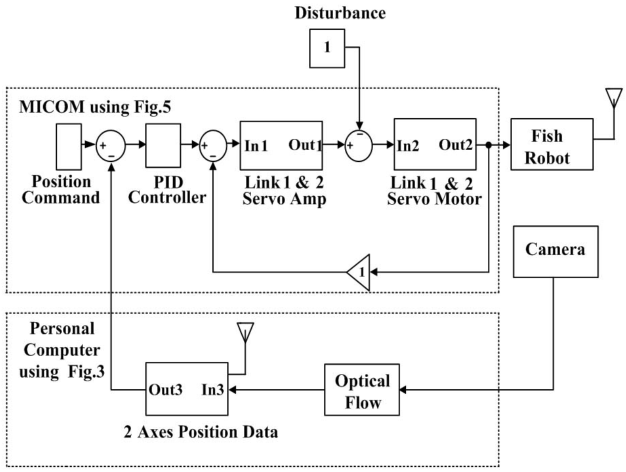


Fig. 7. The proposed robot fish tracking position–control system.

The Simulink model for the automatic tracking control system of the robot fish is shown in Fig. 7. The system will detect the moving object (that is robot fish) in the aquarium and this detected data will send to the fish RF modem and compute the distance between the two robot fishes by using this data, control the robot fish in various directions. It consists of the robot fish, the camera, the optical flow, and two-axis position data blocks. The position command is given to the PID controller from the PC. The PID controller takes the position and controls it. Then, the servo motor takes the position signal and com-pares it with the actual signal, and if any error arises, it will be given as negative feedback to the servo amplifier. The servo amplifier will amplify the signal and feed it back to the servo motor. Ironically, the camera captures the motion of the robot fish and applies optical flow to get the data. The robot fish was built with an RF module and is connected wirelessly to the PC and controlled from MAT-LAB and Simulink through serial communications that sends and receives the data to and from the robot fish. When receiving the data from the RF modem, the robot fish body will be controlled depending on the command. In

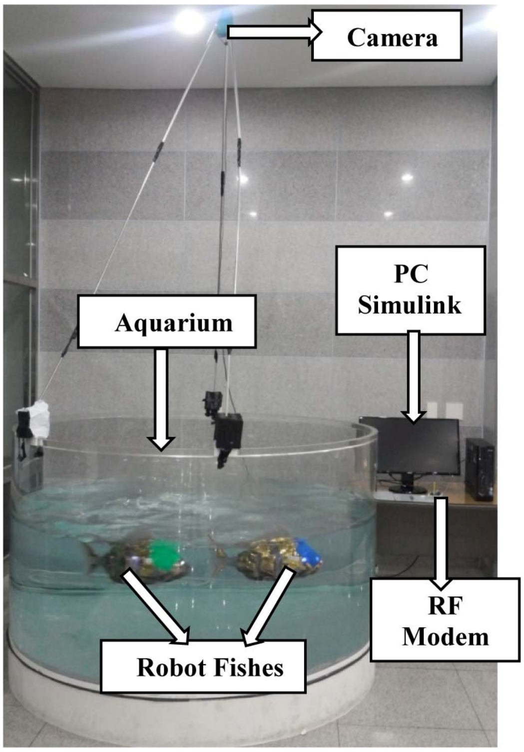


Fig. 8. The experimental setup for tracking control of the robot fish.

the link, there is a servo motor. The servo motor rotate clock wise or counter clock wise with respective angle and angle depends on the control commands like left, right, forward, up and down and these commands has particular angle to realize the left, right, forward, up and down directions. Using these commands, controls the speed of the motor. Here, the speed of the motor is directly proportional to the speed of the robot fish. So that, robot fish could be controlled.

4. Experimental Results

The research system consists of the manufactured robot fish in Fig. 3(a), the RF modem, the camera, and the PC in the aquarium, as in Fig. 8. The design for the area of the aquarium is circular (height = 1 m, diameter = Ø 1.8 m).

The experimental results for position detection of the robot fish are shown in Fig. 9. In this algorithm, it displays two-axis data in the display results block. The display res-ults block contains the two-axis data, namely x, and y axes. The display results block rows contains robot fish two-axis data, that is, (x1, y1: 172, 175), (x2, y2: 199, 159), (x3, y3: 114, 158), and (x4, y4: 87, 199). Here, (x1, y1), (x2, y2), (x3, y3) and (x4, y4) are two-axis coordinates of the robot fish. These coordinates represent the position of a particular robot fish. The two-axis position of the robot fish is det-ected correctly, and the performance of experiment results are satisfactory. Fig. 8 shows the automatic control sys-tem for detecting the robot fish, which consists of robot fish, the camera for real-time video, the RF modem, and the PC for control of data communications. In order to

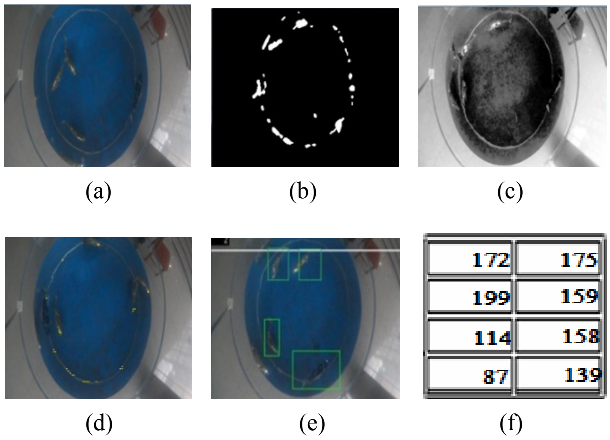


Fig. 9. Experimental result of two-axis position detection for the robot fish (a) video file, (b) RGB to Gray, (c) histogram equalization, (d) optical flow, (e) position-detecting algorithm, (f) the display results.

test the performance for lead-lag action control of the robot fish is shown in Fig. 8 and the MATLAB program sends the data serially to the robot fish via the RF modem. In the program, *serial* is the MATLAB function that creates a serial port object associated with the serial port specified by *port*. The function *fwrite (serial)* in MATLAB writes the binary data to the device. The function *hex2dec* in MATLAB converts hexadecimal data into decimal. The function *set* is used to configure serial port object pro-perties, and *delete* is the function to remove the serial object from memory.

In the definitions, 53 is the start bit, 03 is the data size bit, 73 is manual mode, 61 is automatic mode,11 is the blue fish ID, 47 makes the robot fish move to the front, 4c makes the robot fish move to the left, 52 makes the robot fish move to the right, and 11 is given from the constant block (for example, the datum of the robot fish is 83,03,17,72,65). In this datum, 83 is the starting bit, 03 is the data bit, 17 is the robot fish ID, 72 is the left command, and 65 is the stop bit sent to the serial send block. Giving a position command like 172, 175, the robot fish will move to that particular position in the aquarium, and the robot fish will move into automatic mode and swim automatically. In Fig. 10, robot fish 1 is blue and robot fish 2 is green. The position of robot fish 1 is (x1,y1) and for robot fish 2 it is (x2,y2). Trying lead-lag action, such that robot fish 1 lags behind robot fish 2, the lead-lag action control is the one kind of tracking tech-nique to gather robot fishes. By using this tracking algori-thm, we supposed to control the motion of the robot fishes.

For instance, blue robot fish is swimming faster than the green robot fish, at that moment, the blue robot fish has to stop until green robot fish, otherwise, if green has to wait until the blue robot fish reach the green robot fish. This process is called as the lead-lag action control. To achieve this, we compute the distance between the two robot fish can be calculated with Eq. (16):

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (16)$$

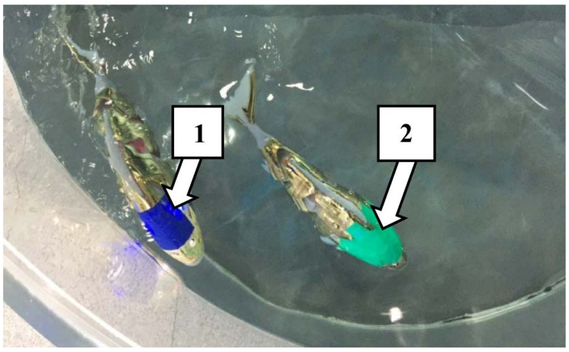


Fig. 10. The trajectory for lead-lag control of the robot fish (a) blue robot fish, (b) green robot fish.

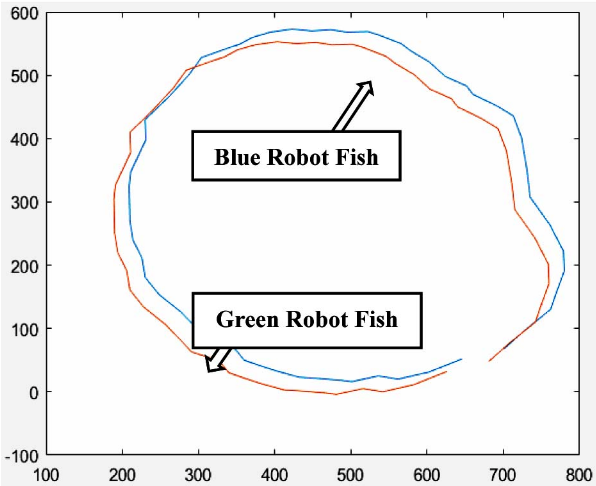


Fig. 11. The trajectory motion of the robot fish from the top view (a) blue robot fish, (b) green robot fish.

where d is the distance between the two robot fishes, x_1 and x_2 are the x-coordinates of robot fish 1 and robot fish 2, and y_1 and y_2 are the y-coordinates of the robot fish1 and robot fish 2.

The test for lead-lag action control is shown in Fig. 10, and the test results are shown in Fig. 11. If the distance in Eq. (16) is satisfied (d<150mm), two robot fish continue swimming in lead-lag action. In order to control the lead-lag action continuously, we define the limit distance, need to satisfy the condition d=150mm. This condition is used to gather the fish robot at one point and segregate from that point. If the distance between the two robot fish is d>150mm, then the lead robot fish will wait for the lagging robot fish until the lagging robot fish reaches the lead robot fish. Also, if the condition d<150 mm is satisfied, the lead robot fish is swimming again. This cycle happens every time. Fig. 11 shows the trajectory motion of the two robot fishes. In the graph, the orange trajectory represents the path of the blue robot fish, and the blue trajectory represents the path of the green robot fish. At the point (300,500), the two robot fishes, lines are intersecting because the swimming motion of the blue robot fish is wide in the aquarium when compare with green robot fish, so that, at this point, the green robot fish crossing the blue robot fish as shown in the Fig. 11. After intersecting, the two robot fishes motions are chang-ing because of these robot fishes control through RF Mo-dem manually. Hence, the experimental analysis of the proposed robot fish tracking control system has been satisfied.

5. Conclusion

This paper realizes control the motion of swimming robot fish in order to implement a robot fish aquarium. And it implements positional control of a two-axis traje-ctory path of the robot fish in the aquarium. Designed a model robot fish, and performance of the robot was verified through certified field tests. Also, this paper proposes realization of robot fish motion-tracking control using an optical flow object–detecting algorithm, which controls the motion of the robot fish using an RF modem. The performance through experimental results using MATLAB and Simulink show, it is possible to control robot fish motion (left, right, straight, up, and down) through specific com-mands in the robot fish aquarium. Also, the robot fish motion can be controlled using the RF modem, which is controlled through MATLAB programming and Simulink from a PC. This was verified by a performance test for the designed robot fish aquarium, which satisfied performance of the robot fish tracking control using the optical flow–object-detecting algorithm from the PC. As well, lead-lag control of the robot fish was satisfied, explaining their motion on the trajectory paths. Hence, the experimental analysis of the proposed robot fish tracking control using the optical flow–object detection algorithm was satisfied. Future plans are to install and operate robot fish in an aquarium in the Daejeon National Science Museum, South Korea.

Acknowledgement

This work was supported by a research grant from the Busan University of Foreign Studies in 2016 to develop this work and to attend a technical conference. The author expresses sincere gratitude to the Busan University of Foreign Studies for this support.

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