# Re-construction of an AUV as a Platform for Oceanographic Research and a Test bed for Implementation of Control Systems Based on Neurobiological Networks

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***Abstract*— This work considers the re-design of an autonomous underwater vehicle (AUV) in which an innovative, neurobiological inspired sensorization control system is being implemented. Hardware architecture and sensorization control software are being developed to allow autonomous navigation procedures for submarine vehicles. After the refurbishment of the vehicle and the update of its control system, the ROV is able to load CTD sensors, chlorophyll, turbidity, optical dissolved oxygen (YSI V6600 sonde) and nitrate analyzer (SUNA) together with ADCP, side scan sonar and video camera, in a flexible configuration to provide a water quality monitoring platform with mapping capabilities.**

## I. Introduction

The need of autonomous underwater robots has become increasingly apparent as the world pays great attention on environmental and resources issues as well as scientific and military tasks. Many autonomous underwater robots have been developed to overcome scientific challenges and engineering problems caused by the unstructured and hazardous underwater environment.

There are a large number of researches underway to investigate enabling technologies pacing further development of autonomous underwater robot systems. Control of AUV in uncertain and non structured environments is a complex process involving non-lineal dynamics behavior. Various advanced underwater robot control systems have been proposed such as sliding mode control (SMC) by Yoerger and Slotine in 1984 [1], nonlinear control by Nakamura and Savant in 1992 [2], adaptive control by Antonelli et al. in 2001 [3], neural network control by Lorenz and Yuh in 1996 and Porto and Fogel in 1992 [4,5], fuzzy control by Smith et al. [6], and visual servo control by Silpa-Anan et al. in 2001 [7]. However, mathematical models of neuronal systems are a link between biology and engineering. The Dynamical Neuronal Theory (DNT) builds complex architectures at local (VITE, AVITE), regional (ART, BCS/FCS, MULITIART) and system (DIRECT, FLETE, CEREBELLUM,…) scale [8-12]. Algorithms based on DNT provide reliable adaptive learning models to different architectures depending on the assigned tasks. Auto-organizational neural networks can solve a wide range of problems such as inverse cinematic or reactive and autonomous navigation. Neuro-biologically inspired architectures are based on hierarchical controllers acting in a parallel way. Here we show some progress done in our refurbished AUV with this kind of control systems, previously and successfully, tried in a terrestrial vehicle.

This paper proposes an adaptive neural architecture that makes possible the integration of a kinematic adaptive neuro-controller for trajectory tracking and an obstacle avoidance adaptive neuro-controller for autonomous underwater vehicles (AUVs). The kinematic adaptive neuro-controller is a real-time, unsupervised neural network, which is termed Self-Organization Direction Mapping Network (SODMN). The network uses an associative learning system to generate transformations between spatial and velocity coordinates. The obstacle avoidance adaptive neuro-controller is a neural network that learns to control avoidance behaviors based on a form of animal learning known as operant conditioning. The efficiency of the proposed neural architecture has been tested experimentally by a differentially driven mobile robot.

This paper is organized as follows. We first describe (Section II) the experimental platform with the navigation system, neural control system and the set of oceanographic instruments installed on the AUV. Section III addresses the experimental results with the proposed scheme for control of avoidance and approach behavior on a terrestrial mobile robot and for the redesigned AUV. Finally, in Section IV, conclusions based on experimental results are given.

## II. Description of the Experimental Platform

### A. *Navigation System of the AUV*

The main goal of the navigation system is to achieve an appropriate level of spatial location at all times, allowing trajectory correction using a neural control algorithm, to process the corresponding corrections. Initially, consider three types of missions and each one different positioning procedure.

A global positioning system (GPS) mounted on the vehicle, as usual, will be modified for navigation in shallow waters when long time submerged operation is required. Two options are being considered: a surface-towing buoy with GPS and RF communications system or a kind trolley-pole linked to the buoy when accuracy in location is a critical factor.

When no accurate bathymetry is available or unexpected wreck can be found the proposed neural control algorithm would avoid collision risk.

In deep waters, regular emersions of the vehicle are not feasible, so the neural control system represents the most suitable system to avoid obstacles and allow the spatial location of the vehicle. Using an inertial navigation system combined with the control algorithm and a calibration of positioning bathymetric points of reference, the position of the vehicle is permanently submerged. In this case, it is important to define the benchmarks in the seabed with the utmost accuracy thus allowing the vehicle to find and modify the following path on the basis of these data. In addition, there is being implementing a complementary algorithm to allow the vehicle to be able to search and find the seafloor reference in case of lost the expected location.

In order to save the maximum level of available energy it is mandatory minimizing the number of 'search and find' operations. So it is strongly recommendable to check the course deviation in the study area before each mission. In this way, definition of the local deviation parameters and its use as inputs to calibrate the control system will minimize the tracking deviation.

*B. Neural Control System*

Figures 1 and 2 illustrate our proposed neural architecture. The trajectory tracking control without obstacles is implemented by the SODMN and the avoidance behavior of obstacles is implemented by a neural network of biological behavior.

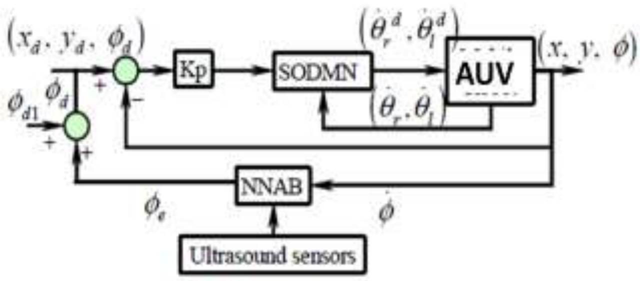


Fig. 1. Neural architecture for reactive and adaptive navigation of an AUV.

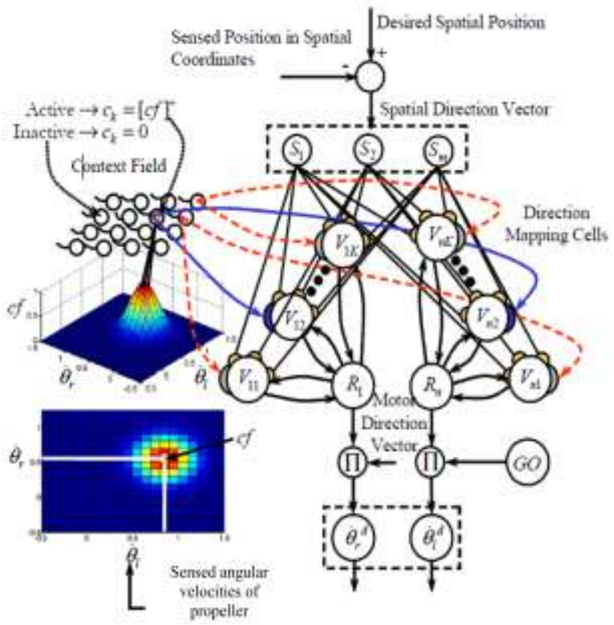


Fig. 2. Self-organization direction mapping network for the trajectory tracking of an AUV robot (SODMN).

At a given set of angular velocities the differential relationship between AUV robot motions in spatial coordinates and angular velocities of propellers is expressed like a linear mapping. The transformation of spatial directions to wheels angular velocities is shown in Fig. 2. The spatial error is computed to get a spatial direction vector (DVs). On one side, the DVs is transformed by the direction mapping network elements $V_{ik}$ to corresponding motor direction vector (DVm). On the other side, a set of tonically active inhibitory cells which receive broad-based inputs that determine the context of a motor action was implemented as a context field. The context field selects the $V_{ik}$ elements based on the wheels angular velocities configuration.

A speed-control GO signal acts as a nonspecific multiplicative gate and controls the movement's overall speed. The GO signal is an input from a decision center in the brain, and starts at zero before movement and then grows smoothly to a positive value as the movement develops. During the learning, sensed angular velocities of wheels are fed into the DVm and the GO signal is inactive.

The learning is obtained by decreasing weights in proportion to the product of the presynaptic and postsynaptic activities [8-10]. The training is done by generating random movements, and by using the resulting angular velocities and observed spatial velocities of the AUV robot as training vectors to the direction mapping network.

The obstacle avoidance adaptive neuro-controller is a neural network that learns to control avoidance behaviors in an AUV robot based on a form of animal learning known as operant conditioning. Learning, which requires no supervision, takes place as the robot moves around a cluttered environment with obstacles. The neural network (shown in Fig. 3) requires no knowledge of the geometry of the robot or of the quality, number, or configuration of the robot's sensors. Our implementation is based in the Grossberg's conditioning circuit, which follows closely that of Grossberg & Levine [11, 12] and Chang & Gaudiano[9].

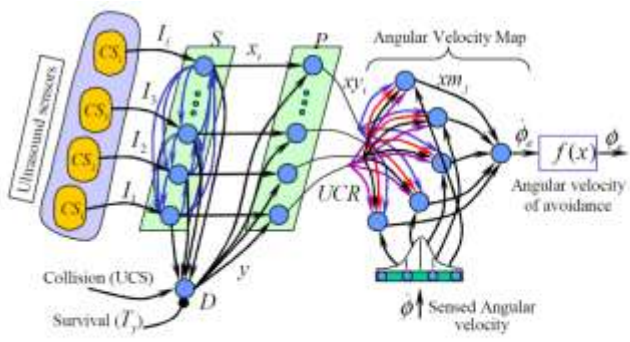


Fig. 3. Neural Network for the avoidance behavior (NNAB).

In this model the sensory cues (both CSs and UCS) are stored in Short Term Memory (STM) within the population labeled S, which includes competitive interactions to ensure that the most salient cues are contrast enhanced and stored in STM while less salient cues are suppressed. The population S is modeled as a recurrent competitive field in simplified discrete-time version, which removes the inherent noise, efficiently normalizes and contrast-enhances from the ultrasound sensors activations. In the present model the CS nodes correspond to activation from the robot's ultrasound sensors. In the network $I_i$ represents a sensor value which codes proximal objects with large values and distal objects with small values. The drive node D corresponds to the Reward/Punishment component of operant conditioning (an animal/robot learns the consequences of its own actions).

Learning can only occur when the drive node is active. Activation of drive node D is determined by the weighted sum of all the CS inputs, plus the UCS input, which is presumed to have large, fixed connection strength. The drive node is active when the robot collides with an obstacle, which could be detected through a collision sensor, or when any one of the proximity sensors indicates that an obstacle is closer than the sensor's minimum range. Then the unconditioned stimulus (USC) in this case corresponds to a collision detected by the mobile robot. The activation of the drive node and of the sensory nodes converges upon the population of polyvalent cells P. Polyvalent cells require the convergence of two types of inputs in order to become active. In particular each polyvalent cell receives input from only one sensory node, and all polyvalent cells also receive input from the drive node D.

Finally, the neurons ($xm_i$) represent the response conditioned or unconditioned and are thus connected to the motor system. The motor population consists of nodes (i.e., neurons) encoding desired angular velocities of avoidance, i.e., the activity of a given node corresponds to a particular desired angular velocity for the AUV robot. When driving the robot, activation is distributed as a Gaussian centered on the desired angular velocity of avoidance. The use of a Gaussian leads to smooth transitions in angular velocity even with few nodes.

The output of the angular velocity population is decomposed by SODMN into left and right wheel angular velocities. A gain term can be used to specify the maximum possible velocity. In NNAB the proximity sensors initially do not propagate activity to the motor population because the initial weights are small or zero. The robot is trained by allowing it to make random movements in a cluttered environment. Specifically, we systematically activate each node in the angular velocity map for a short time, causing the robot to cover a certain distance and rotate through a certain angle depending on which node is activated.

### *C. Set of Oceanographic Instruments Installed on the AUV*

In order to provide a wide range of oceanographic research capabilities, the AUV/ROV will be equipped with several types of environmental and oceanographic instruments [13]. This will allow the vehicle to carry out different kind of missions, depending on the research interest or particular requirements. Two main areas of study with different results will be supported by the vehicle operation: Shallow- and open-water missions.

Figure 4 shows the location of the areas chosen for both type of missions: The Mar Menor coastal lagoon for shallow water missions and the shelf-break off Cape Tiñoso, both located in the Region of Murcia (Spain).


Fig. 4. Map representing both research areas. Aerial view of the Mar Menor Lagoon and Cabo Tiñoso in Cartagena-Murcia, Spain.

*Shallow-water missions*: To carry out this kind of studies the Mar Menor coastal Lagoon has been chosen. The Mar Menor is a hypersaline coastal lagoon located in the Region of Murcia (Spain) in the South Western Mediterranean Sea. Their special ecological and natural characteristics make the lagoon a unique natural, being the largest lagoon in Europe. Its General characteristics are: 6 meters max. depth, 135 $Km^2$

area, 2.5 m mean depth and 42-49 P.S.U. salinity. The Figure 5 shows the Mar Menor Lagoon.


Fig. 5. Location of the study zone. Aerial view of the Mar Menor lagoon, in Murcia, Spain.

Three different mission will be developed in this environment: 1) Water quality monitoring: Using a YSI® multiparametric sonde (measuring temperature, salinity, turbidity, chlorophyll, dissolved oxygen) and a SUNA® nitrates analyzer together with an ADCP (SONTEK®) measuring currents (speed and direction). 2) Mapping: to perform high resolution bathymetries – using sonar side scanner (TRITECH®), and submerged vegetation maps using video cameras. 3) Data acquisition in order to validate high resolution 3D hydrodynamic models.

*Open Water Missions*: Oceanographic processes on the shelf-break off Cape Tiñoso have been chosen as case study. The area is close to Cartagena reaching 300-500 m depth in less than 6 miles off-shore with an easy access to deep water (2500 meters). In the area upwelling currents meet surface currents with high productivity thus allowing a high fisheries effort. In a first phase measurements of temperature, salinity, current velocity and direction (specially in the vertical) will be performed. Figure 6 shows area on the shelf-break where the major fisheries effort (red dots) is made.

### D. *Description of the AUV and its refurbishment*

The rebuilt vehicle was transferred to the Polytechnic University of Cartagena by the Spanish Navy. Originally it was a remotely operated vehicle (ROV) used as a tracking device and neutralizing underwater mines. The vehicle was manufactured in the 90s having an older technology. Also was inactive for about 10 years and its propellants had a great deterioration and some of these do not work. The main objective was to recover the devices could still be exploited and to add new equipment of control, sensing and modern communications. Thus, it would be possible the availability of a vehicle capable of autonomous operation / remote control in order to be intended for use as an oceanographic research platform and test-bed of equipments and systems of all kinds.

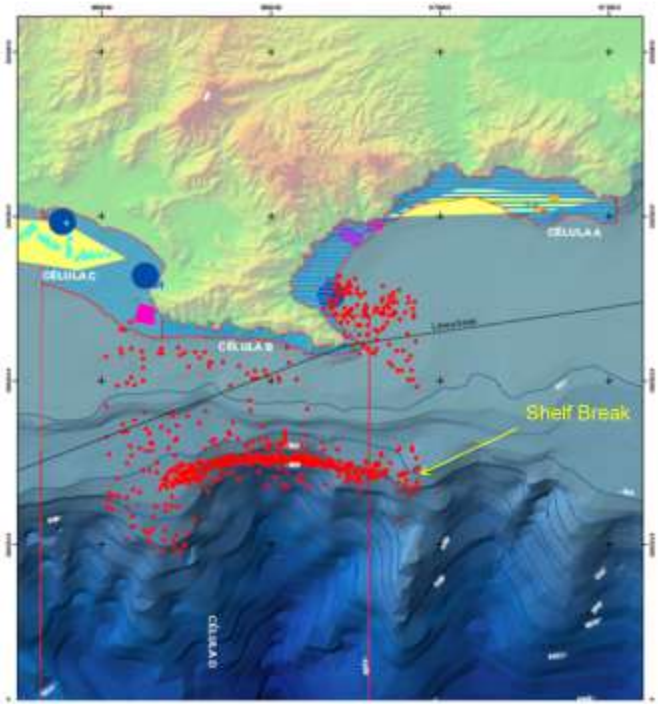


Fig. 6. Shelf-break off Cape Tiñoso. Red dots mean position where local fisheries effort is carried out.

Figure 7 and 8 show the re-construction and reparation of all the propellers components and replacement of new and modern equipment of electronic control and sensing.

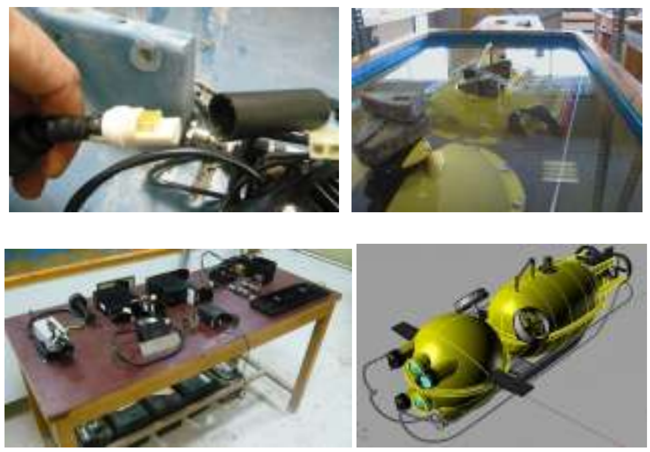

Fig. 7. The re-construction and reparation of the autonomous underwater vehicle. Hydrostatic tests and 3D model have been made.

Fig. 8. Autonomous underwater vehicle from the . UV Lab - UPCT

Figure 9 shows a scheme of interconnection of hardware components of the AUV-UPCT: Battery, CPU, inertial positioning systems, compass, propulsion systems, video capture, inclinometers, water intrusion detectors, monitoring station, and sonars.

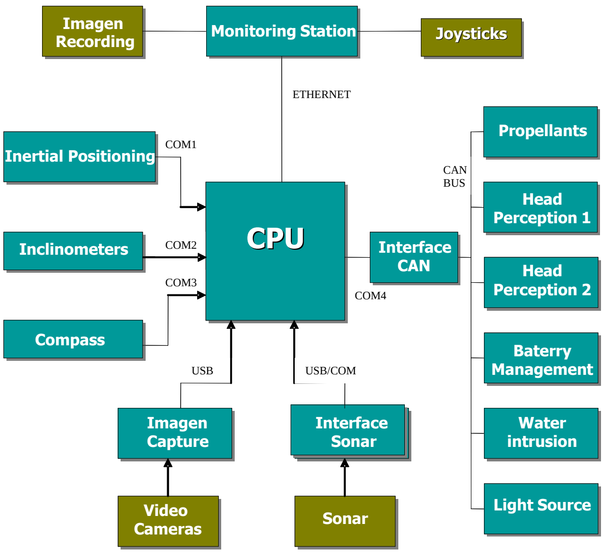

Fig. 9. Interconnection elements of the AUV-UPCT.

The Table I shows the main characteristics of the AUV-UPCT.

## III. Experimental Results

### A. *Proposed Control System for the AUV robots*

Initially, the proposed neural control algorithm was implemented on a terrestrial mobile robot from the Technical University of Cartagena (UPCT) named "CHAMAN". The platform has two driving wheels (in the rear) mounted on the same axis and two passive supporting wheels (in front) of free orientation.

Figure 10 illustrates the mobile robot's performance in the presence of several obstacles. The mobile robot starts from the initial position labeled X and reaches a desired position. During the movements, whenever the mobile robot is approaching an obstacle, the inhibitory profile from the conditioning circuit (NNAB) changes the selected angular velocity and makes the mobile robot turn away from the obstacle. The presence of multiple obstacles at different positions in the mobile robot's sensory field causes a complex pattern of activation that steers the mobile robot between obstacles.

TABLE I
PRINCIPAL CHARACTERISTICS OF THE AUV-UPCT

| |
|---|
| Manufacturer Data: 1986<br>Weight of the Vehicle: 160 Kg.<br>Dimensions: 1680 x 600 x 600 mm<br>Max. Speed.: 4 knots (48V), 2 knots (24V).<br>Operational depth: 300 meters. |
| Test Data:<br>Weight of the Vehicle: 148.4 Kg<br>Ballast: 15 Kg.<br>Total Weight: 163.4 Kg<br>Displacement: 163.8 $dm^3$<br>Ballast Displacement: 1.92 $dm^3$<br>Nett Upthrust: 2.32 Kg . |
| Elements:<br>Video Camera<br>Sonar Navigation<br>Acoustic Transponder<br>Depth Sensor<br>Speed Sensor<br>Power supply unit |

### B. *First Navigation test of the AUV*

The first tests of navigation on the surface and immersion were performed in a pool. These tests confirmed the maneuver of the vehicle and the response sensitivity of the controls in remote mode.

Navigation tests verified directional stability, turns and immersions. In all cases we were able to verify the correct response to requests from the vehicle operator. The test was developed for about an hour, at which time the battery charge did not show signs of exhaustion. It could also verify the accuracy of measurement of total displacement of the submerged vehicle, a fact which is essential to being able to properly ballast in each future operation.

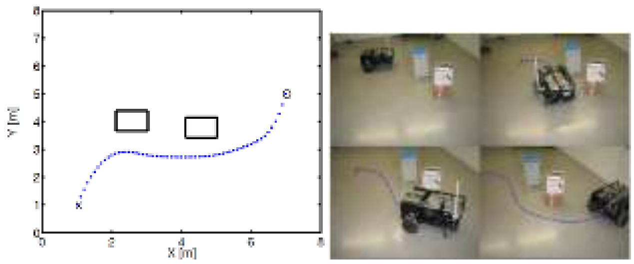

Fig. 10. Trajectory followed by the mobile robot in presence of obstacles using the proposed neural control system.

Importantly, the AUV must be trained ROV mode so that the algorithm learns the maneuvers of avoidance behavior and recovery of the path to unexpected situations, in order to implement the procedures in autonomous navigation mode (unmanned AUV). By this first test we have been able to verify the feasibility of the control system. The Figures 11 to 14 show the early stages of the navigation tests.

Fig. 11. The AUV- UPCT carried out in a pool 11 meters depth.

Fig. 12. Launching of the AUV- UPCT into the pool.

Fig. 13. Surface navigation of the AUV-UPCT into the pool.

Fig. 14. Successful underwater operation tests.

### *C. Previous Environement Analisys on the main area of study.: Mar menor/ Cape Tiñoso the AUV*

Coastal lagoons are one of the most productive areas in the world where many socio-cultural interests meet. The Mar Menor is one of the largest coastal lagoons of the Mediterranean. It is a major touristic destination lodging nearly a million people in high season. During its recent history it has suffered several environmental changes affecting both water quality and bottom features. Opening and inlet in the 70’ brought a decrease in salinity thus allowing access to different species. Touristic development brought artificial beaches and coastal infrastructures changing local hydrodynamics in some areas. Input of urban wastewater and agricultural run-off increased phosphate and nitrate inflows into the lagoon thus starting an eutrophication process. This process is now stabilized due in part, to wastewater treatment plants installed reducing significantly the amount of nutrient entering into the lagoon. As a result of these changes a substitution of *Cymodocea nodosa* and *Ruppia cirrhosa* by the algae *Caulerpa prolifera* was carried out now covering most of the bottom of the lagoon. Increase of chlorophyll in local areas facilitates algae blooms in reduced hydrodynamics areas. The Mar Menor has trespassed several ecological thresholds acquiring different equilibrium points during this time. A high resolution monitoring system is being implemented in the lagoon in the framework of the future Coastal Oceanographic Observing System of Murcia (OOCMUR). The system will contain fixed and mobile platforms recording environmental parameters to be transmitted near-real time to the computational center running high resolution 3D hydrodynamic and ecosystem models. As part of this major effort AUV capabilities will be intensively used. Figure 15 shows some outputs of a hydrodynamic model of the lagoon in Gilabert, 2009 [14].

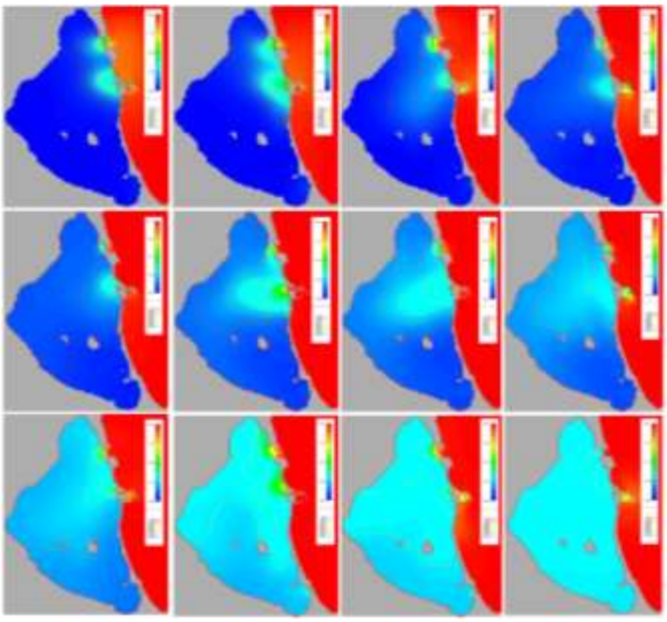

Fig. 15. Hydrodynamic model output of water exchange between the Mar Menor lagoon and its adjacent Mediterranean Sea.

The Cape Tiñoso area is a unique place in the region due to the very narrow continental platform followed by a steep slope. The area has been proposed as a marine protected area due to its natural values, most still unexploited.

## IV. Conclusions

In this paper, we have implemented a neural architecture for trajectory tracking and avoidance behaviors of a mobile robot and secondly the hardware/software architecture is being developed to allow autonomous navigation procedures for submarine vehicles. A biologically inspired neural network for the spatial reaching tracking has been developed. This neural network is implemented as a kinematic adaptive neuro-controller. The SODMN uses a context field for learning the direction mapping between spatial and angular velocity coordinates. The transformations are learned during an unsupervised training phase, during which the mobile robot moves as result of randomly selected angular velocities of wheels. The performance of this neural network has been successfully demonstrated in experimental results with the trajectory tracking and reaching of a terrestrial mobile robot. The avoidance behaviors of obstacles were implemented by a neural network that is based on a form of animal learning known as operant conditioning. The efficacy of the proposed neural network for avoidance behaviors was tested experimentally by a differentially driven mobile robot. The proposed control algorithm can be used for navigations in 2D and 3D.

Tests carried out after the reconstruction of the vehicle and control system refurbishment confirm the validity of the platform for its use as a multitasking vehicle for oceanographic research and missions.

The carrying capacity of remote control operation/autonomous, maneuverability and speed can have a suitable vehicle to call a variety of missions that are anticipated in the future.

The reliability of the platform both in the AUV operation mode in an unstructured environment allows the vehicle to be a testbed for various types of control systems and instrumentation for measurements in an aquatic environment.

New oceanographic instruments are being continuously developed. The capability of remote control operation of the vehicle allow the operation based on real time human control check place and date recover of any new device or instrument.. In the other hand, preprogrammed missions with autonomous obstacle avoidance capability will be implemented in an unmanned manner providing automatic long range survey missions.


## Acknowledgement

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