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DIRECTION AND DEPTH CONTROL SYSTEM DESIGN IN A CARANGIFORM FISH-ROBOT

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Abstract. *In this work is presented the study regarding the pectoral fins influence on direction and depth of an autonomous carangiform fish-robot inside a water tank. According to the data acquired from pressure sensor and a 3-axes accelerometer and gyroscope on the fish-robot, the balance and depth are controlled using two servomotors attached to the pectoral fins. The pressure measured will be used for the depth control of the robot fish and data from the accelerometer and gyroscope will be used in balance control. Another aim of this work is the study of the dynamics of the straightforward movement and methods to turning using known mathematical patterns of a carangiform fish tail movement. The methods to change direction can combine the tail movement with the pectoral fins influence. These initial studies to control the direction and depth of the fish-robot will be used for navigation control system in further development.*

Keywords: Robot Fish, Biomimetic Robot, gait control

1. INTRODUCTION

The development of robots that mimics the behavior of fishes has been recently subject of studies in different research centers. According to WANG (2011), the main reason to build a fish robot instead of underwater vehicles moved by propellers is due to a better efficiency of the dynamics of a fish that bends its own body to move. Electrical actuators and other suitable materials control the motion in a fish robot.

According to Chan (2007), except by submarine vehicles with high speed turbines, fishes have a superior capability to move underwater, generating less noise on the environment, which gives an advantage for using it on marine exploration and surveillance. From this premise, it is clear the benefits to develop a fish robot for use either as marine explorations or for aquarium exhibition.

Among the different applications for a fish robot are: exploration of oceans and rivers, surveillance, wreckage inspection, offshore platforms maintenance, pipes, ducts and environmental inspection, acquisition and analysis of intra-body data.

As presented on Sfakiotakis (1999), fishes can be classified according to the way them thrust their bodies on the following groups: anguiliforms, carangiforms and ostraciforms, as shown in the Fig. 1.

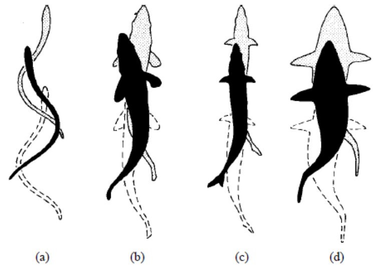

Figure 1. Fish classification due the locomotion mode. (a) Anguiliform, (b) subcarangiform, (c) carangiform and (d) thunniform. (Sfakiotakis, 1999)

According to Chan (2007) the kind of fish with the simplest way of swimming to mimics is the ostraciiform, because it requires only one actuator to perform its motion. In his work pectoral fins are used to improve the roll stability and to better control the vertical motion.

Since 2004 the YU's research team has produced many papers analyzing different points of a fish robot project, particularly of a carangiform type (2004, 2005, 2006, 2007, 2008 and 2011).

The study of fish robot motion by prototypes and computer simulations makes possible the analysis of different structure configurations, permiting a better comprehension of the problem, as presented on CHOWDHURY (2011).

On KIM's (2007) work there is a study of the optimization of the thrust of an articulated fish robot. Its links uses servo motors, and the second connection is done with a spring, to simulate the soft move of fishes. Others studied structures add more pairs of fins (LACHAT, 2006) and (PARAMESWARAN, 2011), besides the use of different sensor to control the attitude of the robot (LIU, 2005).

The works of XU (2011), XIAO (2011) and WANG (2011) presents the model and different control techniques of a fish robot within simulations and experimental results.

The attitude control of a fish robot is proposed by BARBERA (2011), it uses data acquired from digital accelerometers and gyroscopes sensors.

ZHONG (2013) developed a fish robot using a tendon on the tail from a unique rigid string (Fig. 2), obtaining a softer motion with just one servo motor. For the attitude control, it was used pectoral fins.

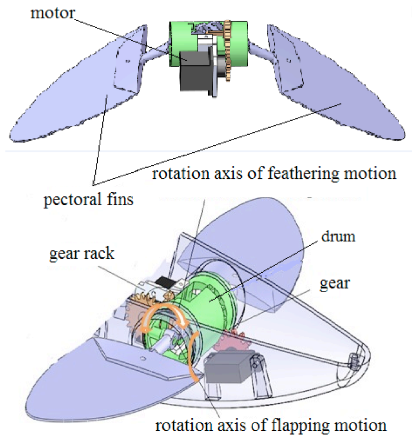

Figure 2. Details of pectoral fin (ZHONG, 2013)

On the PHAMDUY's (2015) work there is a focus on the educational field, which was developed a fish robot that interacts with an iDevice on a didactic platform. It is possible to someone "draw" the track to be followed by the fish on the semiautonomous mode, or to control it manually. There is also a complete autonomous mode.

2. DESIGN DESCRIPTION

As a long term project that the main goal is to obtain a complete autonomous carangiform fish robot that is currently on its second version, there were some features that were redesigned while others were maintained.

The previous version of this work a four-link biomimetic fish with a carangiform structure named *Tucuazul I* (Fig. 3) was designed and built. On that phase several experimental essays were developed in a water tank where the propulsion forces and maneuver issues analysis were performed through the use of a test facility. The forces generated along the tests, when the robot fish movement was generated were measured through the use of a set of strain gauge sensors attached to a vertical bar.

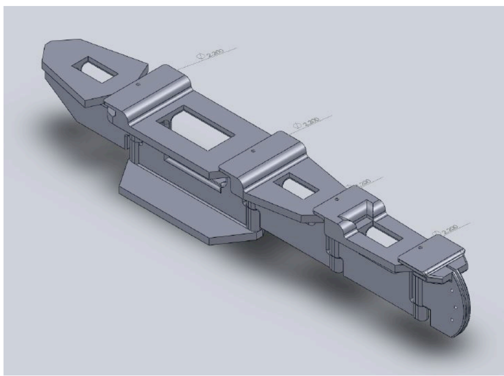

Figure 3. CAD Design of *Tucuazul I (HIRATA, 2013).*

On the present version of Tucuazul (Fig. 4 and Fig. 5) were added new features compared to the previous design, one of them that is first noticeable is the appearance, which looks more like a real fish.

And the most significant change was the addition of pectoral fins, with a very important responsibility for its stability and control of depth changes. It was also added a dorsal fin. Another important modification in the design was the unification of the anterior portion of the body, where there were two links on the first version and now is just one. This last change was done to simplify and enlarge the space where the electronics will be placed. As a consequence of this decision the whole structure became longer and the three servomotor used are standard sized, while the previous version used two micro servos and one standard servo for the tail motion.

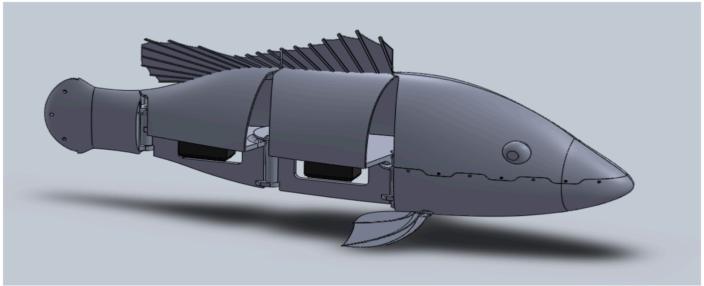

Figure 4. 3D model of Tucuazul V2

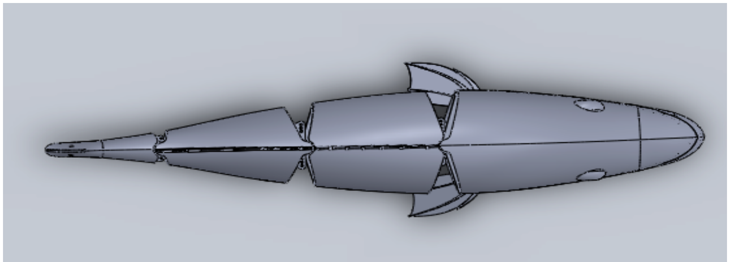

Figure 5. Superior View of Tucuazul V2

3. STUDY OF ROBOT FISH KINEMATICS

3.1 Mathematical model simulations

The same mathematical model were used - Eq. (1) (HIRATA, 2013). The few adaptations in this part were some adjustments on values of the coefficients, due to the new length of the fish as well the reduction of one link in the structure. The new simulation also has given a softer tail's motion (Fig 6 and Fig. 7).

$$y_{body}(x,t) = (c_1 x + c_2 x^2)[sin(kx + \omega t)] + v_c^{3.5} \quad (1)$$

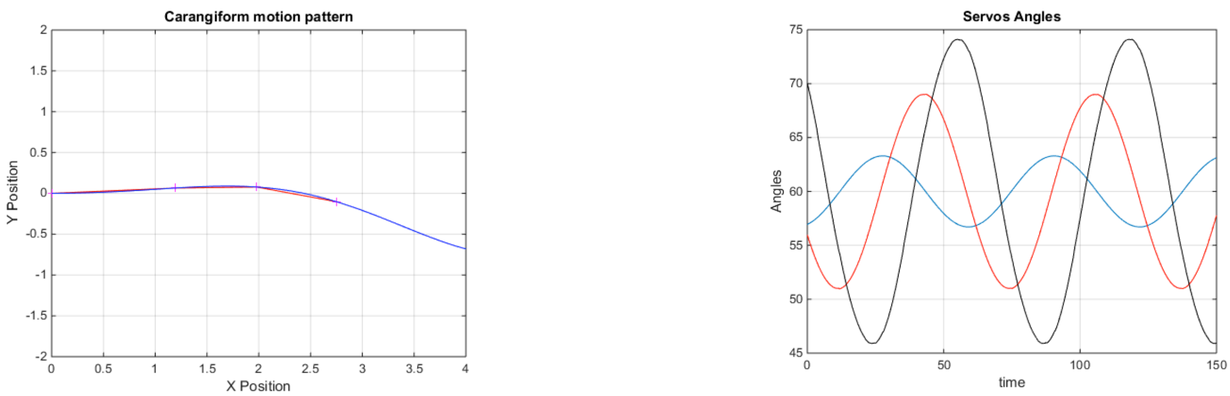

Figure 6. Simulation for a straight forward move.

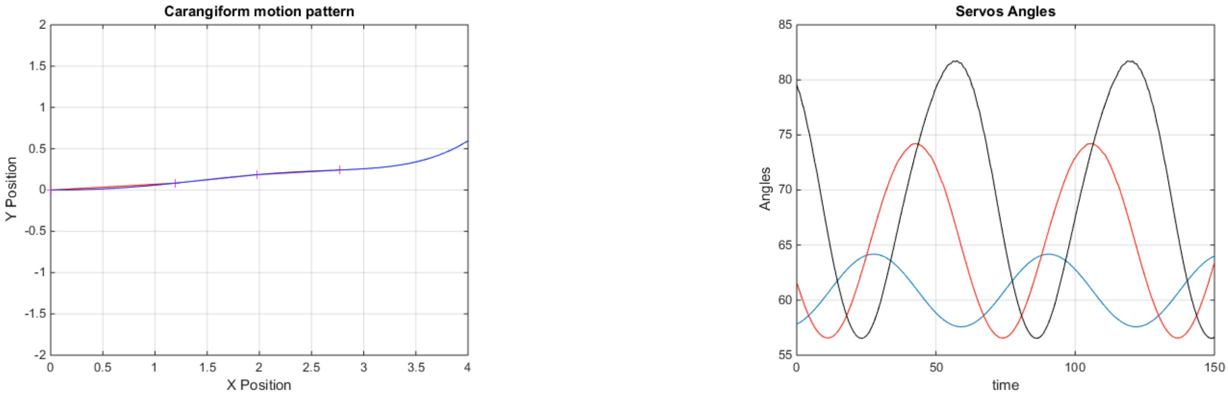

Figure 7. Simulation for turning move.

4. PHYSICAL PROTOTYPE AND CONTROL PROPOSAL

The current version was made of ABS (Acrylonitrile Butadiene Styrene) in a 3D printer (Fig. 8). This prototype will be used to study the influence of pectoral fins on the balance and depth control of an autonomous carangiform fish-robot inside a water tank.

The depth information will be acquired using a pressure sensor because of the proportionality of depth and pressure. A 3-axes accelerometer and gyroscope will also be used to get information about the balance and attitude of the robot.

According to the data received by the pressure sensor, accelerometer and gyroscope the control of depth and balance will be made by both pectoral fins, moved by one servomotor each. This way will be possible to analyze roll, pitch and yaw motions as its vertical position.

Figure 8. Robot fish structure view from the top. Central position (Left) and curve movement (Right)

Another purpose of this work is to study the dynamics of a basic known fish's pattern of motion on the fish-robot to move forward, as well methods of changing the direction to left/right combining actions of the tail and the pectoral fins. These preliminaries researches will be used for a further navigation system to be used on the robot.

The pressure sensor on study to be used is a BMP 180, which also has a temperature sensor integrated on it. This sensor uses I2C protocol to give an interface with a microcontroller.

For the data acquisition is being used the LABVIEW software within an Atmega microcontroller. The communication is done by a serial interface and the data acquired could be shown graphically on the Labview environment.

According to the data received from the pressure sensors was developed a logic using the microcontroller to keep the balance of the fish using the pectoral fins. Another control logic to change the vertical position was also developed using the same principle to act by the pectoral fins.

The idea to keep the fish balance is to make a comparison between the values of both sensors. The sensors values will be sent to the microcontroller, which will analyze the signal received and actuate on the servo motors signal, trying to equalize the value of both sensors received as can be seen at Fig. 9.

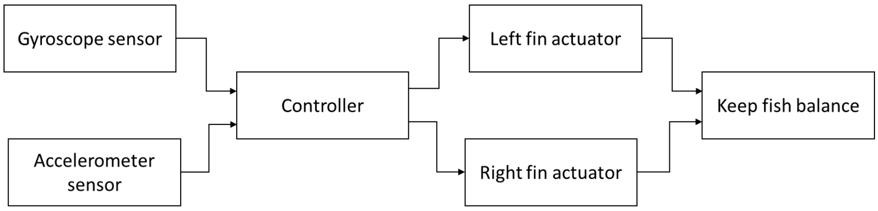

Figure 9. Robot Fish balance control scheme

For the fish level underwater first of all, it is necessary to define the set point. The depth can be calculated from the pressure sensor data. To change the desired level, the controller applies a signal in the actuators (left and right fin) in order to the fish to go deeper. The data at the pressure sensors change feedbacks the control system as can be seen at Fig. 10.

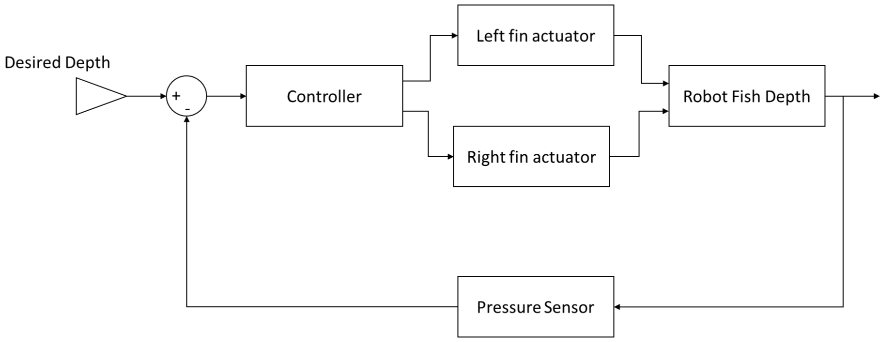

Figure 10. Robot Fish depth control scheme

The connection between the fin and the servomotor can be seen at Fig. 11.

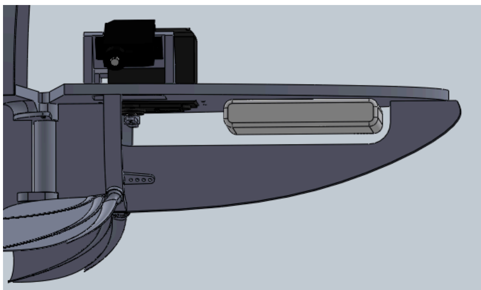

Figure 11. CAD design of the integration between the actuator and the lateral fin

In order to plot in a chart the values of the pressure sensor, it was used the software National Instruments LabVIEW. Inside the fish, using embedded electronics is not possible to acquire data from the sensor like this, because at this stage of the work, the embedded communication has not been developed yet. To analyze the data and the change of pressure inside the fish, it was made a data acquisition from the sensor and the microcontroller.

The following pictures are from previous simulations of the data acquired from the pressure sensor. At Fig. 12 is it possible to see a small variation in the data acquired from the pressure sensor, this kind of variation is due to a little change of depth that could be caused by a loss of balance.

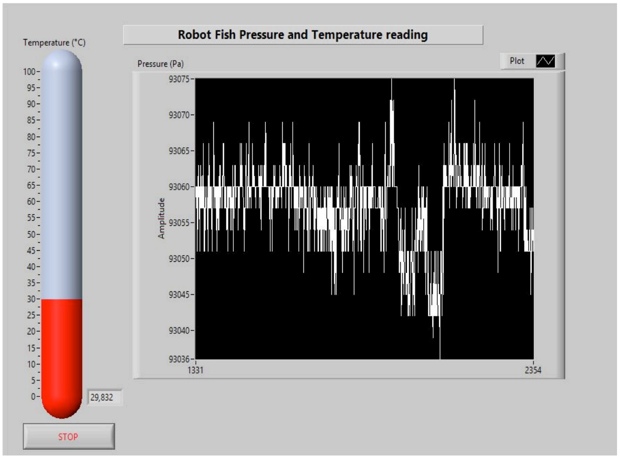

Figure 12. Small variations on the pressure sensor.

At figure 13 it is possible to analyze the case of a great changing of the level inside the water (fish depth control). In this case, the fish is coming back to the surface, as the pressure goes lower, the depth decreases, taking the fish back to the surface.

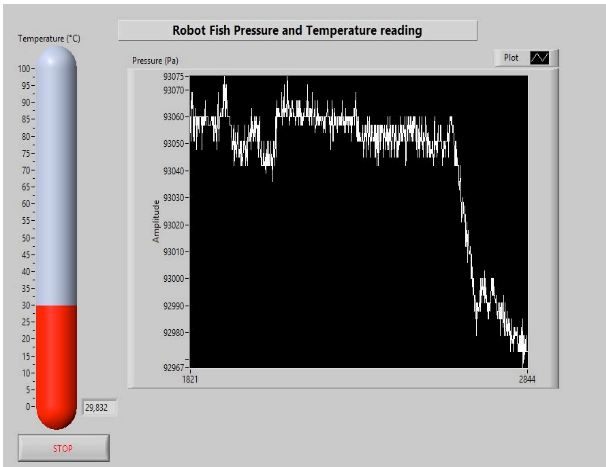

Figure 13. Change in the pressure in one of the fish fins representing the actuation of the motors, for the fish to go to the surface.

5. CONCLUSIONS

The new design of the fish robot was a good evolution of the project, giving more space to embed the electronics and the most important: opening new possibilities of control of its balance and depth using pectoral fins acted by servo-motors according to the data received by pressure, accelerometer and gyroscope sensors.

The facility may also be used to analyze the temperature inside the fish, and constantly the temperature of the environmental which the fish is inserted. In future works it will be possible to analyze the data acquired by the fish's embedded sensors to an external panel, making possible analysis of the water quality, oxygen and even inspections or interactivity.

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