

A DESCRIPTION OF A VERY LOW COST UNDERWATER VEHICLE PROJECT

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Abstract. *This paper presents a description of a very low cost underwater vehicle project, specifically about a remotely operating vehicle (ROV). The main motivation of this research is based on the fact that underwater robotics in Brazil is a recent scientific domain, particularly in experimental aspects. A few project specifications were established, and the actuators, sensors, structure and onboard electronics were projected and constructed. The ROV developed, named ROVFURG-I, has four actuators (motor with helices) and three sensors: two accelerometers (each one working in two axes) and one girometer. There are four degrees of freedom actively controlled. The project was made with two degrees of freedom controlled in passive form (roll and pith angles). The inertial trajectories were obtained with sensors data. However, errors inevitably are integrated and with forty seconds of trajectory the errors become significant.*

Keywords: *Underwater vehicles, robotics, project, ROV, mechatronics.*

1. Introduction

The main objective of the present work is to introduce a description about a very low cost ROV project, controlled in four degrees of freedom. It was projected and constructed a ROV with this characteristics, named ROVFURG-I. This ROV is discussed in more details in next sections.

Most of bibliography divides the underwater robotic vehicles in two groups (Yuh, 2000): Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV). A ROV receives energy and changes information with the panel of control located at the surface through an umbilical cable. From the control panel the operator can plan tasks or use one joystick to maneuver the vehicle directly. An AUV does not suffer the intervention from the human operator during the mission and also it does not possess umbilical cable. The power plant is onboard the vehicle, as well as the central processing unit. Because of handle inexistence, autonomous vehicles have greater freedom of motion and its use grows up due to advances in processors and the ways of energy storage, providing a bigger autonomy to these vehicles.

The scientific field of underwater robotics is not very developed in Brazil yet, in relation to international recent works. One of the first works was the master dissertation of Dominguez (1989), in which it was developed a ROV dynamic model software simulation. After this work, Cunha (1992) proposed an adaptive control to track the position of a ROV. More recently, Hsu *et al.* (2000) proposed a procedure to dynamic model identification of actuators used in ROVs and AUVs (motor with helices). Barros and Soares (2002) showed a proposition of a low cost vehicle which may be in ROV or AUV format. Souza and Maruyama (2002) investigated the performance of some position control laws applied to underwater vehicles. Tavares (2003) presented a basic review work in dynamic modeling and control of underwater vehicles.

In the world-wide level there are a great number of published works in the area of underwater vehicles. An important work was developed by Fossen (1994), in which there are concepts of kinematics, dynamics and control. Fossen and Fjellstad (1995) and Ridao *et al.* (2001) worked with modeling of the interaction between fluid and structure.

2. Structural project

The project of underwater vehicles must be based on requirements aiming at future real applications in the underwater environment. In the case of ROVFURG-I, the project requirements are:

- i. The vehicle must have specific functionality for tasks of inspection in the underwater environment;
- ii. The vehicle must have real possibility of being replicated in bigger dimensions;
- iii. Easiness of construction, assembly and maintenance are demanded;
- iv. Active control in only four degrees of freedom;
- v. Passive control in two degrees of freedom (roll and pitch);
- vi. Effort to use the biggest index of possible nationalization for the components;

vii. Very low cost.

Initially, it was considered two possible structural configurations, named as ROV1 (Fig. 1a) and ROV2 (Fig. 1b). ROV1 has an open frame configuration and its floats are placed at the upper part of the vehicle. The actuators are placed to make possible the control in four degrees of freedom and its onboard electronics is placed in the central cylinder. This vehicle could satisfy all the seven requirements of project relatively well.

As indicated in Fig. 1b, ROV2 does not have an open frame structure, but many of the project requirements also could be satisfied. However, this vehicle would present more difficulties of construction than ROV1, mainly to place the vertical actuator and still, to equilibrate the efforts of weight and push.

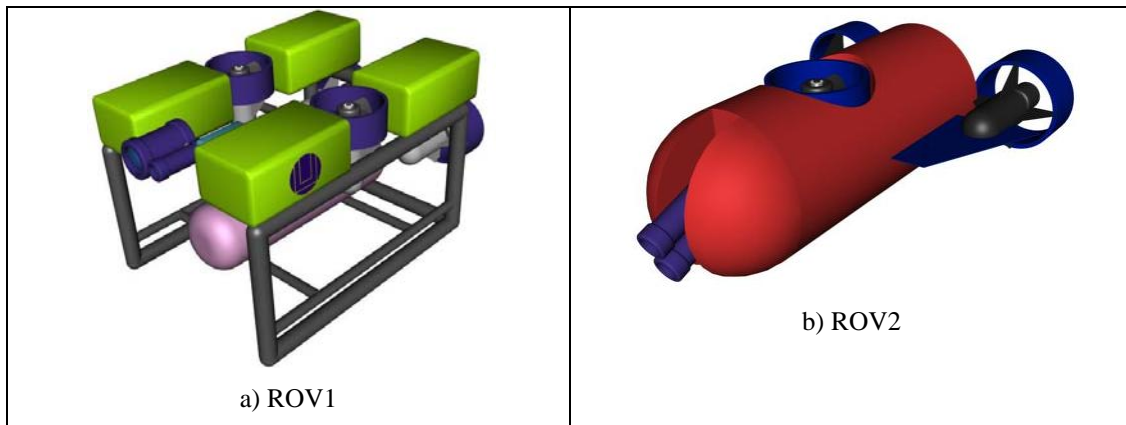


Figure 1. Possible structural configurations of ROV.

The configuration chosen for construction can be seen in Fig. 2. This is the structural format of the ROVFURG-I vehicle. As in the case of ROV1, all the seven project requirements are satisfied. However, ROVFURG-I presents more facilities of construction than ROV1, mainly in relation to the construction of the floats. Another important characteristic of this kind of structure is the facility to equilibrate weight and push, as will be showed in section 6.

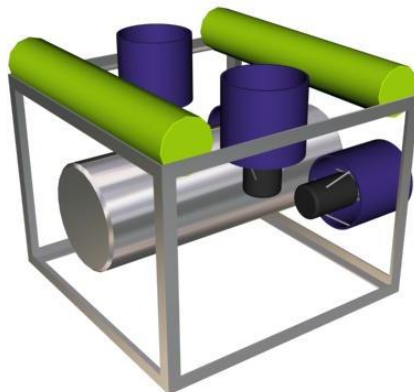


Figure 2. 3D structural aspect of the ROVFURG-I.

In Fig. 2, components in blue indicate the actuators, composed by the motor, helices and duct for water flow. The two cylinders in green are the floats, and the gray one is used to place the onboard electronics, as well as serving also as a float. The actuator's ducts and the floats are in PVC and all the others parts of the structure are in aluminum.

Fig. 3a shows only the structure in aluminum, in which it can be see the supports to fix the actuators and the cylinder that contains the onboard electronics. Fig. 3b shows the fixation details of the floats, actuators and cylinder of the onboard electronics. It can be seen also the weights (in blue) added to the structure in order to equilibrate weigh and push.

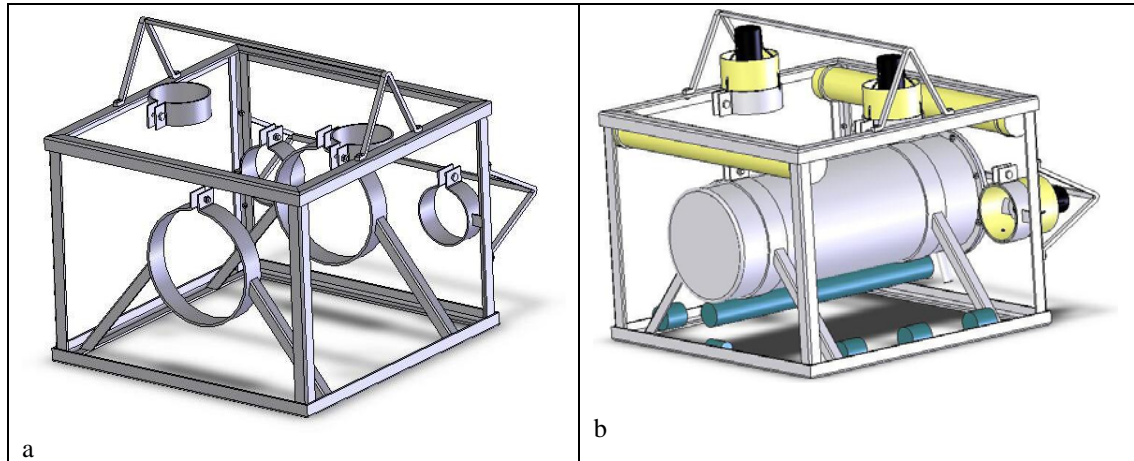


Fig. 3. ROVFURG-I in its structural and final formats.

A photograph of ROVFURG-I can be seen in Fig. 4. To make the experimental results, small pieces of isopor were fixed to the communication cable, in order to guarantee the floating of the cable. This decreases the effects of the cable dynamics on the vehicle.



Fig. 4. A photograph of the ROVFURG-I.

3. Actuators

Five actuators were constructed, constituted by DC motors and helices. The motors were isolated of the contact with the water with retainers placed at its output axis. A study was developed to know the relation between the current (in A) and the thrust (in N) of each motor with helices. For this purpose an experimental support was developed, as showed in Fig. 5. The actuator was fixed to a bar of aluminum and after this, it was submerged inside the water. This bar was connected to a structure that applies a momentum at the other structure size, where a digital scale with great resolution was located. Using the equilibrium of momentum, the thrust of the actuator was measured as a function of the applied current.

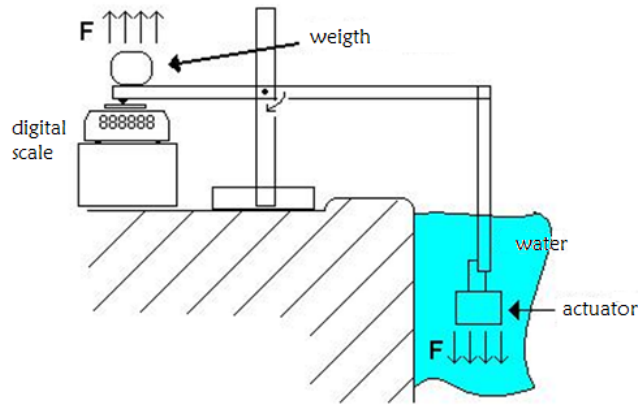


Figure 5. Experimental setup to measure the actuator's thrust as a function of the motor current.

For each actuator, six curves current versus actuator's thrust were obtained. It was adopted the average values to compose the curves showed in Fig. 6. The repeatability was relatively good and it was not found variations greater than 6% between the experiments with a same current. Beyond the repeatability, it can be seen in Fig. 6 that the curves present a linear behavior of the thrust with relation to the current.

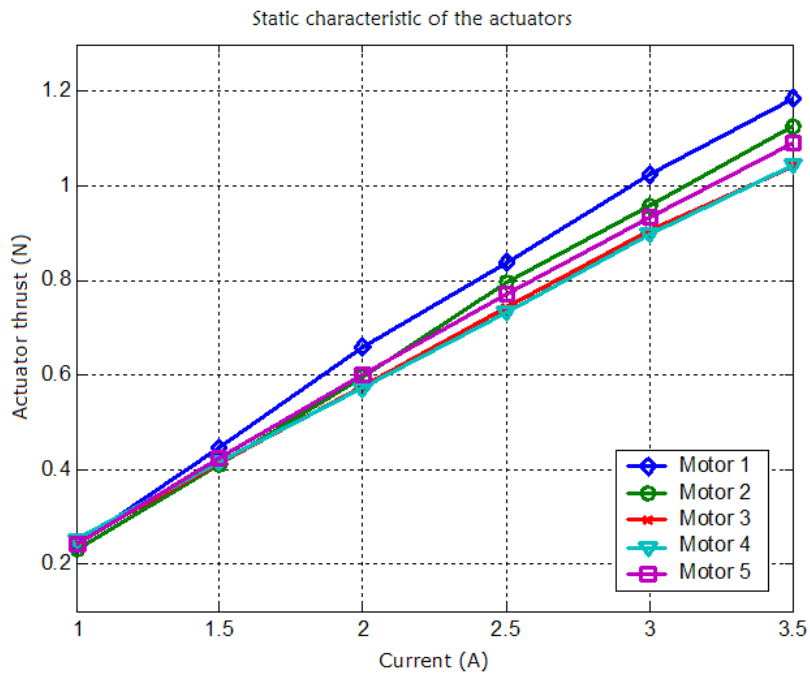


Figure 6. Static characteristics of the five actuators.

4. Electronics and communication

At the surface (outside the vehicle) there is a PC computer running a software (C language) that is responsible for receiving and sending signals to the vehicle (Fig. 7). Inside the vehicle there is the microcontroller (PIC16F877), which is responsible for sending the data acquired from the accelerometers and gyroscope to the surface and controlling the current of the actuators, as instructions received from the PC. To prevent interferences in the sensor's signals acquisitions, it was used in both sensors, beyond the amplification circuits, synchronized circuits of filtering at the cut frequency of approximately 8 Hz. As the microcontroller does not possess outputs with enough power to supply the actuators, a circuit was used to supply the necessary power to the control of these ones. The communication (RS232) was made with 19200 bps, which allows the vehicle to send to the PC at the surface the sensor data each 20ms.

Together with the serial cable, there is another cable to supply the internal circuits and the necessary current of the actuators. The voltage supplied to the vehicle is 220 V (ac), which internally is lowered to the 12 V (dc).

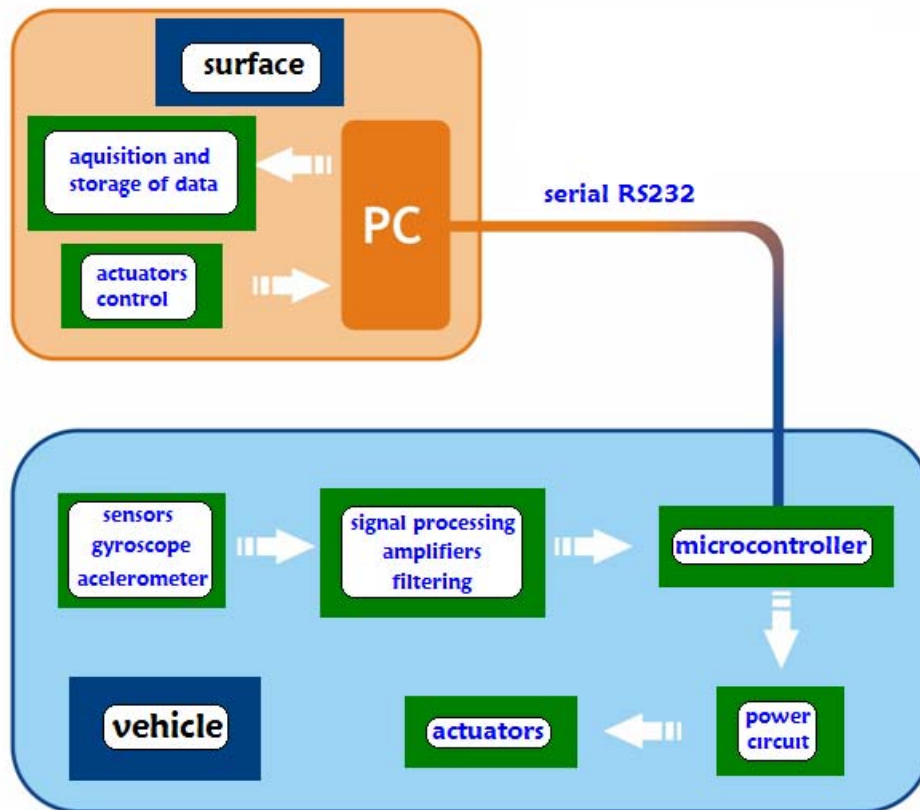


Figure 7. High level block diagram of the electronics and communication systems.

5. Sensors

The ROVFURG-I is equipped with three sensors: two accelerometers and one gyroscope. Each accelerometer supplies signals in two perpendicular axes. Some of the experimental results for the calibration of the sensors are shown to follow.

5.1. Accelerometer

The used accelerometers were ADXL203 model, made by Analog Device, and its resolution, indicated by the fabricant, is $1mg$. Some experiments had been carried out to calibrate the sensors (accelerometers) and also to analyze the repeatability in open loop. Fig. 8 shows six of these experimental results, being the integration of the accelerometer signal. The two horizontal actuators are turned on with 3 A each one. The actuators are turned off when the vehicle reaches 1m. The vertical lines in Fig. 8 show the instants in which the actuators are turned on/off. The repeatability was relatively good, despite the difficulty in repeating experiments with the same conditions in reason of undulations of the water movement. However, the double integration of the accelerometer signal seems to be not good to use as inertial measure due to bias errors. In a future closed loop control implementation, the accelerometer signal will be used as inclinometer, to detect pitch and roll motion.

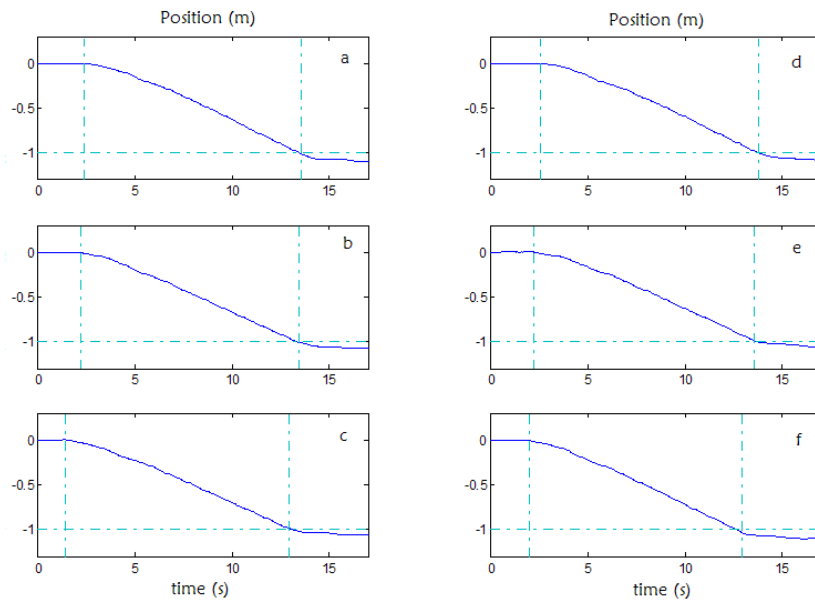


Figure 8. Linear position measure (repetition of six experimental results).

5.2. Gyroscopy

The tests with the gyroscope had been made in analogous form in relation to that ones carried on with the accelerometer. Also in this case the two horizontal actuators are turned on, one with $3A$ and another one with $-3A$ and then, the vehicle rotates around the Z axis (yaw). Fig. 9 shows the integration of the gyroscope measure (rate-gyro output integration) for six different experimental results. The two horizontal actuators are turned off when the vehicle rotates 360 degrees. The instants in which the actuators are turned on/off are represented by vertical straight lines in Fig. 9. As in the case before, the repeatability was relatively good, considering the fact that the experiments are in open loop with different conditions of the water.

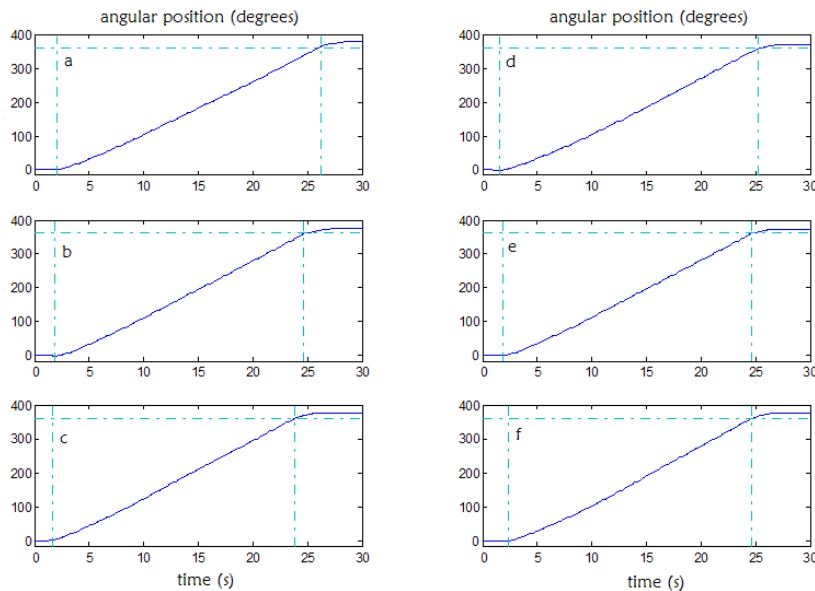


Figure 9. Angular position measure, repetition of the six experimental results.

6. Passive control

The restoring torques results from the distance between the centers of push (Archimedes Principle) and gravity. This torque is responsible for the maintenance of the vehicle in the horizontal position, acting as a passive control. To

modify this torque it is necessary to modify physic characteristics of the vehicle as the volume, the position of the push center (Archimedes principle), the mass and the position of the center of mass. To verify the performance of this passive control, some experiments had been made with all actuators turned off. The vehicle was inclined manually and soon after that, it is free to vibrate only due to the effect of the restoring torque. Figs 10a and 10c show the response in pitch, and Figs 10b and 10d the response in roll. The graphs of this figure are resultant of the integrations of the accelerometers measures. It can be seen that the time response is almost the same for roll and pitch, equal to approximately six seconds. The restoration dynamics could be visualized as being of second order, with a damping ratio 0.43 and a natural frequency of $2.85rd/s$, dynamic approximately valuable to roll and pitch motions.

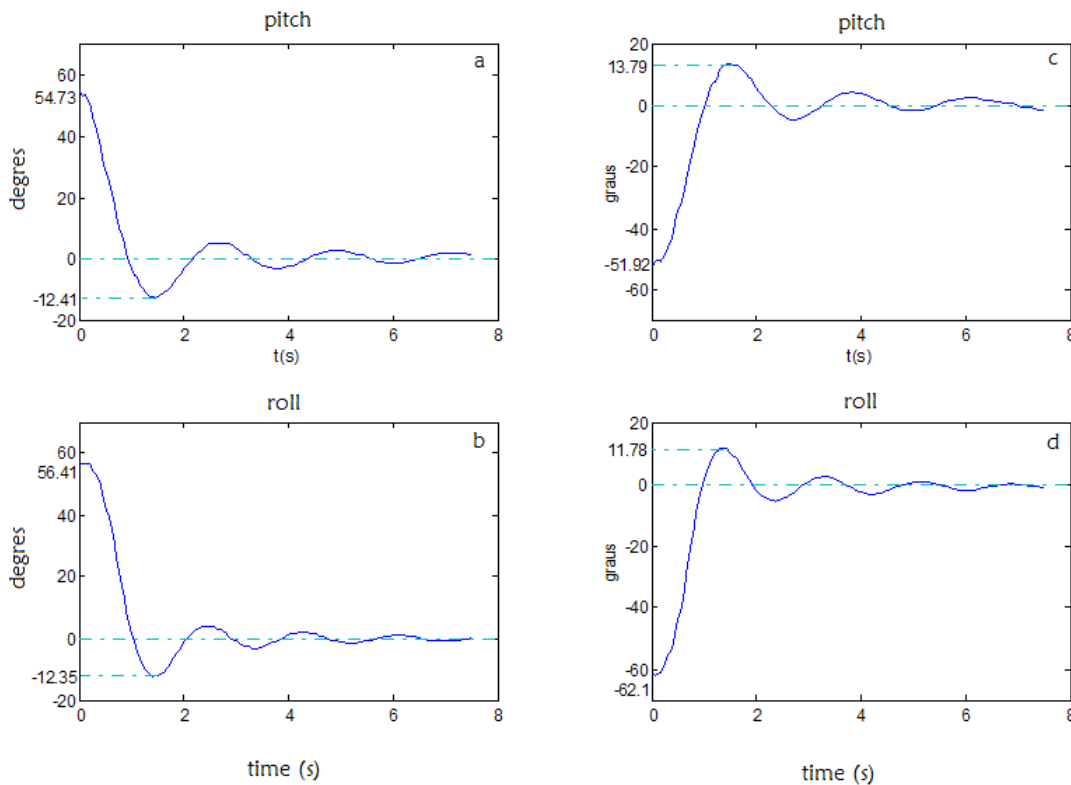


Figure 10. Open loop experimental response showing restoring torques.

7. Conclusions

This paper introduces a description about a very low cost ROV project. The proposed open frame structure allows an easy construction and posterior adaptation to embark equipments, as video camera or manipulator robots. This structure still allows an easy experimental determination of the distribution of masses and floats, in order to guarantee neutral floatability and passive control in two degrees of freedom (roll and pitch). The actuators had been constructed and the final cost of the vehicle was very small (approximately US\$ 500). However, this is a critical point of the project because the control performance of the vehicle depends directly on the quality of the actuators. The constructed actuators for the ROVFURG-I possess low capacity in torque and do not allow working in depths greater than thirty meters. Good results were obtained with the projected passive control. The vehicle reaches stability with null roll and pitch angles in six seconds, approximately. Future works will be concentrated in the substitution of the actuators for other ones, also made with our own manufacture, but with a bigger torque capacity. The new actuators will be projected to reach depths on the order of a hundred meters. A video camera also will be installed in the frontal part of the vehicle. The protection of this camera will have a format to diminish the drag in the frontal direction. As a final conclusion, it can be said that the present work contributes to show the viability to construct underwater vehicles with a very low cost.

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