



## RESEARCH ARTICLE

### FISH ROBOT POSITION CONTROL USING THE OBJECT TRACKING ALGORITHM

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#### ARTICLE INFO

##### Article History:

Received 22<sup>nd</sup> August, 2016

Received in revised form

19<sup>th</sup> September, 2016

Accepted 28<sup>th</sup> October, 2016

Published online 30<sup>th</sup> November, 2016

##### Key words:

Fish robot,  
Biomimetic robot system,  
Image processing,  
RF modem,  
Moving object,  
Object tracking algorithm.

#### ABSTRACT

In the last two decades, the research on biomimetic fish robots has fascinated scientific communities' attention progressively. With its character of high flexibility and intelligence, biomimetic fish robot has developed in the field of underwater robots. Predominately, Biomimetic robot systems are robots that mimic the structure and function of biological systems such as natural fish, cheetah, ant, kangaroo and snake etc. This paper addresses the detecting the moving objects that is earlier developed fish robot in the aquarium because we need to acquire the position to track the fish robot. This algorithm has modeled to detect the position of the fish robot using the MATLAB and Simulink. This intends to recognize the neighborhood of the fish robots using an image processing technique through video device that is camera. Here, we have applied the proposed object tracking algorithm to control the motion of the fish robots. This algorithm used to detect the moving objects, by using this detecting position data; we compute the distance between two fish robots using mathematical expression. Then, we send this data to control and track the fish robots through RF (Radio Frequency) modem. Certainly, the performance test of object tracking algorithm has been satisfied by the proposed experimental system.

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**Citation: Prof. Dr. Kyoo Jae Shin and YogendraRao Musunuri, 2016.** "Fish robot position control using the object tracking algorithm", *International Journal of Current Research*, 8, (11), 41012-41020.

## INTRODUCTION

"A lot of conventional thinking pervades the field of robotics," says Morley Stone, a program manager in the US Defense Advanced Research Projects Agency's defense sciences office ([www.darpa.mil](http://www.darpa.mil)). In the last two decades, the research on biomimetic fish robots has fascinated scientific communities' attention progressively (Polverino *et al.*, 2012). With its character of high flexibility and intelligence, biomimetic fish robot has developed in the field of underwater robots (Hongli Liu *et al.*, 2014). Predominately, Biomimetic robot systems are robots that mimic the structure and function of biological systems such as natural tuna, cheetah, ant, kangaroo and snake *et al.* The robotic dynamics is the 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. Oftenly, biological systems have inspired to make robots (KyooJae *et al.*, 2010). "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 ([www.ihmc.us](http://www.ihmc.us)). We have designed the fish robot in the field of underwater robots. The performance of the developed biomimetic robot is excellent because it imitates the natural

Fish such as Korean DOMI (KyooJae *et al.*, 2014). We have explored manuscripts that detecting object algorithms such as; the design of aquarium robot world using detecting fish robot position method (KyooJae *et al.*, 2016), realization of aquarium fish robot system with drawing fish of augmented reality (KyooJae *et al.*, 2016) and realization of fish robot tracking control using position detecting algorithm (KyooJae *et al.*, 2016). In the previous paper, the designed fish robot has researched to develop an algorithm to find and track the position of the fish robot. In order to realize the aquarium robot world, it needs to track the fish robots. The proposed aquarium fish robot world consists of PC (Personal Computer), Camera, fish robot, and RF (Radio Frequency) Modem as shown in the Fig.1. The developed fish robot consists of the head, 1<sup>st</sup> stage body, 2<sup>nd</sup> stage body and tail which is connected through two-point driving joints of the fish robot. The Model is analysis to maximize the momentum of the fish robot and the body of the robot is designed through the analysis of the biological swimming (KyooJae *et al.*, 2015). Also, Light hill dynamics was applied to the kinematic analysis of the robot fish swimming algorithm. We have applied to the approximate method of the streamer model that utilizes techniques to mimic the biological fish (KyooJae *et al.*, 2015). The swimming fish robot has two operating modes such as manual and autonomous modes. In the manual mode the fish robot swimming is operated by using the RF Transceiver. In the autonomous mode the robot is controlled through the

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microcontroller unit. It consists of two servo motors and three PSD (Position Sensitive Detector) sensors in the fore head of fish robot to detect obstacles; Air bladder device in ahead portion used to moving central weight point and communication port is used to receive data (KyooJae *et al.*, 2016). We have designed an aquarium robot world using fish robot. In order to realize the aquarium robot world, it needs the position data so that it has researched about the detecting fish robot using the boundary detecting, color weight and objet tracking algorithms. In this paper, the newly proposed method: object tracking algorithm is applying to the fish robot to detect the position and analyze the motional behavior when we track the fish robot. The object tracking algorithm accumulates fully based on the frames of moving object in the moving picture (KyooJae *et al.*, 2015). In this algorithm, detect the moving object using the optical flow technique because it is one of the good techniques to analyze the motion between two consequence frames. The frame is composed of picture elements just like a chess board (KyooJae *et al.*, 2015). Here, picture elements (has some coordinates, no pixel coordinate would not match on the screen.

So that, this algorithm correlates the two frames and estimate the motion between two frames to find the position of the object because every object has some particular pixels (KyooJae *et al.*, 2016) when image captured by camera, that would not change continuously, so that, could detect the position of fish robot (KyooJae *et al.*, 2015). It was verified by the performance test for the designed aquarium fish robot world.

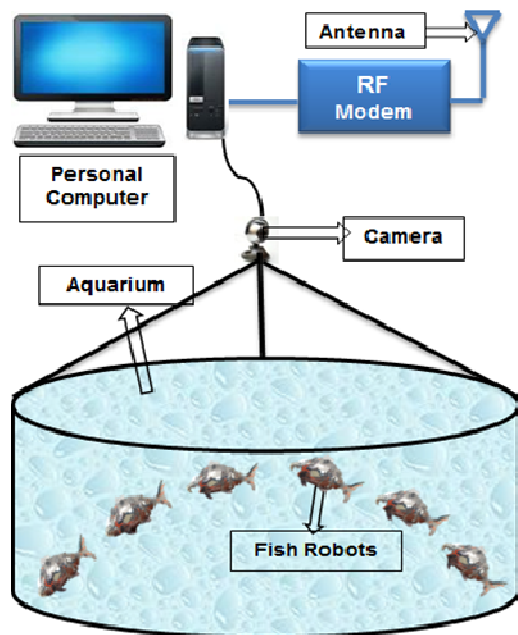


Fig.1. The aquarium fish robot world to control the fish robot

### Modeling of the fishrobot control

Biomimetic robot systems has developed in the field of underwater robots for an aquarium. The assembled fish robot consists of the head, 1<sup>st</sup> stage body, 2<sup>nd</sup> stage body and tail, which is connected through two point driving joints as shown in the Fig.2(a). Because the robot is need to maximize the momentum and the body of the robot is designed through the analysis of the biological fish swimming. Also, it was applied to the kinematics analysis of fish robot swimming algorithms, which is basically Lighthill dynamics. The center of the fish

robot gravity is transferred to a one axis sliding and it is possible to the submerged and emerged of robot by the weight moving unit (KyooJae *et al.*, 2016). In addition to the configuration of the entire fish robot, the control system was designed to apply an artificial intelligence algorithm and apply the AVR microcontroller in order to mimic the biological control for the robot. The control system mainly consists of RF modem, three PSD sensors, two Servo motors and weight moving unit. These are connected to the Microprocessor (Micom). The Micom should operate the all connected devices to it and the RF modem is used to control the action of the fish robot in the manual mode like left, right, forward, up and down. Otherwise, PSD sensors were used to detect the obstacles like aquarium walls and other objects such as fish robots, and servo motors operated with the sensor feedback signal. The weight balancing unit used to balance the fish robot using the sliding method. In the sliding method, the slider mechanism (Weihs, 1972) has used to slide the weight balancing unit. So that, when weight balancing unit come towards the head of the fish robot, then the fish robot goes down, otherwise, the weight balancing unit come towards the tail of the fish robot, it floats on the water as shown in the Fig.2(b), and communication port designed for data acquisition from the PC. The swimming form of fish robot is a continuous function with discrete function for the kinematic streamer model through the analysis by Lighthill (Kim, 2012), which is equal to the equation (1), and it expresses the movement of the biomimetic fish robot.

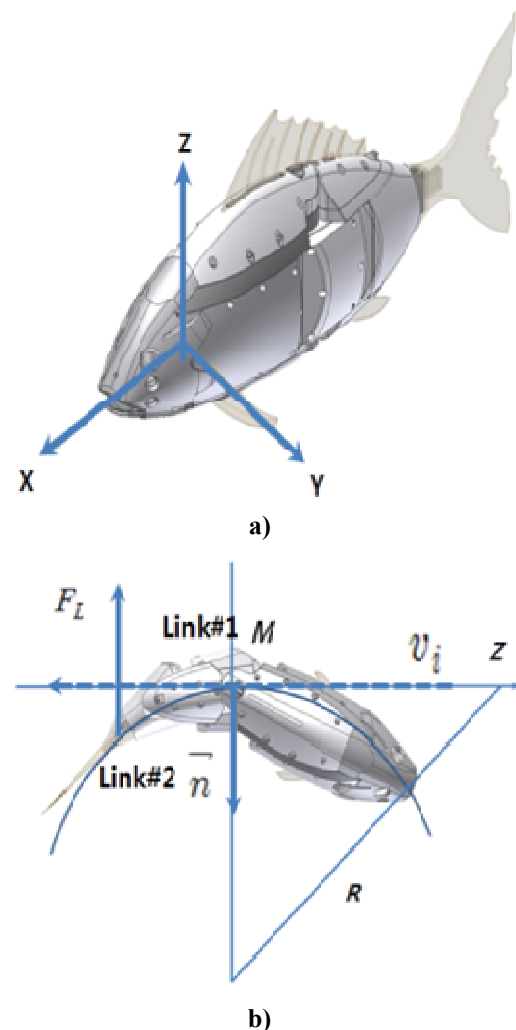


Fig. 2. (a) The acting axes of the fish robot, (b) The exerted lift and swimming rotation in the aquarium

$$y_i(x,t) = (C_1x + C_2x^2) \sin(kx - 2\pi ft) \\ = (C_1x + C_2x^2) \sin\left(kx - \frac{2\pi}{\lambda} i\right) \quad (1)$$

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,  $k = \frac{2\pi}{\lambda}$  is multiples of the body wave or body wave number and  $\lambda$  is the wave length,  $\omega$  is the body wave frequency of the biomimetic fish robot and  $f$  is the propelling frequency.

The error is defined in the equation(2) which is the traveling wave approximation using the 3 joints, and the joint angle can be approximated as equation (3) by a sine wave having the same frequency as like as traveling wave.

$$error = \sum_{i=0}^{n-1} \int_{x_i}^{x_{end}} |g(x) - f(x)| \quad (2)$$

$$\theta_i = a_i \sin(2\pi ft + p_i) \quad (3)$$

Then, the frequency of the fish robot can be determined using the light hill analysis to swim in the water. In order to up and down swimming, the robots swim are designed to move back and forth to the center of gravity (Hirata *et al.*, 2000) estimation point by the sliding weight center point method that is like as the gravity principle of bio-mimetic fish robot (Kim, 2012). It is important to control the tracking speed, so that the speed of the motor is highly depends 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 composed of a sensor to sense the speed and an amplifier with gain  $K$  (proportional control) in the configuration of fish robot. The speed at the motor shaft is sensed by the potentiometer with gain  $K_t$  and PID (Proportional-Integral-Derivative) controller can be expressed in the equation (4).

$$PID(s) = K_p + K_d s + \frac{K_i}{s} \quad (4)$$

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  $\omega_m$  using the potentiometer gain  $K_t$ . Hence, assuming  $L_a = 0$ , we will get equation (5).

$$\omega(s) = \frac{K_m / R_a J}{s + (R_a B + K_b K_m / R_a J)} V_a(s) \quad (5)$$

where  $\omega(s)$ : The speed of the fish robot,  $K_m$ : motor gain,  $R_a$ : armature resistance,  $J$ : moment of motor inertia,  $B$ : viscous friction coefficient of the motor shaft,  $K_b$ : gain of back emf,  $L_a$ : armature inductance,  $T_L$ : external load torque considered as a disturbance and  $V_a(s)$ : the applied voltage. In order to control link angle, the simulink model to control the link body

of the fish robot has shown in the Fig.3. In this, first block is the dynamic motion of the fish robot and remaining blocks are the model is used to control the link angle of the fish robot. The link angle output (LAO) has expressed in the equation (6).

$$LAO = \frac{s^2 K_m K_d + s K_t K_p + K_t K_m}{s^3 R_a J + s^2 (K_m K_b + R_a B + K_m K_t K_d) + s (K_m K_t K_p) + K_m K_t K_i} \quad (6)$$

Where  $K_m$  is the motor gain,  $K_d$  is the differential gain,  $K_t$  is the integral gain,  $K_p$  is the proportional gain,  $J$  is moment of motor inertia,  $K_b$  gain of back emf,  $K_t$  is the angle signal gain,  $R_a$  is the armature resistance,  $B$  is the viscous friction coefficient of the motor shaft,  $L_a$  is the armature inductance,  $T_L$  is the external load torque considered as a disturbance and  $V_a(s)$  is the applied voltage. The link angle command has produced from the equation (1)~(3). The error is computed that subtract the angle command to feedback signal of the link angle that is defined by the integral processing of the link potentiometer output signal. The error is compensated by PID controller and converted it into the driving signal of dc motor. The external disturbance torque  $T_L$  is compensated by feedback of the motor speed and it is realize the control of link angle of the fish robot. The control of the fish robot can be monitored through the live video which is connected to the live video device that is camera.

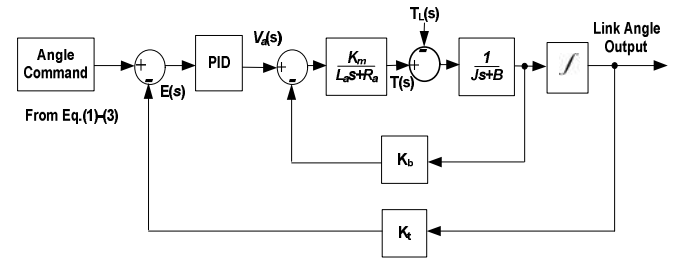


Fig. 3. The link angle control of the fish robot

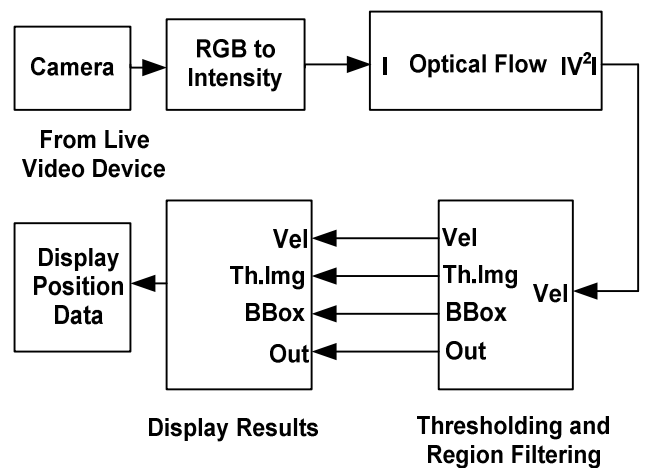


Fig. 4. The position detecting of fish robot using the optical flow

#### Design of detecting objects using an optical flow

We designed the modeling of an object to detect the fish robot in the aquarium as shown in the Fig.4. Generally, the motion is an intrinsic property of the world and integral part of our visual experience.

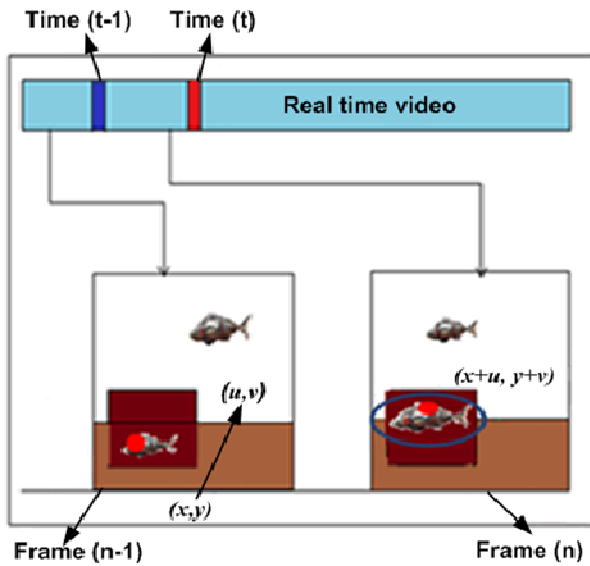


Fig. 5. The position concept design of the fish robot

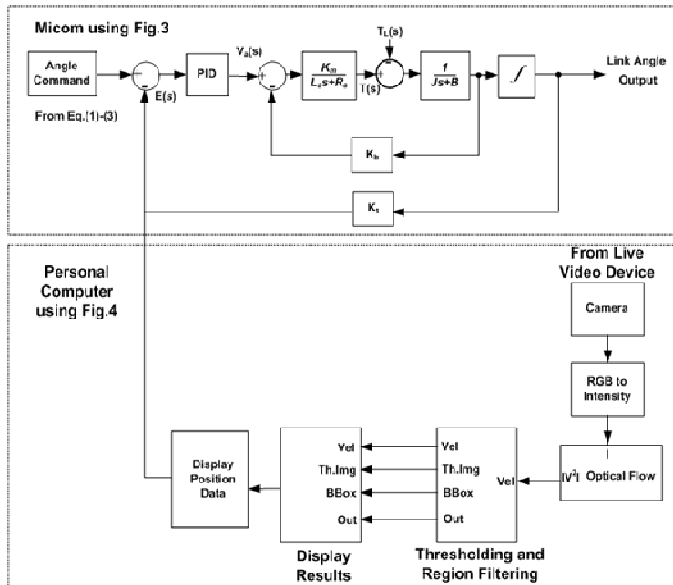


Fig. 6. The proposed object tracking position control system

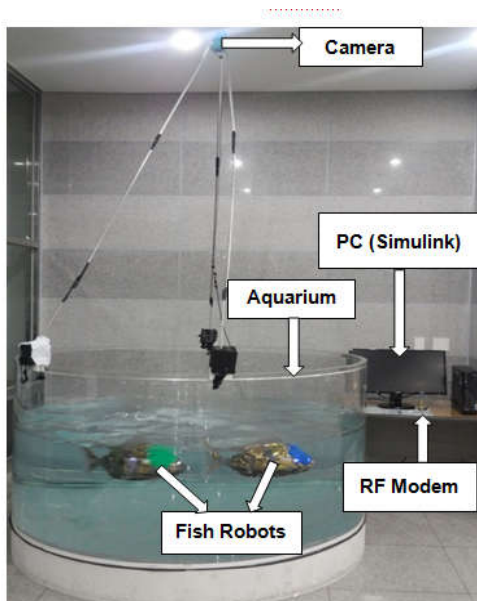


Fig. 7. The realization of fish robot using object tracking algorithm

The model of the detecting an object consists of live device block which is camera, rgb to gray, optical flow, thresholding and filtering, and display results. In this, the main concerns about an Optical flow. The aim of an optical flow is to estimate the motion filed from time-varying image intensity. The Optical Flow (KyooJae *et al.*, 2015) is used to analyses the motion of the moving objects and it estimates the direction and speed of object motion from one image to another image and from one video frame to another. The Simulink model as shown in the Fig.4 and it consists of several major blocks such as:

(1) **Live video device:** This is the video device which is connected to the Simulink library from the image acquisition tool box. To set the camera, double click on this block → select the camera → select apply button →select ok (KyooJae *et al.*, 2015).

The output of this block is image and given as input to the second block that is RGB to Gray.

(2) **RGB to Gray:** This block takes the color data and converts into the gray color by using the color codes which starts from 000 to 255.

(3) **Optical flow:** This optical flow is the pattern of apparent motion of objects,surfaces, and edges in a visual scene caused by the relative motion between an observer and the scene. In this, the velocity of each frame will be estimated by using Optical flow method (KyooJae *et al.*, 2016).

(4) **Thresholding and Filtering:** This block thresholds the image and filters the image from original image. This model locates the fishes in each binary image using the Blob Analysis block. Then, it uses the Draw Shapes block to draw a green rectangle around the fish robots.

(5) **Display Results:** The Results window shows the position of number of fishes around green rectangle in the region of aquarium.

(6) **Display Position Data:** This window shows the position data of the detected fish robot in the aquarium.

### The proposed position detecting of fish robotusing object tracking algorithm

Fish Robots are swimming in the specially designed aquarium robot world to analyze and control the motion of the fish robot. This designed robotic fishes for aquarium is tested to analyze the motion of Robotic fish. The position of the robotic fish is analyzed by using the optical flow (Barron *et al.*, 1992).The Optical Flow (KyooJae *et al.*, 2016) block estimates the direction and speed of object motion from one image to another or from one video frame to another video frame. In this method, the video is divided into the different number of frames and every position of the frame has allocated with different coordinates. The Fig.5 shows real time video and two frames, like frame (n-1), frame (n) respectively. Let us consider the time period of two frames be (t-1) and (t) seconds respectively. In the real time video, it is the continuous process of moving images from the start time to stop time. In the Fig.5, the position of object differs from frame n to frame (n-1) (Maria Petrou *et al.*, 2005).

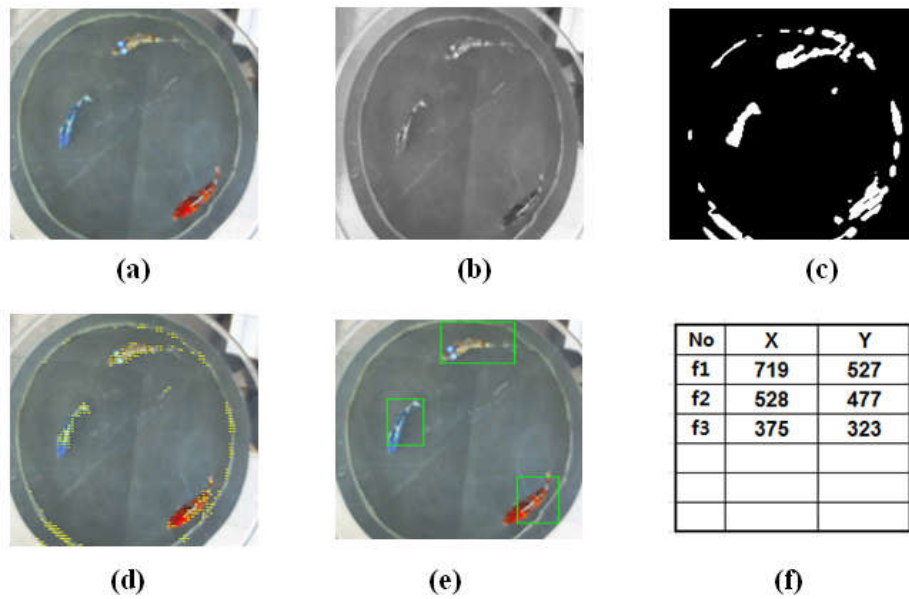


Fig. 8. Experimental result of 2 axes Position detection of fish robots. (a) Video file, (b) RGB to Gray, (c) Threshold image, (d) Optical flow, (e) Object tracking algorithm, (f) Display results

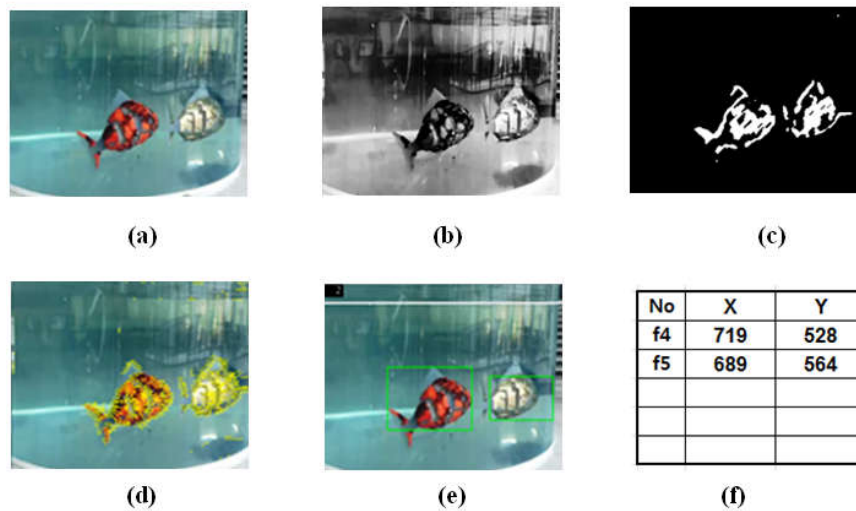


Fig. 9. Experimental result of 2 axes Position detection for fish robots. (a) Video file, (b) RGB to Gray, (c) Threshold image, (d) Optical flow, (e) Object tracking algorithm, (f) Display results

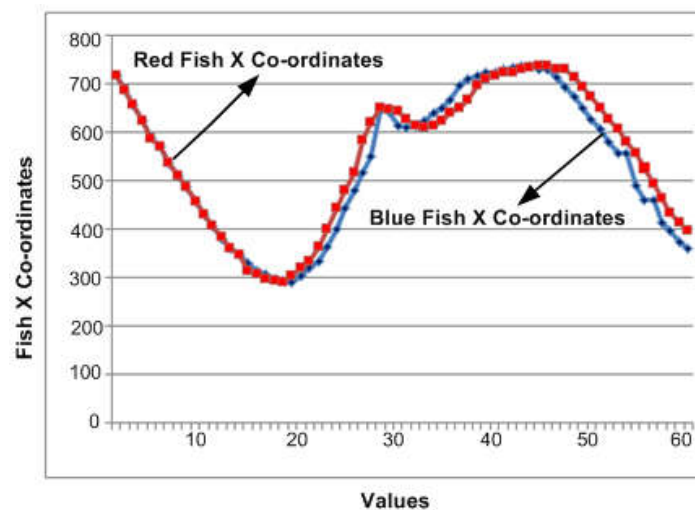


Fig. 10. The tracking of two fish robots in x direction

In the Fig.5 representing two images are different frames and they will have allocated different coordinates when compare (n-1) frame and (n) frame, the position will be changed, but pixel coordinates of the object will remain same so that the position of the object will be detected (William K Pratt *et al.*, 1978). So that assume the intensity of two images is same, this is expressed mathematically in the equation (6).

$$I_2(x + u, y + v) = I_1(x, y) \quad (6)$$

The above equation can be expressed with time is shown in the equation (7) (KyooJae *et al.*, 2016).

$$I_2(x + u, y + v, t + 1) = I_1(x, y, t) \quad (7)$$

The equation (7) becomes, after applying Taylor series left hand side that is

$$\frac{dI}{dx}u + \frac{dI}{dy}v + \frac{dI}{dt} = I(x, y, t) = I(x, y, t) \quad (8)$$

After solving the equation (8), we get the equation (9) (KyooJae *et al.*, 2016).

$$\frac{dI}{dx}u + \frac{dI}{dy}v = -\frac{dI}{dt} \quad (9)$$

where  $\frac{dI}{dx} = I_x$ ,  $\frac{dI}{dy} = I_y$ ,  $\frac{dI}{dt} = I_t$  the equation (9) becomes the equation (10).

$$I_x u + I_y v = -I_t \quad (10)$$

The equation (10) is called as standard equation of an optical flow. This is used to detect the motion of the frames in video and can get the motion vectors on the object as shown in the experimental results in the Fig.8 (KyooJae *et al.*, 2016). To calculate the optical flow between two images, you must solve the following optical flow limitation equation is shown in the equation (11).

$$I_x u + I_y v + I_t = 0 \quad (11)$$

where  $I_x$ ,  $I_y$  and  $I_t$  are the spatiotemporal image brightness derivatives, where  $u$  is the optical flow in the horizontal ( $x$ ) direction and  $v$  is the optical flow in the vertical ( $y$ ) direction. By assuming that the optical flow is smooth over the entire image, this method computes an approximate direction of the velocity field  $[u, v]^T$  that minimizes the following equation is (KyooJae *et al.*, 2015).

$$E = \iint (I_x u + I_y v + I_t)^2 dx dy + \alpha \iint \left\{ \left( \frac{\partial u}{\partial x} \right)^2 + \left( \frac{\partial u}{\partial y} \right)^2 + \left( \frac{\partial v}{\partial x} \right)^2 + \left( \frac{\partial v}{\partial y} \right)^2 \right\} dx dy \quad (12)$$

In this equation  $\frac{\partial u}{\partial x}$  and  $\frac{\partial u}{\partial y}$  are the spatial derivatives of the optical velocity component  $u$ ,  $v$  and  $\alpha$  scales the global

smoothness term. This method minimizes the equation (12) to obtain the velocity field,  $[u, v]$  for each pixel in the image. This method is given in the following equations (13) and (14) (KyooJae *et al.*, 2015).

$$u^{k+1}_{x,y} = \bar{u}^k_{x,y} - \frac{I_x (I_x \bar{u}^k_{x,y} + I_y \bar{v}^k_{x,y} + I_t)}{\alpha^2 + I_x^2 + I_y^2} \quad (13)$$

$$v^{k+1}_{x,y} = \bar{v}^k_{x,y} - \frac{I_y (I_x \bar{u}^k_{x,y} + I_y \bar{v}^k_{x,y} + I_t)}{\alpha^2 + I_x^2 + I_y^2} \quad (14)$$

In these equations  $[u^k_{x,y}, v^k_{x,y}]$  is the velocity estimate for the pixel at  $(x, y)$  and  $[\bar{u}^k_{x,y}, \bar{v}^k_{x,y}]$  is the neighborhood average of  $[u^k_{x,y}, v^k_{x,y}]$  when  $k = 0$ , the initial velocity is 0. Calculate  $u$  and  $v$  by following steps.

- (1). Compute  $I_x$  and  $I_y$  using the Sobel (KyooJae *et al.*, 2015) convolution kernel,  $[-1 \ -2 \ -1; \ 0 \ 0 \ 0; \ 12 \ 1]$ , and its transposed form, for each pixel in the first image.
- (2). Compute  $I_t$  between images 1 and 2 using the  $[-1 \ 1]$  kernel.
- (3). Assume the previous velocity to be 0, and calculate the average velocity for each pixel using  $[0 \ 10; \ 10 \ 1; \ 0 \ 10]$ , as a convolution kernel.
- (4). Iteratively solve for  $u$  and  $v$ .

In order to solve the optical flow constraint equation for  $u$  and  $v$ , the proposed method divides the original image into smaller video frames and assumes a constant velocity in each frame to compare two frames to detect the position. Then, the two axes can be displayed on the two axes data display on the PC in the display block. These experimental results are as shown in the Fig.9. The proposed object tracking position control system consists of control the link body of the fish robot and optical flow detecting algorithm as shown in the Fig.6. After detecting the moving object, we get the position data. By using the position data, we use the RF Modem to communicate the fish robot data between PC and fish robot. By using the angle commands, the fish robot can turn left, right, forward, up, and down. This motion can be achieved with moving the link body of the fish robot. By using this link control, we can perform the tracking control of the fish robots. This optical flow algorithm is applying to the fish robot to detect the position to analyze the motional behavior of the fish robot and it works fully based on the frames (images) of moving object. So that, this algorithm compares the two frames and estimate the motion between two frames to find the position of the object because every object has some particular pixels when image captured by camera, that would not change continuously, so that, could detect the position of fish robot. It was verified by the performance test for the designed aquarium fish robot world.

## RESULTS AND DISCUSSION

The proposed aquarium robot world consists of Aquarium, fish robot, top view camera, RF (Radio Frequency) Modem and PC as shown in the Fig.7. The designed fish robot was controlled by driving the servo motor using a battery and the continuous



motion of fish robots was captured by using the camera, and then it sent to the PC. To acquire the data, use the live videodevice block from the Simulink data acquisition tool box and the Simulink Model as shown in the Fig.4. Then, we acquired the video data and analyzed by using the object tracking algorithm. The experiment of this algorithm held in two camera views. They are front view camera and top view camera respectively. The experimental results of the top view camera areas shown in the Fig.8. Let us consider three fish robots f1, f2, and f3. Let f1 be the orange fish robot, f2 be the blue fish robot and f3 be the gold fish robot and its coordinates are  $(x_1, y_1)$ ,  $(x_2, y_2)$  and  $(x_3, y_3)$  respectively, as shown in the results. The Fig. 8 (a) shows the original video captured by the camera and it covers the entire aquarium robot world to detect the swimming motion of the fish robot. The Fig.8(b) shows converting frame from RGB to gray to distinguish the object from the background. The Fig.8(c) shows the result of the threshold or filtered the image used to detect the object in the frame. The Fig.8(d) shows the motion vectors are surrounded by the fish robot which gives the position of the fish robot. The Fig.8(e) shows the thick rectangle is surrounded by the fish robot that indicates detecting the fish robot in the aquarium and the Fig.8(f) shows the fish robot coordinates after detecting the moving object are  $(x_1, y_1: 719, 527)$ ,  $(x_2, y_2: 528, 477)$  and  $(x_3, y_3: 375, 323)$ . In this analysis, the performance of experiment result is satisfactory by using the object tracking algorithm. The experimental results of the optical flow algorithm using the front view camera as shown in the Fig.9. Let f4 be the orange fish robot, and f5 be the gold fish robot and its coordinates are  $(x_1, y_1)$  and  $(x_2, y_2)$  respectively, as shown in the results. The Fig.9(a) shows the original video captured by the camera and it covers the front view of the aquarium robot world to detect the swimming motion of the fish robot. The Fig.9(b) shows converting frame from RGB to gray to distinguish the object from the background. The Fig.9(c) shows the result of the filtered object using the threshold value in the frame. The Fig. 9(d) shows the motion vectors are surrounded by the fish robot which gives the position of the fish robot. The Fig.9(e) shows the thick rectangle is surrounded by the fish robot that indicates detecting the fish robot in the aquarium and the Fig.9(f) shows the fish robot coordinates after detecting the moving object are  $(x_1, y_1: 719, 528)$ ,  $(x_2, y_2: 689, 564)$ . By using this position data, we send the control data to control and track the fish robots using RF (Radio Frequency) modem. The RF modem able to send the data as well as receive the data because it has both transmitter (TX) and receiver (RX) modules included in the single unit with low carrier frequency, from/to the PC. When we compare the performance of the two views of the camera, the top view camera detecting the waves of the water, it makes some noise while detecting the object.

And come to other side, in the front view also, the water disturbance makes noise while detecting object, but front view gives some better results than top view camera because of low wave disturbance. The Fig.10 depicts the tracking of two fish robots in x between the two fish robots, in which, red color tracking line represents the red fish robot and blue color tracking line represents the blue color fish robot. When we compare the motion between two fish robots in x direction as shown in the Fig.10. In this graph, on x-axis has taken as values and y-axis has taken as fish x coordinates. It describes the, two fish robots are started at same point and ended at same point. After some distance, at the point (20,300), two fish robots are segregating each other, from this point, blue fish robot follows the red fish robot and bound with two fish robots parallel to swim each other.

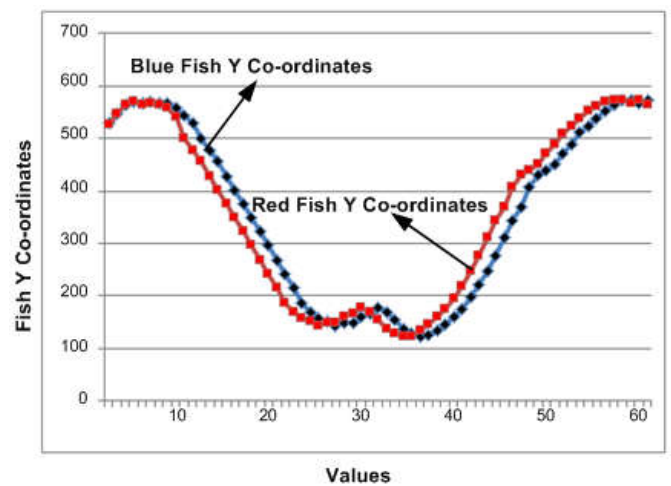


Fig. 11. The tracking of two fish robots in the y direction

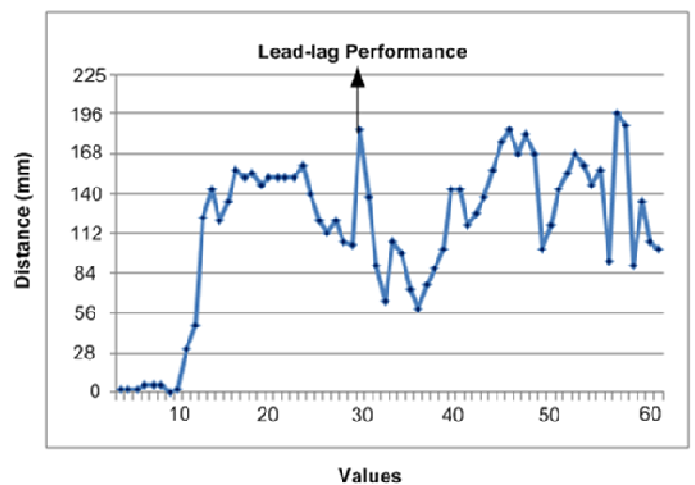


Fig. 12. The lead-lag distance tracking between the two fish robots

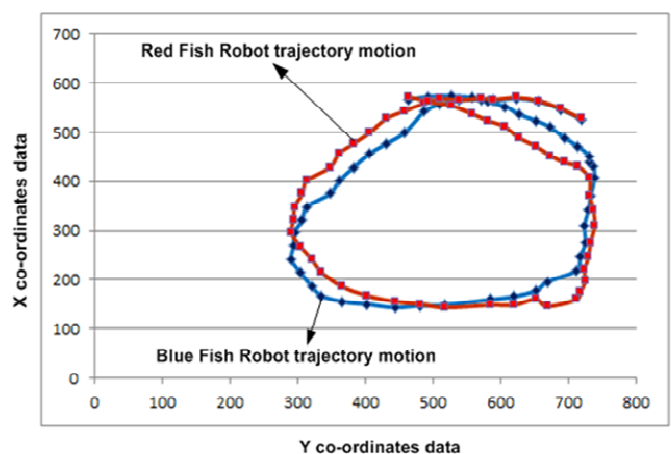


Fig. 13. The trajectory motion of the two fish robots

The Fig.11 depicts the tracking of the two fish robots in y direction between the two fish robots. In this, blue line represents the blue color fish robot and red line represents the red fish robot. When we compare the tracking of two fish robots in the y direction as shown in the Fig.11. In this graph, on x-axis has taken as values and y-axis has taken as fish y co-ordinates. These two fish robots are started at the same point and ended at the same point, after some distance, at this point (10,480), these two fish robots are segregating each other, from this point blue fish robot follows the red fish robot and bound

with two fish robots parallel to swim each other. The Fig.12 depicts the distance between the two fish robots such as red fish robot and blue fish robot. Let us consider the position of the blue fish robot is  $(x_1, y_1)$ , and the position of the red fish robot is  $(x_2, y_2)$ . It will perform the lead-lag action that is red fish robot is lead from the blue fish robot. The distance between the two fish robots will be computed by using the mathematical expression as shown in the equation (15).

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (15)$$

Where  $d$  is the distance between two fish robots,  $x_1$  and  $x_2$  are the x-coordinates of the blue fish robot and red fish robot,  $y_1$  and  $y_2$  are the y-coordinates of the blue and red fish robots. It is realized to test for lead-lag motion control as shown in Fig.12. In this graph, on x-axis has taken as values and y-axis has taken as lead-lag distance. If the distance in equation (15) is satisfied the condition of  $d < 150$  mm, two fish robots are swimming continuously such as lead-lag motion. If the distance between two fish robots is  $d > 150$  mm, then lead fish robot will wait for the lag fish robot until lag fish robot reaches the lead fish robot. Also if the condition of  $d < 150$  mm is satisfied, and the lead fish robot is swimming again. This cycle continues continuously. The Fig.13 shows the trajectory motion of the two fish robots. In this graph, on x-axis has taken as fish x-coordinates and y-axis has taken as fish y-coordinates. The red color trajectory line represents the trajectory path of the red fish robot and blue color trajectory line represents the trajectory path of the blue fish robot. The performance test of the object tracking algorithm has been satisfied.

## Conclusion

In this paper, the designed fish robot is used to mimic the biological swimming fish because the performance of the fish robot is excellent. To find the position, we have to detect the moving object which has used the fish robot in the aquarium robot world. In this, we have proposed method, which is optical flow to detect the position of the moving object that is fish robot. The designed fish robot is used the Simulink Model to display the coordinates of the fish robot to analyze the position of the fish robot as it has shown above. By using this position data, we have used the object tracking algorithm as shown in the Fig.6 and corresponding equations implemented in this algorithm from (6) to (14) and send the control data to control and track the fish robots using RF (Radio Frequency) modem. By using this algorithm, we have realized the lead-lag action of the fish robots using the equation (15). This method is modeled in the Simulink for tracking and detecting the fish robot. The experimental results as shown in the above figures from the Fig.(8) to Fig.(13). Finally, we compare the performance of object tracking algorithm, it is confirmed that excellent performance in the field test such as filtering image, enhancing, object detecting, motion vectors and localize the boundary and finally achieved the tracking control of the fish robot through lead-lag action. We realized the lead-lag error minimum is 56 mm and maximum is 196 mm, as shown in the Fig.12, so that, the condition of lead-lag action ( $56 < d < 196$  mm) has satisfied. Certainly, the performance tests of this algorithm have been satisfied by the proposed experimental system.

## Acknowledgement

This work was supported by the KOREA Ministry of Science, ICT and Future Planning. We conduct the Science and Culture

convergence project: Meeting of Robot and Child Picture in the New Sea World Using 3D Hologram. It has supported the research fund. Also, this work granted for Busan University of Foreign Studies.

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