ISSN: 0798-1015

REVISTA ESPACIOS

Vol. 41 (32) 2020 • Art. 15

**Recibido**/Received: 07/07/2020 • **Aprobado**/Approved: 16/08/2020 • **Publicado**/Published: 27/08/2020

# Identification model of a bioinspired shark robot using thunniform locomotion

## Modelo de identificación de un robot bioinspirado en un tiburón usando locomoción tuniforme

CABRERA, Fausto R.[1,2]
ROSSI, Claudio [3]

**Abstract**
Here is presented a design and implementation of a white shark robot, the robot emulate his locomotion using a caudal fin. The prototype was built with servomotors in the tail, through a couple of experiments and control theory a mathematical model was determined and tested, due to the experiments was developed in a real environment, the model considered the interaction between all the variables acting, the model represents effitiently the movement of the real robot in short distances.
**key words:** bioinspired fish robot, caudal fin, identification system, locomotion

**Resumen**
Aquí se preenta el diseño e implementación de un robot tiburón blanco, este emula su desplazamiento utilizando aleta caudal. El prototipo fué construido utilizando servomotores en la cola, mediante un par de experimentos y teoría de control un modelo matemático fue determinado y probado, dado que, los experimentos fueron llevados a cabo en un entorno real, el modelo considera la interacción entre todas las variables que interactúan, el modelo representa eficientemente el movimiento del robot real en pequeñas distancias.
**Palabras clave:** robot pez bioinspirado, aleta caudal, sistema de identificación, locomoción

## 1. Introduction

Robots are really important nowadays, some jobs who are repetitive, difficult, disgust and dangerous are made by robots, for example subaquatic exploration field (Rodriguez 2014)

Bioinspired robots appear, according to (Zhang 2016), during the last two decades, robot fish presents an alternative to conventional propulsion in underwater vehicles, with some important differences than permit emulate the natural movement of his biological simile.

Underwater vehicles are commonly studied in some fields, one of theme is improving UV (Underwater Vehicle) navigation in order to expand the capabilities of these vehicles for underwater missions, using sensors for

---

1 Profesor. Facultad de Informática y Electrónica. Grupo de investigación en tecnologías de la Electrónica y Automatización (GITEA), Escuela Superior Politécnica de Chimborazo. fausto.cabrera@espoch.edu.ec.
2 Candidato PhD. ETSI Industriales. Universidad Politécnica de Madrid. f.cabrera@alumnos.upm.es.
3 Full professor. ETSI Industriales. Universidad Politécnica de Madrid. claudio.rossi@upm.es.

interaction (Akyildiz, Pompili, and Melodia 2006). Underwater Automated Vehicles (UAV) are commonly used when humans can't access or are dangerous, for example they preserve their popularity both in civilian and military purposes where the goals are improving navigation and control (Sarig 1993)

Bioinspired fish robots are studied because conventional systems have limitations, some fishes are specially adapted to their environment, their systems of propulsion, stability and sensing abilities that could provide inspiration for improving UUV technology (MacIver, Fontaine, and Burdick 2004).

After reviewing relevant documentation about bioinspired fish robots, most topics shown investigation in control, locomotion (BFC mainly) and dynamic models (Filipe et al. n.d.), leaving aside the application of the robot in real environment, different kind of sharks live around the sea world, BFC with thunniform mode presents the fastest displacement, the white shark swim with this mode, therefore, the present document aboard his analysis.

Relevant information about dynamical model of carangiform mode of BFC could be showed in (Barrett, Grosenbaugh, and Triantafyllou n.d.), there are few or non-information about dynamics in subcaringiform, thunniform and anguiliform modes.

## 2. Methodology

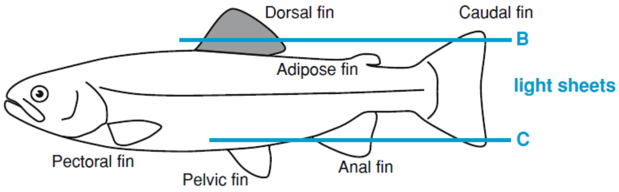
### 2.1. Locomotion systems

BCF locomotion could be oscillatory or undulatory, but only ostraciform mode is really oscillatory, the others are undulatory (Sfakiotakis, Lane, and Davies 1999),

Fish fins are showed in figure 1, all of them have part in locomotion, in the present case the BFC is used, and thunniform mode presents de less amplitude in undulatory movements, but it permits increase in velocity comparing with the other wavelet modes.

**Figure 1**

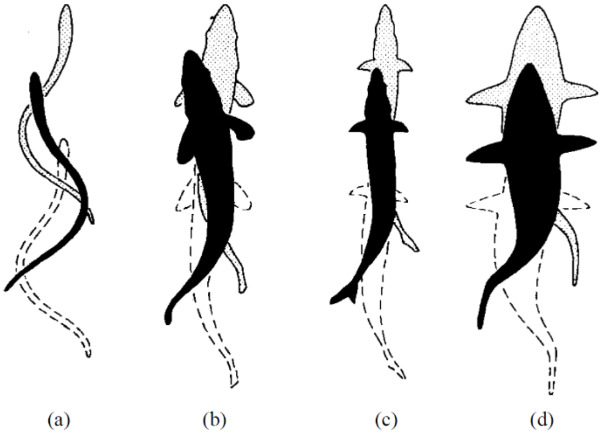
Fish fins used in locomotion



Source: (Lauder and Madden 2007)

Undulatory BFC has four swimming modes (Anguiliform, Subcaringiform, Caringiform, Thunniform) (Sfakiotakis, Lane, and Davies 1999). The figure 2 shown this techniques, white shark uses thunniform mode, this kind of fishes measure up to 1,5 meters long, so, in this work the robot prototype will be scaled 1:3.

**Figure 2**
Gradation of BCF swimming movements from (a) anguilliform, through (b) subcarangiform and (c) carangiform to (d) thunniform mode

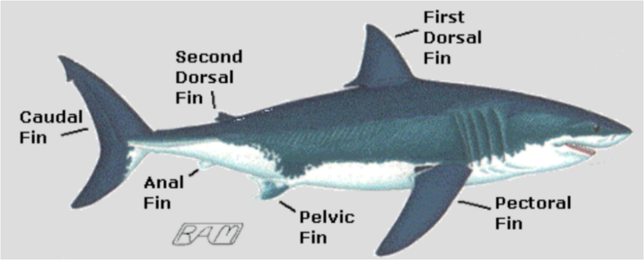


Source: (Sfakiotakis, Lane, and Davies 1999)

In thunniform swimming mode lateral significative movements occurs just in caudal fin, it produces more than 90% of the propulsion, due to undulator's movement this case could be treat as waves translation according to (Yu et al. 2004), but this dynamic equations could be present errors, so, a first order transfer function identification is presented.

For identification the shark fins that are involved in displacement was recreated, so, pectoral, dorsal, second dorsal, anal, pelvic and caudal fin, showed in Figure 3, will be part of the prototype.

**Figure 3**
Black shark morphology

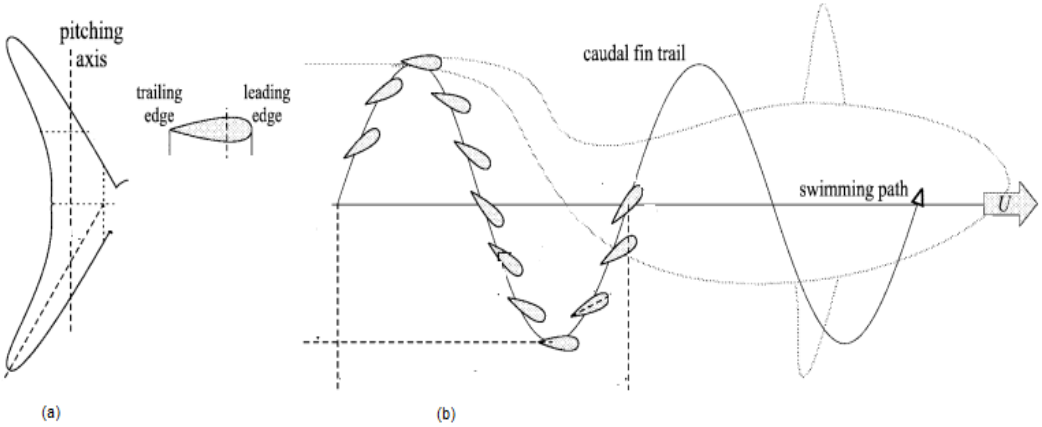


Source: (Aidan n.d.)

Thunniform swimers are largely restricted to the caudal oscillating hydrofoil, it minimize body drag. Typical thunniform swimers presents according their fork length 15.1-25.5 cm mean tailbeat frequencies of 4.57 and 7.03 Hz at swimming speeds of 40 cm/s and 80-100 cm/s respectively (Lingham-Soliar 2005).

The prototype has 2 Degrees of Freedom as is showed in Figure 5, therefore the recreation of real movement of white shark could will be possible, using two actuators and programming a sequence for body translation, the sequence has to follow thunniform mode as is showed in Figure 4.

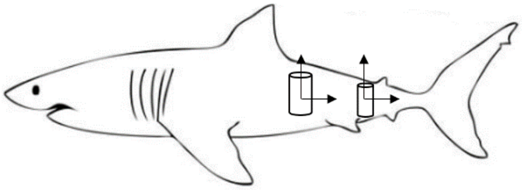
**Figure 4**
(a) Lateral view of caudal fin for tuniform locomotion
(b) Trajectory of a oscillatory caudal fin



Source: (Sfakiotakis, Lane, and Davies 1999)

Two degrees of freedom is considering in the present work, due to an experience in relative last works.

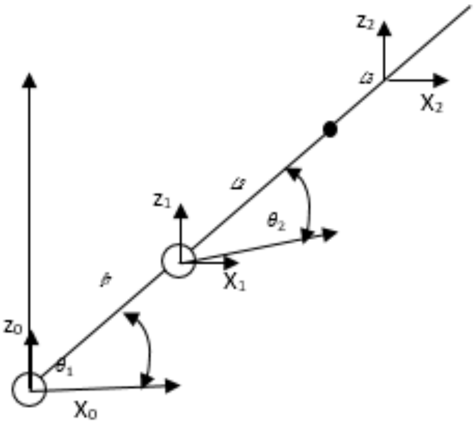
**Figure 5**
Proposed white shark degrees of freedom.



Source: Author

Figure 6 present a representation of the robot in links, as is showed, 3 links are consider (the las joint has not an actuator is just a semirigid link that will be deflect a little for natural swimming recreation), θ1, θ2 corresponds to angles of each articulation, l1, l2 and l3 are link sizes.

**Figure 6**
Link representation of a robotic prototype.



Source: Author

## 2.2. Buoyancy

The prototype will be tested in freshwater, and the movement is constrained to one plane, it can be possible due to buoyancy analysis, in order to obtain a functional identification the robot fish must be submerged in water at least enough to test the caudal fin functionality, therefore, to achieve this goal there are necessary the parameters of the robot showed in Table I.

**Table 1**
Robot fish parameters

| Parameters | Value | Dimension |
|---|---|---|
| Mass | 5 | $Kg$ |
| Gravity | 9.8 | $m/s^2$ |
| $\boldsymbol{\rho_{H_20}}$ | 997 | $Kg/m^3$ |
| $\boldsymbol{\rho_{foam}}$ | 20 | $Kg/m^3$ |
| Volume | 0.0026872702 | $m^3$ |

Source: Author

The buoyancy could be calculated by:

$$E = (\rho_{H_20})(g)(V)$$

Where:

$\rho_{H_20}$= fresh water

$g$= gravity

$V$= displaced volume

To achieve the fish robot immersion, the sum of forces has to be zero, a negative sign means that the fish is too weight and the body tends to sink, a positive value means that the body tends to float, so, there are cavities in the fish body were is possible to add a special foam with lower density as the water,

$$\sum Fy = E - W$$

it permits the immersion control and reduce the problem to a plane, in order to minimize the problem to the translation in a shaft, the body is cylindrical and symmetric, the elements who conform the system are distributed in such a way that the gravity center is in the center of the body, and movements of the actuators are controlled for a symmetric movement.

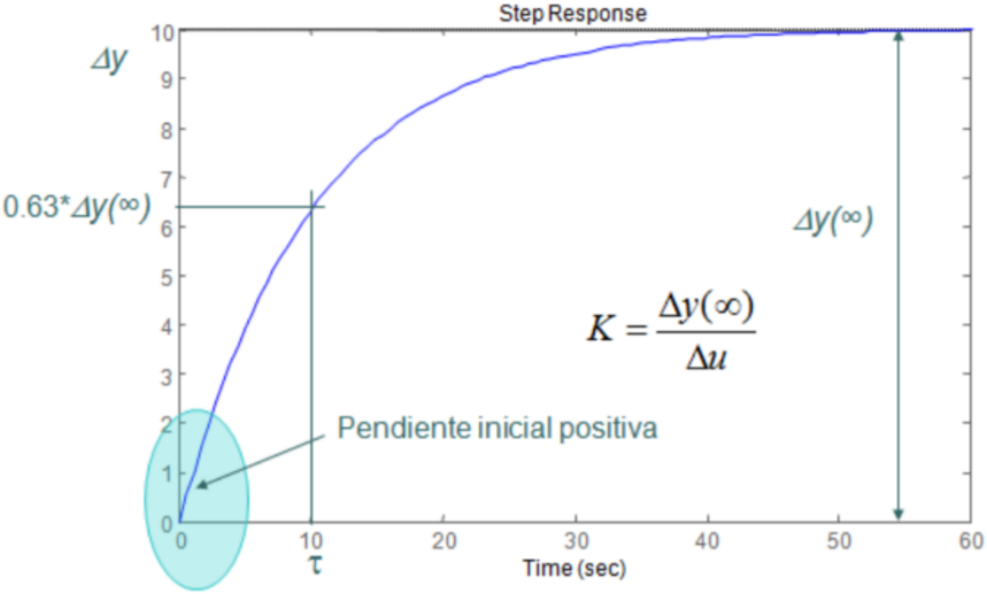
## 2.2. System Identification

Pure first order identification seems to be a correct estimation due to the system doesn't present oscillations or delays, the transfer function presents the following form:

$$G(s) = \frac{K}{1 + \tau s}$$

The first order response can be showed in figure 7, Shark robot has a T=1.20 seconds, so, the frequency is f=0.83, therefore the output signal is velocity, for position, the output signal has to be integrated

**Figure 7**
First order step response



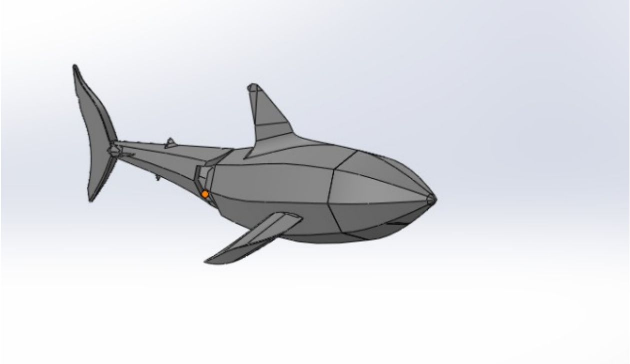
Source: (Bueno 2011)

---

## 3. Design and implementation

The robot was designed in a Cad software as is showed in Figure 8, then, the pieces were implemented using 3d printing with PLA material.

**Figure 8**
White shark robot final design



Source: Author

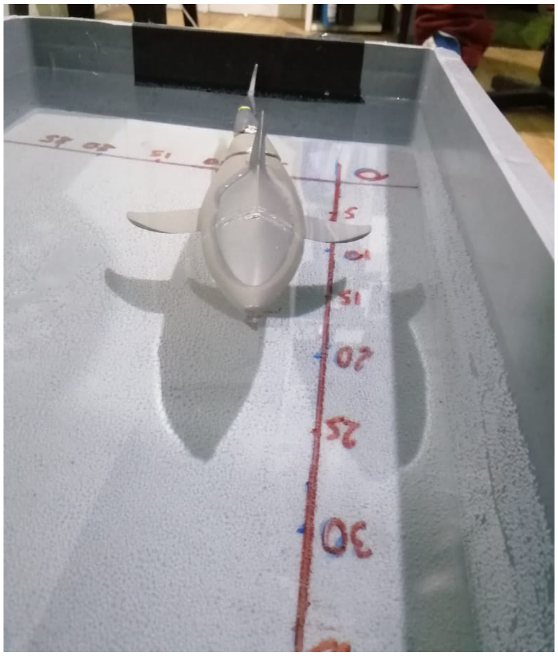
SG90 servos were the actuators, whom previously has to be waterproofed, using silicon and grease for isolate mechanical and electrical parts, one the fish was built, it was necessary to seal all de robot body.

The first servo who is the first joint, has the following restriction: 50 to 130 degrees, and joint 2: 70 to 110 degrees, in order to ensure the thunniform mode in BCF locomotion.

Start and stop signals are set via Bluetooth and a cellphone application, it permits lower disturbances in experimental tests, and autonomy near to 30 minutes. The prototype can be showed in Figure 9.

**Figure 9**

Bioinspired robot prototipe



Source: Author

---

## 4. Results

Table II presents experimental test results, it consists in apply a step entry to the system during a time, therefore, is possible to read the output manually in order to obtain a transfer function that determine the system dynamic.

**Table 2**

Experimental data, t1:test 1, t2:test 2,t3:test 3, t4:test 4

| Sample time | Output t1 | Output t2 | Output t3 | Output t4 | Output mean |
|---|---|---|---|---|---|
| 3 | 0.12 | 0.10 | 0.14 | 0.15 | 0.13 |
| 6 | 0.18 | 0.17 | 0.20 | 0.22 | 0.19 |
| 9 | 0.27 | 0.25 | 0.29 | 0.30 | 0.28 |
| 12 | 0.36 | 0.35 | 0.36 | 0.39 | 0.36 |
| 15 | 0.47 | 0.44 | 0.47 | 0.49 | 0.47 |
| 18 | 0.59 | 0.54 | 0.60 | 0.60 | 0.58 |
| 21 | 0.68 | 0.63 | 0.70 | 0.70 | 0.68 |
| 24 | 0.77 | 0.73 | 0.81 | 0.80 | 0.78 |
| 27 | 0.86 | 0.81 | 0.91 | 0.89 | 0.87 |
| 30 | 0.95 | 0.90 | 1.02 | 0.99 | 0.97 |
| 33 | 1.05 | 0.98 | 1.11 | 1.08 | 1.05 |

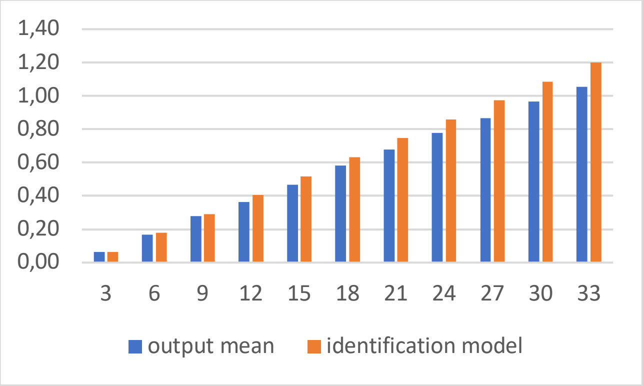
Source: Author

With the data it is possible to find a first order transfer function, it is possible to find the error between real signals and simulated signals obtained from the new model.

$$F(s) = \frac{0.0379}{0.3276s + 1}$$

For plant estimation we considering as input the frequency and output the velocity, it is necessary to integrate the output to obtain the position, the results are showed in graphic 1.

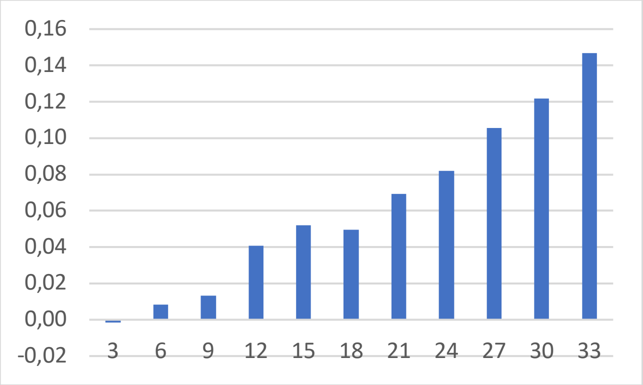
**Graphic 1**
Identification model
vs experimental data



Source: Author

In Graphic 2 the modeling error is presented, where it is possible to see that the error increase in function of the distance, it means that the model works in close distances.

**Graphic 2**
Error model



Source: Author

## 5. Conclusions

The principal objective of this investigation was the experimental identification of the black shark robot with thunniform mode BFC, the fish was constructed with all of fins as his biological simile use for locomotion, thunniform mode has an important advantage over the other ones, is the faster swim mode, there are few or non-information about kinematics or dynamics models for this mode of locomotion, the present work present an innovative application of conventional techniques of identification, the model is valid but presents errors, maybe in future works new techniques of identification could be more efficient.

## Bibliographic references

Aidan, Martin. (2019) “Fins to the Left, Fins to the Right . . .” http://www.elasmo-research.org/education/white_shark/fins.htm.

Akyildiz, Ian F., Dario Pompili, and Tommaso Melodia. (2006). "State-of-the-Art in Protocol Research for Underwater Acoustic Sensor Networks." In *WUWNet 2006 - Proceedings of the First ACM International Workshop on Underwater Networks*, , 7–16.

Barrett, D., M. Grosenbaugh, and M. Triantafyllou. (2019) "The Optimal Control of a Flexible Hull Robotic Undersea Vehicle Propelled by an Oscillating Foil." In *Proceedings of Symposium on Autonomous Underwater Vehicle Technology*, IEEE, 1–9. http://ieeexplore.ieee.org/document/532833/

Bueno, Angel Martínez. (2011). *Sistemas de Control Automático Identificación Experimental de Sistemas*. https://rua.ua.es/dspace/bitstream/10045/18965/1/Identificacion experimental de sistemas.pdf

Filipe, Joaquim et al. *ICINCO* (2015). *Proceedings of the 12th International Conference on Informatics in Control, Automation and Robotics : Colmar, Alsace, France, 21-23 July, 2015*. https://ieeexplore.ieee.org/document/7347789 (August 7, 2019).

Lauder, George V., and Peter G.A. Madden. (2007). "Fish Locomotion: Kinematics and Hydrodynamics of Flexible Foil-like Fins." *Experiments in Fluids* 43(5): 641–53.

Lingham-Soliar, Theagarten. (2005). "Caudal Fin in the White Shark, Carcharodon Carcharias (Lamnidae): A Dynamic Propeller for Fast, Efficient Swimming." *Journal of Morphology* 264(2): 233–52.

MacIver, Malcolm A., Ebraheem Fontaine, and Joel W. Burdick. (2004). "Designing Future Underwater Vehicles: Principles and Mechanisms of the Weakly Electric Fish." *IEEE Journal of Oceanic Engineering* 29(3): 651–59.

Rodriguez, Cárdenas. (2014). "'Prototipo de Robot Submarino Con La Capacidad de Seguimiento de Trayectorias Mediante Tratamiento de Imágenes,.'" *Universidad Pedagógica Nacional.*

Sarig, Y. (1993). "Robotics of Fruit Harvesting: A State-of-the-Art Review." *Journal of Agricultural Engineering Research* 54(4): 265–80. https://www.sciencedirect.com/science/article/pii/S0021863483710206 (April 30, 2018).

Sfakiotakis, M., D.M. Lane, and J.B.C. Davies. (1999). "Review of Fish Swimming Modes for Aquatic Locomotion." *IEEE Journal of Oceanic Engineering* 24(2): 237–52. http://ieeexplore.ieee.org/document/757275/ (August 7, 2019).

Yu, Junzhi, Min Tan, Shuo Wang, and Erkui Chen. (2004). "Development of a Biomimetic Robotic Fish and Its Control Algorithm." *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics* 34(4): 1798–1810.

Zhang, P. (2016). "'A Flexible , Reaction-Wheel-Driven Fish Robot : Flow Sensing and Flow-Relative Control,' Pp. 1221–1226, 2016." : 1221–1226.