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International Journal of Current Research
Vol. 9, Issue, 01, pp.44659-44665, January, 2017

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

A STUDY ON AQUARIUM WORLD DESIGN OF AN AUGMENTED REALITY WITH 3D HOLOGRAPHIC FISH

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ARTICLE INFO

Article History:
Received 27th October, 2016
Received in revised form
17th November, 2016
Accepted 14th December, 2016
Published online 31st January, 2017

Key words:

Robot fish,
3D holographic fish,
Color,
Mimic,
Augmented reality,
OpenCV,
Color mark.

ABSTRACT

This paper is concerned with motion tracking control of the robot fishes along with the 3D holographic fishes using Radio Frequency (RF) modem, multi-link and free-swimming biomimetic robot; the researched robot fish motion control is related to the speed control through RF modem and it focuses on detecting the moving object in the water as well as tracking the robot fish along with 3D holographic fish in the aquarium world designed for an augmented reality. Color attracts the every one and easy way to recognize an object. Physically, the object of the color recognizes because of light leaving from their surfaces. In the aquarium robot world, various colors of robot fishes along with 3D holographic fishes are mimicking the behavior of the real fish and it forms an augmented reality. In this study, this algorithm is designed to detect the position of the robot fish using color detection algorithm with the Open CV through camera. By using this position data, we are able to track the robot fishes using color mark. At this color mark zone, these robot fishes and 3D holographic fishes will be stopped until this color mark remove from this zone, and 3D holographic fishes will swim, following the robot fishes, after remove this color mark, again robot fishes and 3D holographic fishes swim, this tracking process will be continued until this algorithm stops. The performance test of this detecting algorithm has been satisfied.

Citation: Prof. Dr. Kyoo Jae Shin, Muhammad Akbar and Yogendra Rao Musunuri, 2017. "A study on aquarium world design of an augmented reality with 3Dholographic fish", *International Journal of Current Research*, 9, (01), 44659-44665.

INTRODUCTION

Recently developed bio-inspired robots were designed by inspired from the nature; the robot dynamics is a fairly new-category of bio-inspired design (Kyoo Jae *et al*., 2014; Kim *et al*., 2012). For many years human beings have been impressed by the incredible swimming ability of the natural fish, and much attention on the high efficiency and maneuverability of its propulsion. They have been tested in the aquarium for collision avoidance, maneuverability, and control performance, posture maintenance, path design, and data communication. All control actions of motors for fins, data acquisition from various sensors such as infrared distance sensors, pressure sensor, acceleration sensors, and communication for monitoring and data processing are processed. Especially, this field is about making the robots that are inspired from the biological systems from the nature (Polverino *et al*., 2012). In the aquarium, different color robot fishes are mimicking the natural fish. The proposed aquarium robot fish 3D holographic world consist of robot fishes, camera, Radio Frequency (RF) modem, drawing table, scanner, beam projector, 3D hologram fish and Personal Computer (PC) is shown in the Fig.1.

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Today detection of the object is very important but it depends on an object and environment. An object can be detected either by its shape or color. The choice of color space classification depends on several factors including which is provided by the digitizing hardware and utility for the particular application (James Bruce *et al*). Several color spaces are in wide use such as Hue Saturation Intensity (HSI), YUV and Red Green Blue (RGB). Color is an essential for pattern recognition and computer vision, it is an attractive feature because of its simplicity and its robustness to scale changes and object positions. Generally, the color of an object depends on its characteristics of the perceiving eye and brain. Physically, objects can be said to have the color of the light leaving their surfaces. We consider the robot fish motion as a moving object and its coordinates are found at every instinct of the aquarium. In this study, this algorithm is designed to detect the position of the robot fish using color detection algorithm with the Open CV through camera. By using this position data, 3D holographic fishes follow the robot fishes and also, we are able to track the robot fishes using color mark. At this color mark zone, these robot fishes and 3D holographic fishes will be stopped until this color mark remove from of this zone, after remove this color mark, again robot fishes and 3D holographic fishes swim, it forms an augmented world. Our aim is to present free swimming robot fishes, 3D Holographic fishes and other sea creatures directly drawn by people in the aquarium at Daejeon National Science Museum, Daejeon, South Korea.

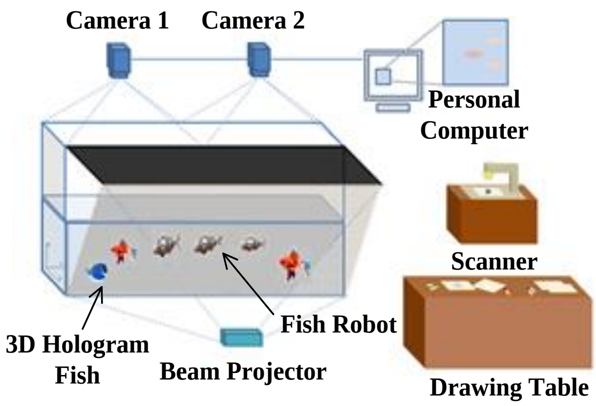


Fig. 1. The proposed aquarium robot fish 3D holographic world

Modeling to control the robot fish

Biomimetic robot systems developed in the field of underwater robots for an aquarium world. The assembled robot fish consists of the head, 1st stage body, 2nd stage body and tail, which is connected through joints is shown in the Fig.2(a).The designed robot fish needs to maximize the momentum to mimic the biological fish swimming.The center of the robot fish gravity is transferred to sliding and it is possible to the submerged and emerged of robot fish by the weight moving unit, here,weight moving unit acts as slider (Kyoo Jae *et al*., 2016). The control system mainly consists of RF modem, three PSD sensors, two servo motors and weight moving unit; these are connected to the AVR microcontroller and it should operate the all connected devices to it and the RF modem is used to control the action of the robot fishes in the manual mode like left, right, forward, up and down. Otherside, PSD sensors were used to detect the obstacles like aquarium walls and other objects such as robot fishes, and servo motors operated withthis sensor feedback signal. The weight balancing unit used to balance the robot fish 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 robot fish, then the robot fish goes down, otherwise, the weight balancing unit come towards the tail of the robot fish, it floats on the water is shown in the Fig.2(b). The swimming form of robot fish 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 robot fish.

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

where $y_i(x,t)$ is the transverse displacement of the bio-mimetic robot fish 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 robot fish respectively, $k = 2\pi/\lambda$ is multiples of the body wave or body wave number λ is the wave length, ω is the body wave frequency of the biomimetic robot fish and f is the propelling frequency. The error is defined in the equation (2) which is the traveling wave approximation using the 2 joints, and the joint angle can be approximated as equation (3) by a sine wave having the same frequency as like as traveling wave.

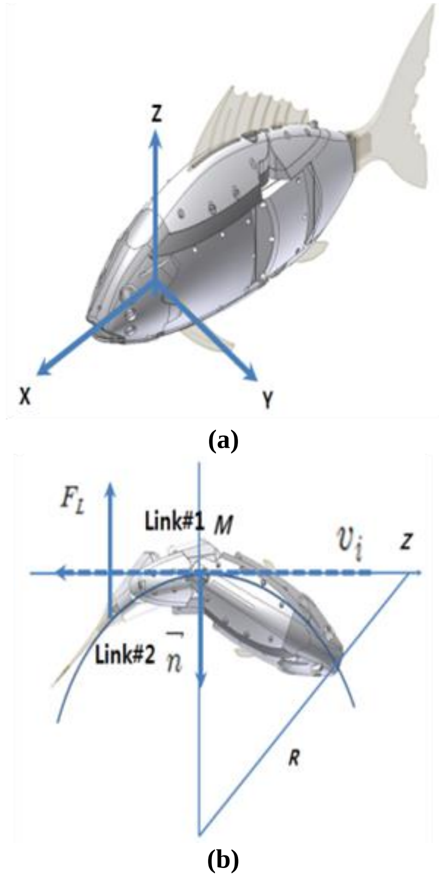


Fig2.(a) The axes of the robot fish, (b) The link angle rotation in the aquarium

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

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

Then, the frequency of the robot fish 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) while estimation point by the sliding weight center point method that is like as the gravity principle of bio-mimetic robot fish (Kim, 2012). It order to control the tracking speed, so that the speed of the motor is highly depends on the value of torque (T_L). It can be improved 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 robot fish. The speed at the motor shaft is sensed by the potentiometer with gain K_t and Proportional-Integral-Derivative (PID) controller can be expressed in the equation (4).

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

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} into speed using the potentiometer gain K_t. Hence, assuming L_a= 0, we will get equation (5).

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

where $\omega(s)$ is the speed of the robot fish, K_m is the motor gain, R_a is the armature resistance, J is the moment of motor ineria, B is the viscous friction coefficient of the motor shaft, K_b is the gain of back emf, 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.

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

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

where K_m is the motor gain, K_d is the differential gain, K_i 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 gian, 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 potetiometer 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 robot fish.The control of the robot fish canbe monitored through the live video which is connected to the camera. In this study, we use image segmentation to extract the different regions in the image; for example, they may have similar brightness, or color (Kyoo Jae *et al*., 2016), which may indicate that they belong to the same object or facet of an object. Chroma (Maria Petrou *et al*., 2010) is the strength of an object color, if an object have the high chroma, its reflectance must be such that it reflects a large amount of light from part of the spectrum, and little light from the remainder. The potential range of chroma varies strongly for different values and hues: at maximum value (white) and minimum value (black) (Kyoo Jae *et al*., 2016), chroma can only be zero. As we move away from these extremes the range of possible chroma increases up to a maximum at some intermediate value. The value at which this maximum chroma occurs dependson the hue, and for example is very high for yellow, low for violet and blue. The color segmentation can be possible to realize with the OpenCV (Milan Sonaka *et al*., 2015) is shown in the Fig.3. This position tracking control system consists of camera, color extraction, contour (Kyoo Jae *et al*., 2015), and color mark tracking algorithm. Here, we propose a novel approach for color segment that is convert the RGB scale into HSV (Kyoo Jae *et al*., 2016). HSV is a family of color spaces used as a part of the color image. H is the Hue, S is the saturation and Vis the Value. HSV color spaces are defined by a mathematical coordinate transformation from an the underlying RGB color (Kyoo Jae *et al*., 2016) space is absolute. Here, the color V gives gray scale image and the threshold value in between 0 to 1. To select the particular color, we give a threshold value of particular color, so that, it gives black and white image and detect the specific color object. For example, if we select the threshold value of blue color, then we give a range value in HSV that is (100,100,100) for the lower blue and (120,255,255) for the upper blue, then it extracts only the blue color and if we select the threshold value of HSV that is (0,200,100) for the lower red and (10,255,255) for the upper red (Kyoo Jae *et al*., 2016), then it extracts the red color. This object data sent to the contour. This will be generated the coordinates of the filtered color object. Through the color segment algorithm, it can be produced position data of the robot fish. By using this position data, we are able to control the robot fish using the command from the RF modem through serial port. When the robot fishes swim, place the color mark at a particular position. If the robot fishes reach that zone,the robot fishes will stop. Moreover, the robot fish will again swim after we release the color mark. The performance of this tracking system has been satisfied.

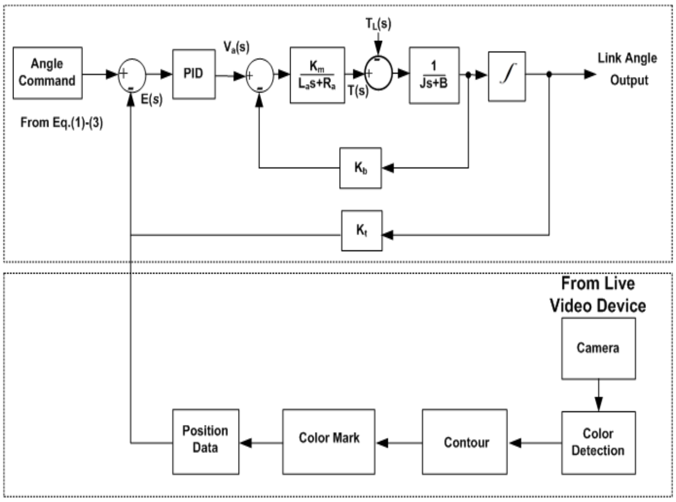


Fig. 3. The position tracking control system using the open CV

3D holographic world

3D Hologram

In today society, hologram (Lance Winslow., 2007) is the interesting technology, many people use hologram for different activities such as: video games, movies, teleconference, presentation, and virtual reality realms. Hologram is a technique that enables a light field, which is generally the product of light source scattered off objects, to be recorded and later reconstructed when the original light field is no longer present, due to the absence of the original objects (Hariharan., 2002). Here, we will design the 3D hologram by using Cinema 4D and Pepper's Ghost Technique for 3D hologram projection.

Cinema 4D

Cinema 4D is a 3D modeling application developed by MAXON Computer GmbH in Germany. This application is capable to make animation, motion graphic, modeling 3D object, rendering, and common features that can be found in 3D modeling applications. In this study, we will use this application to create 3D hologram modeling and animation.

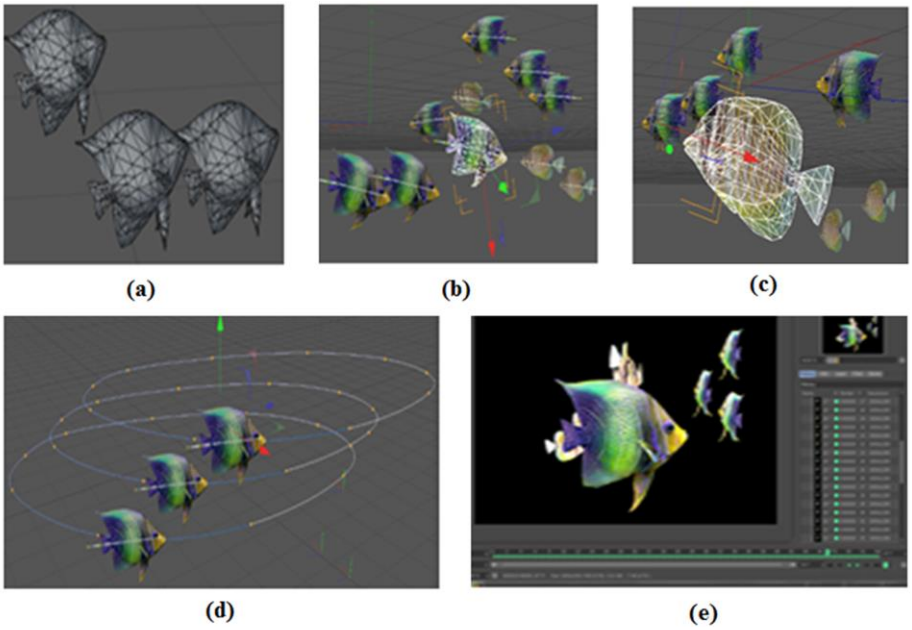


Fig. 4. Step of Reproduce 3D Hologram: (a) Modeling, (b) Coloring and Texturing, (c) Rigging, (d) Animating, (e) Rendering

3D Hologram Modeling and Animation

There are five steps to create a 3D hologram is shown in the Fig.4 and explained as below.

1) 3D modeling

Modeling is the process of taking a shape and molding it into a complete 3D mesh.

2) Coloring and texturing

It is applying color and texture to the surface of 3D character. Here, we have to choose the color and texture carefully in order to emphasize the effect of 3D hologram to the 3D character.

3) Rigging

It is rigging the 3D character. Rigging is the process of placing virtual bones to the 3D character in order to allow the animators to move them. This is needed to make the motion of the 3D character becomes more realistic and natural.

4) Animating

In here, the animators start to make the animation based on the story board and animating using key poses.

5)Rendering

Rendering is where the graphics get created and then exported into video animation. The main idea of hologram is to rebuild the object to be appeared in another place where the real object is not belonging there. This case is similarly same when we look at ourselves into the mirror. Actually we only see our reflection (Abin Baby, 2013) in the mirror, but it looks to be real.In this study, we will use *Pepper's Ghost* technique for 3D hologram projection (David Kim., 2014) which is shown in the Fig.5.

To implement this technique, we have to make two kind of room for preparation. The first room is the main room where the viewers are able to see the hologram and another room is the hidden room where the real object is located.

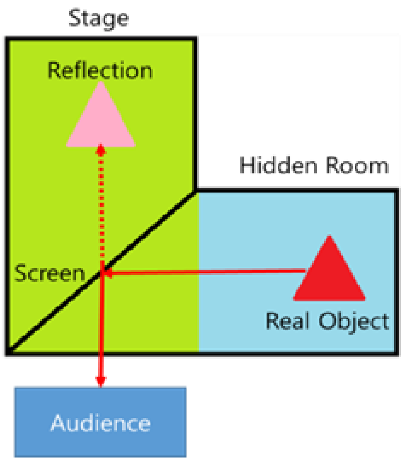


Fig. 5. Pepper's Ghost Technique

The proposed augmented reality system

The proposed augmented reality system consists of mainly two blocks namely 3D hologram and robot fish control blocks is shown in the Fig.6. The 3D hologram block consists of position command, making of 3D hologram, 3D fish coordinate data and augmented reality sub-blocks. For instance, the children draw the fish on the drawing table and scan the drawing fish through the scanner and it can be extracted the fish boundary in the scanned drawing fish paper and converted into the 3D hologram, when user give the position command, it will be followed by the 3D holographic fish. The robot fish control block consists of camera, OpenCV library, color segment algorithm, color tracking algorithm, position data and robot fish (from the Fig.2). Here, we had used the OpenCV library along with the python programming language, when the camera interface with the PC through the Open CV library, it would detect the color of the object (robot fish) and by using this position data, we are able to track the robot fishes using color mark. At this color mark zone, these robot fishes will be stopped and will continue swimming when the color mark removes from this zone. Now, using the 3D fish coordinate data, it will be followed the real robot fishes and it forms an augmented reality. The performance of the proposed augmented reality system has been satisfied.

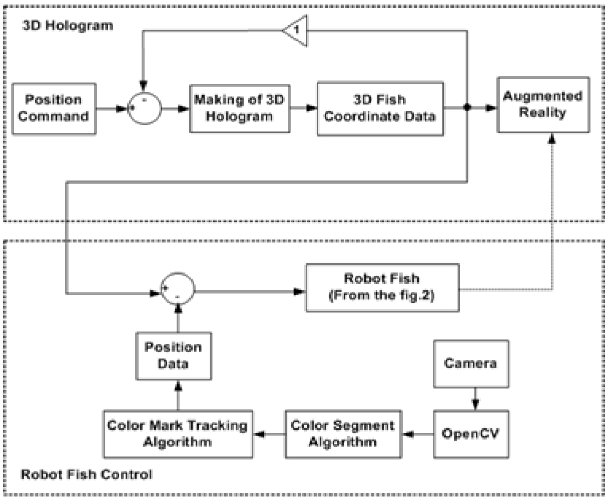


Fig. 6. The proposed augmented reality system

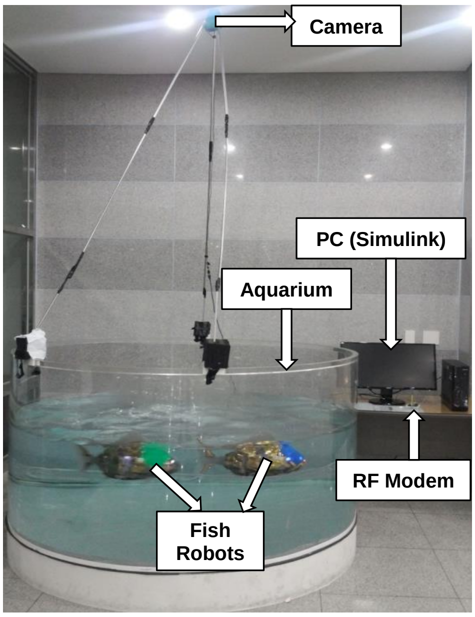


Fig. 7. The realization of robot fish using Open CV

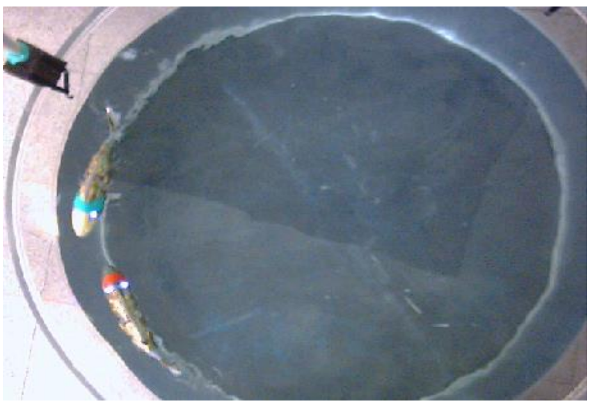
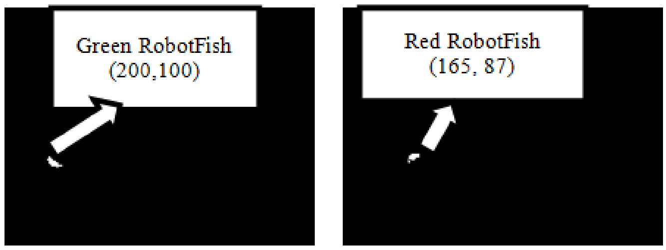


Fig. 8. The original motion of the robot fish, using Open CV



(a) **(b)**

Fig. 9. (a) The color detection of the green robot fish (200,100) (b) The color detection of the red robot fish (165, 87)

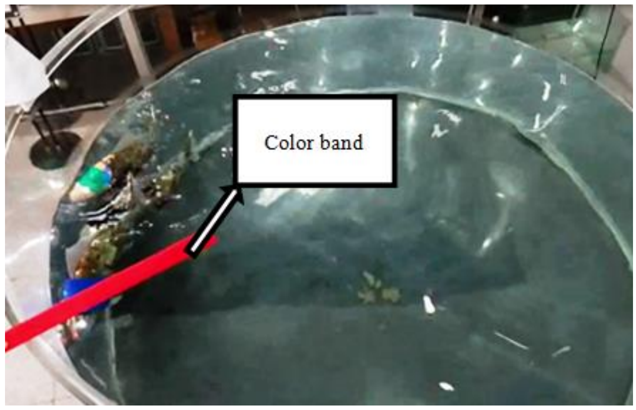
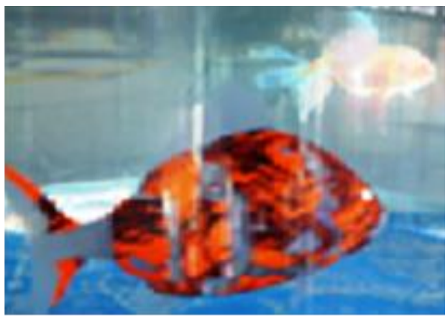


Fig. 10. The color mark tracking control of robot fish

(a)



(b)

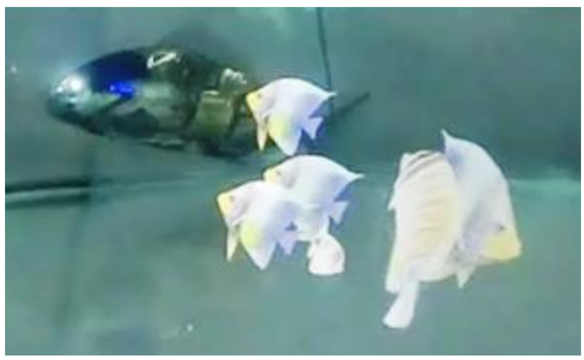


Fig. 11. (a) (b) Realization of robotfishes with 3D hologram Fish, (c) Augmented reality

RESULTS AND DISCUSSION

The proposed aquarium robot fish of 3D holographic world consists of aquarium, robot fish, top view camera, RF modem, 3D holographic fish and PC is shown in the Fig.7. The designed robot fish was controlled by driving the servo motor using a battery and the continuous motion of robot fishes was captured by using the camera, and then it sent to the PC. To acquire the data, we had used the Fig.3. Then, we are able to track the robot fish using the Fig.6. The Fig.8 shows the original motion of the robot fish from camera and it shows the two robotfishes in which one robot fish has green color segment and other robot fish has red color segment. These two robot fishes are swimming opposite to each other that is green color segment robot fish is swimming counter clockwise direction and red color segment robot fish is swimming clock wise direction. So that, the color extraction detected the green robot fish and converted to black and white image which has shown in the Fig.9(a) and the detected green robot fish position at (200,100). The detected red robot fish has shown in the Fig.9(b) and the detected red robot fish has position at (165, 87). These two robot fishes are swimming opposite to each other. By using this position data, we send the control data to control and track the robot fishes using color mark from the RF modem. At this color mark zone, these robot fishes will be stopped until this color mark remove from of this zone, after remove this color mark, again robot fishes.The RF modem able to send the data as well as receive the data because it has both transmitter (TX) and receiver (RX) included in the single unit with low carrier frequency, from or to the PC. 3D Hologram fish is used to give an effect of augmented reality in the aquarium world. This fish will swim together with the robot fish in the aquarium. For this purpose, 3D Hologram fishes were designed using 3D animation maker. Then, we display the 3D Hologram fish using reflection technique into the fish aquarium tank. This type of hologram produces very high quality images. Practically, we emit the fish 3D Hologram video from the mini beam projector into the dark surface in the floor and then it will be reflected into the hologram screen in the fish aquarium is shown in the Fig.11(a) and Fig.11(b). The realization of the augmented reality is shown in the Fig.11(c) and the experimental results of this algorithm have been satisfied.

Conclusion

In the conclusion, this paper described an overall motion tracking control of the robot fishes along with the 3D holographic fishes using Radio Frequency (RF) modem, multi-link and free-swimming biomimetic robot. In this paper, the performance test of the designed robot fish is excellent. To find the position of robot fish in the aquarium robot world, we had used the color segment algorithm and the designed robot fish is used as the object to be detected their position by OpenCV and to analyze the position of the robot fish as it has shown above. Furthermore,this algorithm is designed to detect the position of the robot fish using color detection algorithm with the Open CV through camera. By using this position data, we were able to track the robot fishes using color mark. At this color mark zone, these robot fishes and 3D holographic fishes will be stopped until this color mark removed from of this zone, and 3D holographic fishes followed the robot fishes, after removed this color mark, again robot fishes and 3D holographic fishes swim, this tracking process will be continued until this algorithm stops. The performance test of this detecting algorithm has been satisfied.

Future research should be focused on 3D Hologram, this research includes the robot fish will lead to the 3D Hologram fish, this reality is known as augmented reality and robot fish tracking control techniques will also be developed.

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 and it supports the research fund. Also, this work granted for Busan University of Foreign Studies.

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