International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 9 – No.7, September 2015 – www.ijais.org

# Multi-agent Systems and its Application to Control Vehicle Underwater

Ettibari Miftah
Phd Student in Computer Science at the National Higher School of Electricity and Mechanics (ENSEM)

Adil Sayouti
Dr. Professor at the School Royal Naval of Morocco (ERN) Equipe Architecture des Systèmes, ENSEM

Hicham Medromi
Dr. Professor at the National Higher School of Electricity and Mechanics (ENSEM)

## ABSTRACT
An autonomous mobile robot must perform non- repetitive tasks in an imperfectly known environment and uncooperative and even hostile. In this context the missions assigned to the underwater vehicle can't be defined precisely, and this drone should have the capability to interpret, analyze the environment, decide on appropriate action and react to asynchronous events. It also must permanently reconfigure to adapt to external conditions and objectives. To fill the requirements and to harmonize decision, reaction and performance with distributed intelligence, the control architecture proposed it's an hybrid architecture, based on multi-agent systems, combines the benefits of reactive and deliberative architectures. In this work, we first studied the principle of the underwater vehicle; the analysis identified the desired characteristics. In the second part, we focused on multi-agent systems in order to understand the link between the approach "Distributed Artificial Intelligence" [1] and our project. After discussing the different control architectures in the third part, we finally treat the solution proposed in this article and general modeling of underwater vehicle. The development of our architecture is based on this modeling. These developments are part of the overall project initiated by the EAS team of the Computer Laboratory, systems and renewable energy (LISER) of the National School of Electrical and Mechanical (ENSEM).

## Keywords
Remote control, control architecture, distributed systems, MAS, mobile robot, modeling, underwater vehicle.

## 1. INTRODUCTION
We ask that authors follow some simple guidelines. In essence, we ask you to make your paper look exactly like this document. The easiest way to do this is simply to download the template, and replace the content with your own material.

Robotics is a very good example of multidisciplinary area that involves many issues such as mechanical engineering, mechatronics, electronics, automation, computer science or artificial intelligence [2]. Depending on the area of origin of the authors, there exists various definitions of the term robot, but they usually revolve around this:
Nevertheless, the undeniable interest in mobile robotics is to have greatly increased our knowledge of the location and navigation of autonomous systems.
A distinction without much ambiguity a number of problems in mobile robotics in general and especially mobile underwater vehicles. Obviously, the material aspect of selecting and sizing both the mechanical structure of the system as its engine, its power supply and architecture of its control and monitoring system appears as the first item to be treated.
The choice of structure is often made from a panel of known solutions and for which it has already resolved the problems of modeling, planning and control. The choice of the actuators and their diet is usually quite traditional. Most mobile robots are thus powered by electric motors with or without commutator, fed by power converters operating on battery power. Similarly, the command and control architectures for mobile robots are not different from those of more conventional automatic or robotic systems. However, there are distinguished in the general case, two levels of specialization, specific to autonomous systems: a decisional layer, which is responsible for the planning and management (sequential, temporal) events and a functional layer, responsible for generation real-time controls actuators. In the next section, we will deal with the different types of underwater vehicles.

## 2. VEHICLE UNDERWATER
The term "surface vehicle " represents autonomous buildings and vessels sailing the oceans and seas. In any case, these ships can't dive or perform any activity below the level of the sea.

The classification covers only the vehicle underwater. This distinction, vehicles, commonly known UUV (Unmanned Underwater Vehicles) is classified according to six main categories:

- The AUV (Autonomous Underwater Vehicles): This type of UAV is fully autonomous.
- Les MUV (Micro Autonomous Vehicles): These vehicles are used to inspect pipelines pipelines, gas pipelines and ship hulls.
- Les SAV (Solar - Powered Autonomous Vehicles).
- Les AUG (Autonomous Underwater Gliders): this category includes the vehicles that use positive buoyancy to surface and a negative buoyancy to dive.
- Les BUV (Biomimetic Underwater Vehicles): these underwater vehicles are based on the morphology and patterns of movements of aquatic animals such as stingrays.

- The ROV (Remotely Operating Vehicles): This class of vehicle is different from the first five described here, in the sense that these machines are controlled by operators.

Our goal is to provide a solution which allows you to assign the mobile robot of autonomy capacity, intelligence and distribution tasks [3]. This need has led us to study in detail the choice of control architecture and programming approach.

Our choice fell on MAS because they best meet the desired characteristics in control architecture. The MAS will be presented in the next section.

## 3. MULTI-AGENT SYSTEM (MAS)

The term Oriented Agent (OA) approach [4] is set for the first time there ten years only. However, since then, much research has been done on agents, MAS and programming OA.

Agents are programming OA that are the objects to Object Oriented (OO). Make sure to have some consensus in the multi-agent on the definition and characteristics of an agent community. This has led to several debates and has long been a source of division among researchers. Fortunately, diverged have faded and the majority of area stakeholders now agree on the overall characteristics required of agents [5] (Fig.1), namely: autonomy, located, responsive, social, proactive, active and learning.

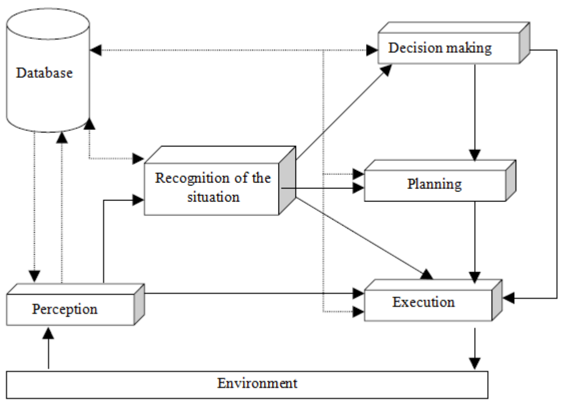



**Fig .1 : Architecture of agent**

In the next section, we will approach our proposed architecture based on multi-agents system [6] [7].

## 4. CONTROL ARCHITECTURE PROPOSED

In order to have an autonomous underwater vehicle, we defined one hand the elementary behaviors operating on the principle of operation of a submarine in general, and secondly, we determined the reactions adequate to unexpected situations. What makes ample simple to use to optimize its autonomy, learning and effectiveness of implementation of tasks in the military field as in the field of research. Indeed, we proposed the EAAUVS (Architecture For Autonomous Underwater Vehicle System), based on multi-agent approach [8], that runs around two loops at different time scales: real-time loop Agents closely associating perception and action agent, and another loop (comprising Diagnostic Agent and Agent decision) taking place on a slower time scale that manages one hand the decision based on representations, of various other unforeseen events. This architecture has been extended by the addition of communication mechanisms and information sharing (Agent Interface) to ensure the man-machine interface and other platforms.

The EAUAVS architecture that we proposed is an hybrid architecture [9] (fig.2) which consists of four blocks arranged around a fifth: the perception of agents, a diagnostic agent, a Decision agent and agents Action.

The core of this architecture is based on the representations of the environment.

The sensors (Inertial, sonar, cameras ... etc.) that the vehicle has to provide data collection agents that create representations of the environment [10]. These representations are instances of specialized perception models. For example, for a visual behavior around the hull of a boat, the representation may be restricted to edge coordinates detected in the image, which represents the hull forward. For representation, references are attached to the process it has created: creation date and various data relating to the sensor (position, depth, attitude, altitude...). The representations are stored in a database. Performances are site specific instant in the environment of the vehicle, whose spatial and temporal locations are known. The collection process is activated or inhibited by the agent Diagnosis and also receive information on running behavior. This information is used to predict and check the consistency of representation. The Diagnostic Agent ensures updates representations periodically or exceptionally, oversees the environment (detection of new events) and algorithms (predictive / feedback control) and ensures efficient use of resources. The module action agent chooses behaviors underwater vehicle depending on the target, the current action, representations and their approximate reliability. Finally, these behaviors control the actuators of the underwater vehicle in closed loop with the corresponding processes of perception [2].

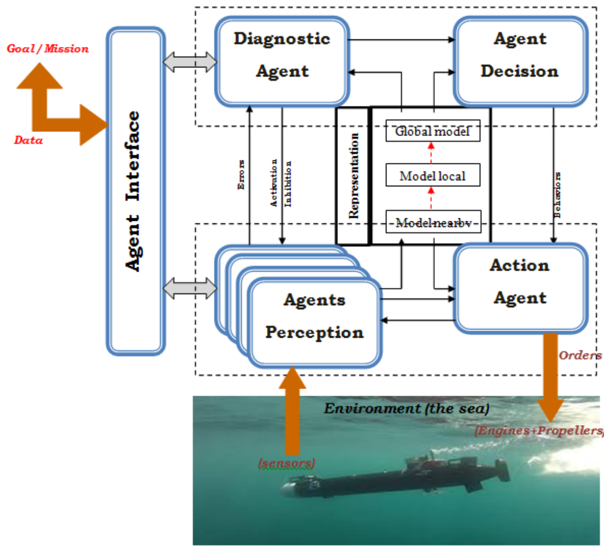



**Fig .2: block diagram of the architecture EAUAVS**

The key ideas of this architecture are:

- The use of sensory- motor behavior internally and externally connecting the perceptions and actions of lower level : the internal coupling compares a prediction of the next perception, estimated from the previous perception and the current order , with perception obtained after the application of the order, to decide if the current behavior normally or should be changed.

- Use collection process: In order to create representations of the local environment and located. No global environmental model is used; however, local representations of low and high level can be built from the instantaneous local representations.

- The quantitative evaluation of each performance: each algorithm associated the evaluation parameters that assign to each performance built a numerical value that expresses the confidence that can be given. This is important because any processing algorithm has a range of validity and its internal parameters are best suited for certain situations: there is no perfect algorithm that always gives good results.

- Using a diagnostic agent: he oversees executions processing algorithms of perception regardless of current actions. It takes into account the processing time required for each process of perception, and the cost in terms of required computing resources. It also examines new events due to the dynamics of the environment [11], which may mean a new danger or opportunities leading to behavior change. It can also draw the process to verify that the sensors are working nominally and may receive error signals from the current collection process. In practice, for example with a vision sensor (camera), the Diagnostic Agent focuses on the lighting conditions, the consistency between the movement of the robot underwater and the temporal coherence of the performances, and error signals issued by collection process. With this information it is then possible to invalidate representations due to faulty sensors or misused.

- The Decision Agent module develops an action plan by choosing the sensor-motor behavior [12] to be activated or inhibited depending on the target (in goal), performances and events available emitted from the Diagnostic Agent. This module is the highest level of architecture. It should be noted that the quantification of representations plays a key role in the decision process of the selection of behavior: first representation may be more or less adapted to the current situation, depending, for example, the probe used or the conditions of the acquisition of perception. For example a camera used to record night sequences give representations on which a trust should be assigned a priori, the same thing is also, for a pressure sensor based on a translation invariant while the vehicle is submerged, that this assumption is incorrect); secondly certain performances may be more attractive to certain behaviors or could provide enhanced assistance to choose between several behaviors (for example, a wall of behavior in a pool needs more information on the contours that velocity vectors, and that a tracking behavior has opposite needs). Therefore, each behavior also assigns a weight to each representation in terms of its direct use, and this weight is combined with the intrinsic evaluation of the data representation.

- The module action agent includes the low level controllers operating on the actuators [13]. It uses valid representations provided by collection agents to calculate control laws.

- The use of a mode of human-computer interaction more advanced (Agent Interface) to facilitate the use of submarine robot and increase the decision-making autonomy of the mobile system to implement behavior more tactics [14].

This modular architecture allows to independently developing different processes from each of the four entities, before integrating them together. Its originality lies in both the low-level loop between perception and action, necessary for active vision and all situated approach of perception, and the decoupling of perception and action processes, which become behavior during execution. This avoids duplication of common components, saves computing resources when representations are common to several behaviors and limit conflicts during access to material resources of the underwater vehicle. Compared to other hybrid architectures (three-layer approach that develops the following three levels: symbolic level, reactive behaviors, low control), we tried to focus more on the relationships between these three levels to take into account the heterogeneous aspect of loops characterizing a complex robot (underwater vehicle).

In addition, the proposed architecture with both loops between perception and action, at a low level, the other based on representations, seems a plausible model of a biological perspective: while sensor-motor the low, closed loop, is a characteristic of simpler organisms, cognitive ability of higher organisms, such as mammals, can be explained by another loop based on a dynamic model of the environment and organization, operating in direct action mode with a slower time scale. This loop also allows high-level open the planning phase to verify the validity of certain representations and can trigger updating.

Finally, the diagnosis is a concept used in biological vision, and offers a concept of effective monitoring for artificial systems, a reference batch process and reaction on discrete events. Asynchronous property of the control architecture is due to this diagnosis, this solution is based on a test cascade party hardware and software and the correction of information processing errors, and we believe this property is a keystone in complex systems, which face unpredictable environments and limited resources.

In order to design the action Agent, we have to develop the control law based on modeling of underwater vehicle.

## 5. MODELING OF UNDERWATER VEHICLE

In this chapter we discuss the modeling of an underwater vehicle type of autonomous torpedo that we will realize the long term. The model equations describe the laws governing behavior of the underwater vehicle in space (6 degrees of freedom). They are modeling and two distinct aspects: kinematics and dynamics [15].

Modeling requires the step of defining the reference against which to describe the evolution of the machine, as shown in Fig.3. We first define an absolute reference frame $R_0$ (O, $X_0$, $Y_0$, $Z_0$), with:

- $X_0$ longitudinal axis coincides with the geographic north,

- $Y_0$ transverse axis oriented to the east,

- $Z_0$ normal axis downwards (sea floor).

International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 9 – No.7, September 2015 – www.ijais.org

The essential feature of this benchmark is that it is stationary relative to the Earth which gives it the properties of a landmark galilean or inertial. The rotation of the earth is considered negligible effect at the machine and its vicinity.

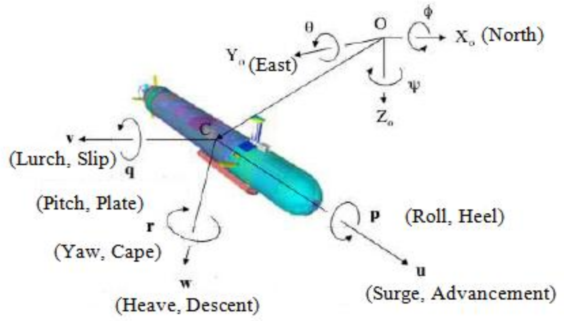



**Fig .3 : Fixed and inertial cues, state variables**

A second mark Rv (C, Xv, Yv, Zv) linked to the vehicle used to express the speed of the craft. The main vehicle inertia axes coincide with the axes of reference:

- Xv longitudinal axis oriented from the rear towards the front of the machine,

- Yv transverse axis oriented starboard,

- Zv normal axis directed from the top down.

The choice of the origin point C of this mark is strategic. The SNAME (Society of Naval Architects and Marine Engineers) provides a method for choosing a location based on geometric characteristics of the machine (SNAME, 1950).

For example, if the apparatus comprises symmetry planes, the origin point C is at the intersection of these planes of symmetry. If the center of gravity or buoyancy of the vehicle located in this intersection, the point of origin is coincident with one of those two points.

To describe the behavior (position and orientation) of the machine, the following notation will be used after the standard established by the (SNAME, 1950). The origin of C, Rv mark is confused with the vehicle's center of gravity. To set the position of the vehicle, the point C is defined in the absolute coordinate system $R_0$ by its Cartesian coordinates:

$$n_1 = (x, y, z)^T$$

The orientation of the craft, as defined in the absolute coordinate system is expressed by:

$$n_2 = (\varphi, \theta, \psi)^T$$

Or $\varphi$, $\theta$ and $\psi$ are respectively the angles of roll, pitch and yaw (Fig.3).

The general position vector is given by:

$$n = (n_1, n_2)^T$$

To set the vehicle's velocity vector $\nu$ expresses in Rv, we adopt the following notation:

$$\nu_1 = (u, v, w)^T$$

Or u, v and w respectively represent the linear advancement speed, slip and fall, and:

$$\nu_2 = (p, q, r)^T$$

Or p, q and r are respectively the angular velocities of roll, pitch and yaw.

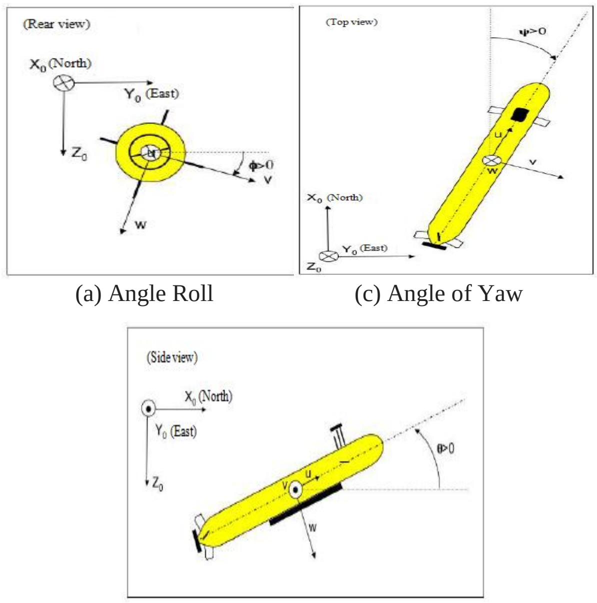
The overall velocity vector is then:

$$\nu = (\nu_1, \nu_2)^T$$

## 5.1 Kinematic

- **Euler angles**

The " Euler angles " used correspond to the system told RTL robotics for Roll, Pitch, Yaw ($\varphi$, $\theta$ and $\psi$) described in Fig.4.




(a) Angle Roll (c) Angle of Yaw

(b) Angle Pitch

**Fig.4 : The Euler angles**

Further descriptions may be used, for example, the direction cosines, Euler parameters or quaternions. The major drawback of the representation by the Euler angles is the existence of a singularity for a pitch angle $\theta=\pi/2\pm k\pi$. A description by quaternions avoids this singularity. However, in our case, this singularity corresponds to an extreme situation that the machine, hypothetically, will never reach. Indeed, the control applied to the vehicle is supposed to change the torpedo zero pitch ($\theta = 0$), so far removed from the critical angle of $\pi / 2$.

- **Transformation of linear velocities**

The path of the vehicle in the inertial reference frame related to the Earth is determined by the kinematic equation:

$$\dot{n}_1 = Jc_1(n_2)\,\nu_1$$

Or, $Jc_1(n_2)$ is the rotation matrix R (x, y, z) at Rv (Xv, Yv, Zv) is a unit determining matrix having to reverse its transpose:

$$Jc_1(n_2) = \begin{pmatrix} \cos\theta\cos\psi & \sin\theta\sin\phi\cos\psi - \sin\psi\cos\phi & \sin\theta\cos\phi\cos\psi + \sin\psi\sin\phi \\ \cos\phi\sin\psi & \sin\theta\sin\phi\sin\psi + \cos\phi\cos\psi & \sin\theta\cos\phi\sin\psi - \cos\psi\sin\phi \\ -\sin\theta & \cos\theta\sin\phi & \cos\theta\cos\phi \end{pmatrix}$$

International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 9 – No.7, September 2015 – www.ijais.org

- **Transformation of the angular velocities**

The angular velocities in the various pins in question are bound by the relation:

$$\dot{n}_2 = Jc_2(n_2)\,\nu_2$$

Or $Jc_2(n_2)$ is the matrix:

$$Jc_2(n_2) = \begin{pmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi/\cos\theta & \cos\phi/\cos\theta \end{pmatrix}, \theta \neq \pi/2 \pm k\pi$$

- **General relationship of kinematics**

Generally, the kinematic relationship is:

$$\dot{n} = Jc_2(n_2)\,\nu = \begin{bmatrix} \dot{n}_1 \\ \dot{n}_2 \end{bmatrix} = \begin{bmatrix} Jc_1(\dot{n}_2) & 0_{3*3} \\ 0_{3*3} & Jc_2(\dot{n}_2) \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \end{bmatrix}$$

After having developed the kinematic part, we are interested in the dynamic part.

## 5.2 Dynamic

The dynamics of an underwater vehicle is in studying the movements caused by the effects of certain control actions such as the orientation of the surfaces, or external, such as wave action when sailing in the vicinity of the surface, or ocean currents.

- **Dynamics of a rigid body**

The general equations of motion of a solid deformable reflect the translational and rotational movements of this solid. They are based on Newton's and Lagrange formalism and they are established by adopting the Conventions (SNAME 1950).

Let G be the coordinates of the vehicle's center of gravity

$\overrightarrow{CG} = [x_G, y_G, z_G]^T$ in the landmark vehicle, the vehicle mass m, and $\Gamma_{1} = [X,Y,Z]^T$ and $\Gamma_{2} = [K,M,N]^T$ respectively the forces and moments that apply on the vehicle.

This gives two sets of equations:

**Equation forces** The dynamic translation of a rigid body is reflected in the following form:

$$m\,[\,\dot{\nu}_1 + \nu_2 \wedge \nu_1 + \dot{\nu}_2 \wedge \overrightarrow{CG} + \nu_2 \wedge (\dot{\nu}_2 + \overrightarrow{CG}\,) = \Gamma_1$$

**Equation times** $I_0$ is the vehicle inertial matrix defined by:

$$I_0 = \begin{pmatrix} I_{XX} & -I_{XY} & -I_{XZ} \\ -I_{YX} & I_{YY} & -I_{YZ} \\ -I_{ZX} & -I_{ZY} & I_{ZZ} \end{pmatrix}$$

With $I_{ii}$ as the moments of inertia and $I_{ij}$ being products of inertia.

The dynamic rotation of a rigid body is:

$$I_0\,\dot{\nu}_2 + \nu_2 \wedge (I_0\nu_2) + m\overrightarrow{CG} \wedge (\dot{\nu}_1 + \nu_2 \wedge \nu_1) = \Gamma_2$$

**Synthesis** If one develops the two preceding equations, we obtain:

$$X = m\,[\,\dot{u} - vr + wq - x_g(q^2 + r^2) + y_g(pq - \dot{r}) + z_g(pr + \dot{q})]$$

$$Y = m\,[\,\dot{v} - wp + ur - y_g(r^2 + p^2) + z_g(qr - \dot{p}) + x_g(qp + \dot{r})]$$

$$Z = m\,[\,\dot{w} - uq + vp - z_g(p^2 + q^2) + x_g(rp - \dot{q}) + y_g(rp + \dot{p})]$$

$$M = I_{YY}\dot{q} + (I_{XX} - I_{ZZ})rp - (\dot{p} + qr)I_{XY} + (p^2 - r^2)I_{ZX} + (qp - \dot{r})I_{YZ}$$
$$+ m\,[z_g(\dot{u} - vr + wq) - x_g(\dot{w} - wq + vp)]$$

$$N = I_{ZZ}\dot{r} + (I_{YY} - I_{XX})pq - (\dot{q} + rp)I_{YZ} + (q^2 - p^2)I_{XY} + (rq - \dot{p})I_{ZX}$$
$$+ m\,[x_g(\dot{v} - wp + ur) - y_g(\dot{u} - vr + wq)]$$

This system of equations can be written in matrix form and becomes:

$$M_{rb}\,\dot{\nu} + C_{rb}\,\nu = \Gamma$$

Or,

- $M_{rb}$ is the system inertia matrix, positive definite:

$$M_{rb} = \begin{pmatrix} m & 0 & 0 & 0 & mz_G & -my_G \\ 0 & m & 0 & -mz_G & 0 & mx_G \\ 0 & 0 & 0 & my_G & -mx_G & 0 \\ 0 & -mz_G & my_G & I_{XX} & -I_{XY} & -I_{XZ} \\ mz_G & 0 & -mx_G & -I_{YX} & I_{YY} & -I_{YZ} \\ -my_G & mx_G & 0 & -I_{ZY} & -I_{ZY} & I_{ZZ} \end{pmatrix}$$

- $C_{rb}$ is the matrix of Coriolis and centrifugal forces, a[illegible]etric:

$$C_{rb} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ -m(yGq+zGr) & m(yGp+w) & m(zGp-v) \\ m(xGq-w) & -m(zGr+xGp) & m(zGq+u) \end{pmatrix}$$

$$\begin{array}{ccc} m(yGq+zGr) & -m(xGq-w) & -m(xGr+v) \\ -m(yGp+w) & m(zGr+xGp) & -m(yGr-u) \\ -m(zGp-v) & -m(zGq+u) & m(xGp+yGq) \\ 0 & -Iyzq-Ixzp+Izzr & Iyzr+Ixyp-Iyyq \\ Iyzq+Ixzp-Izzr & 0 & -Ixzr-Ixyq-Ixxp \\ -Iyzr-Ixyp+Iyyq & Ixzr+Ixyq-Ixxp & 0 \end{array}\Bigg)$$

Almost all of underwater vehicles are symmetrical with respect to their vertical plane leading to the following numerical simplifications:

$$I_{xy} = I_{yz} = 0$$

$$y_G = 0$$

- $\Gamma = [\Gamma_1, \Gamma_2]^t$ is the vector of forces and moments which are applied to the vehicle, which may be decomposed as follows:

$$\Gamma = \Gamma_h + \Gamma g + \Gamma_u + \Gamma_p$$

Or,

- $\Gamma_h$ gathers hydrodynamic forces and moments,
- $\Gamma g$ is the vector of forces and moments due to the action of gravity and buoyancy,
- $\Gamma_u$ is the vector of forces and moments generated by the vehicle actuators.

We consider that it is determined by adding the effects of each of the vehicle actuators,

- $\Gamma_p$ combines the forces and moments resulting from disturbances from the environment (sea currents, waves ...).

- **Hydrodynamic Efforts**

They act on any body immersed in relative motion in a viscous fluid, and can be classified as follows:

1. The forces and moments due to inertia and mass of water added,
2. The forces due to viscous friction of the fluid on the body that correspond to the lift and drag forces.

The main difficulty lies in their knowledge and formulation. Indeed, these efforts can't be obtained analytically.

**Inertia and mass of water added** From the physical point of view, all mobile body open water causes a displacement of a certain quantity of this water. The balance of forces due to inertia and mass of water added can be put in the form:

$$\Gamma_{aj} = -(M_a \dot{v} + C_a(v)v)$$

Or,

- $M_a$ is added water inertia matrix positive definite and can get the following form:

$$M_a = \begin{pmatrix} X_{\dot u} & X_{\dot v} & X_{\dot w} & X_{\dot p} & X_{\dot q} & X_{\dot r} \\ Y_{\dot u} & Y_{\dot v} & Y_{\dot w} & Y_{\dot p} & Y_{\dot q} & Y_{\dot r} \\ Z_{\dot u} & Z_{\dot v} & Z_{\dot w} & Z_{\dot p} & Z_{\dot q} & Z_{\dot r} \\ K_{\dot u} & K_{\dot v} & K_{\dot w} & K_{\dot p} & K_{\dot q} & K_{\dot r} \\ M_{\dot u} & M_{\dot v} & M_{\dot w} & M_{\dot p} & M_{\dot q} & M_{\dot r} \\ N_{\dot u} & N_{\dot v} & N_{\dot w} & N_{\dot p} & N_{\dot q} & N_{\dot r} \end{pmatrix}$$

An essential property of this matrix is $M_{ij} = M_{ji}$. We can also add that, by convention, all the coefficients are negative. It should also be noted that the form of symmetries has a torpedo type gear will simplify this matrix. If we consider that the vehicle has two planes of symmetry, a next (XvYv) and the other follows (XvZv), then we have:

$$M_a = -\begin{pmatrix} X_{\dot u} & 0 & 0 & 0 & 0 & 0 \\ 0 & Y_{\dot v} & 0 & 0 & 0 & Y_{\dot r} \\ 0 & 0 & Z_{\dot w} & 0 & Z_{\dot q} & 0 \\ 0 & 0 & 0 & K_{\dot p} & 0 & 0 \\ 0 & 0 & M_{\dot w} & 0 & M_{\dot q} & 0 \\ 0 & N_{\dot v} & 0 & 0 & 0 & N_{\dot r} \end{pmatrix}$$

- $C_a$ is the matrix of Coriolis forces and hydrodynamic centrifugal forces.

It is of the form:

$$C_a = \begin{pmatrix} 0 & 0 & 0 & 0 & -a_3 & a_2 \\ 0 & 0 & 0 & a_3 & 0 & -a_1 \\ 0 & 0 & 0 & -a_2 & a_1 & 0 \\ 0 & -a_3 & a_2 & 0 & -b_3 & b_2 \\ a_3 & 0 & -a_1 & b_3 & 0 & -b_1 \\ -a_2 & a_1 & 0 & -b_2 & b_1 & 0 \end{pmatrix}$$

With,

$$a_1 = X_{\dot u} u + X_{\dot v} v + X_{\dot w} w + X_{\dot p} p + X_{\dot q} q + X_{\dot r} r$$

$$a_2 = Y_{\dot u} u + Y_{\dot v} v + Y_{\dot w} w + Y_{\dot p} p + Y_{\dot q} q + Y_{\dot r} r$$

$$a_3 = Z_{\dot u} u + Z_{\dot v} v + Z_{\dot w} w + Z_{\dot p} p + Z_{\dot q} q + Z_{\dot r} r$$

$$b_1 = K_{\dot u} u + K_{\dot v} v + K_{\dot w} w + K_{\dot p} p + K_{\dot q} q + K_{\dot r} r$$

$$b_2 = M_{\dot u} u + M_{\dot v} v + M_{\dot w} w + M_{\dot p} p + M_{\dot q} q + M_{\dot r} r$$

$$b_3 = N_u u + N_{\dot v} v + N_{\dot w} w + N_{\dot p} p + N_{\dot q} q + N_r r$$

International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 9 – No.7, September 2015 – www.ijais.org

For a submarine class for traveling at low speed, some terms (coupling) become negligible, leading to the following form:

$$Ca = \begin{pmatrix} 0 & 0 & 0 & 0 & -Z_{\dot w}w & Y_{\dot v}v \\ 0 & 0 & 0 & Z_{\dot w}w & 0 & -X_{\dot u}u \\ 0 & 0 & 0 & -Y_{\dot v}v & X_{\dot u}u & 0 \\ 0 & -Z_{\dot w}w & Y_{\dot v}v & 0 & -N_{\dot r}r & M_{\dot q}q \\ Z_{\dot w}w & 0 & -X_{\dot u}u & N_{\dot r}r & 0 & -K_{\dot p}p \\ -Y_{\dot v}v & X_{\dot u}u & 0 & -M_{\dot q}q & K_{\dot p}p & 0 \end{pmatrix}$$

**Lift and Trail** These are forces acting on any body incidence to a viscous fluid flow. The angle ε is defined in Fig.5.

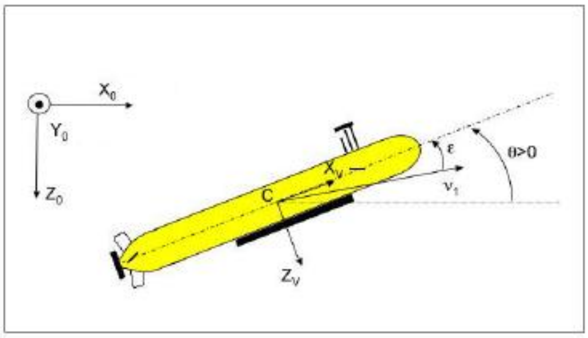



**Fig .5 : Setting the angle ε**

The efforts of lift and drag are two components of water resistance efforts to movements of the craft. The lift and drag terms tend to be used for actuators fins or rudders guy, and when it is the main body of the vehicle out actuators, we then speak of depreciation efforts. The balance of forces due to depreciation can be put in the form:

$$\Gamma_{am} = (D_p + D_t(\nu)\nu)$$

- $D_p$ is lift matrix, negative definite and steady:

$$D_p = -\begin{pmatrix} X_u & 0 & 0 & 0 & 0 & 0 \\ 0 & Y_v & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_w & 0 & 0 & 0 \\ 0 & 0 & 0 & K_p & 0 & 0 \\ 0 & 0 & 0 & 0 & M_q & 0 \\ 0 & 0 & 0 & 0 & 0 & N_r \end{pmatrix}$$

- $D_t$ is drag matrix, negat[illegible]he resulting effort has a quadratic term:

$$D_t = -\begin{pmatrix} X_{uu}|u| & 0 & 0 & 0 & 0 & 0 \\ 0 & Y_{vy}|v| & 0 & 0 & 0 & 0 \\ 0 & 0 & Z_w|w| & 0 & 0 & 0 \\ 0 & 0 & 0 & K_{pp}|p| & 0 & 0 \\ 0 & 0 & 0 & 0 & M_{qq}|q| & 0 \\ 0 & 0 & 0 & 0 & 0 & N_{rr}|r| \end{pmatrix}$$

- **Gravity and Buoyancy**

When stopped, the gear is only subjected to its weight and buoyancy. These forces depend on the characteristics of the craft and of aquatic properties.
P is the density of sea water, which depends on the salinity, pressure and temperature. Let Δ the volume of the torpedo and F coordinate vehicle center of buoyancy $\vec{CF} = [x_F, y_F, z_F]^t$ in the benchmark vehicle. g is the acceleration of gravity.

The buoyancy is the force exerted on any submerged part of a body.
It is equal to the force opposing the weight of the displaced fluid volume $B = -\rho\Delta g$ .Vehicle weight equals $W = mg$.
Fig.6 distinguishes three possible behaviors for a submerged solid:
- (a) the solid rises to the surface,
- (b) the solid is a hydrostatic equilibrium
- (c) solid dives.

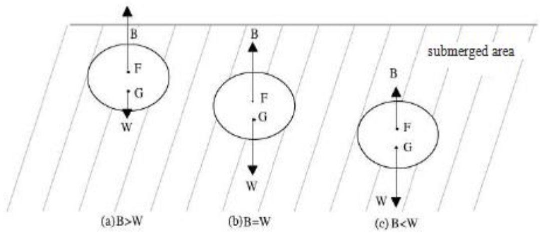



**Fig.6 : Equilibrium of a submerged body**

The vector of hydrostatic forces $\Gamma_g$ is then:

$$\Gamma_g = g\begin{pmatrix} -(m-\rho\Delta)\sin\theta \\ (m-\rho\Delta)\cos\theta\sin\varphi \\ (m-\rho\Delta)\cos\theta\cos\varphi \\ (y_Gm - y_F\rho\Delta)\cos\theta\cos\varphi - (z_Gm - z_F\rho\Delta)\cos\theta\sin\varphi \\ -(z_Gm - z_F\rho\Delta)\sin\varphi - (x_Gm - x_F\rho\Delta)\cos\theta\cos\varphi \\ (x_Gm - x_F\rho\Delta)\cos\theta\sin\varphi + (y_Gm - y_F\rho\Delta)\sin\theta \end{pmatrix}$$

- **Hydrodynamic Actuators**

The actuators can be divided into two groups:
1. Those that act by modifying the flow characteristics of an existing (Mobile surfaces: ailerons and rudders)

International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 9 – No.7, September 2015 – www.ijais.org

2. Those that generate the flow of fluid which may be initially at rest (propellant).

Concerning mobile surfaces, we present here only the effects due to the lift and drag, as the effects due to the mass and inertia of added water can be neglected compared to those due to the main body.

Regarding engines, there are great varieties, but we are interested only in the screw propeller.

**Moving surfaces** The operating principle is based on the one already stated in chapter 5.2. Any surface incident with respect to a viscous fluid flow is subjected to a lifting force $F_p$ perpendicular to this surface and parallel $F_t$ drag force thereto ( Fig.7) .

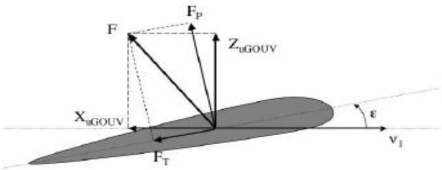



**Fig.7: Sectional view of the control surface**

Consider a mobile wing whose axis of rotation is at a distance $d_a$ from the origin of the reference vehicle. With the assumption that the control surface is attached to a perpendicular surface, the coefficients of lift and drag reported to the wing axes are defined by:

$$Cz_s = \frac{2\pi\lambda s_e\,[1-3(e_s/c_s)^2]}{\sqrt{\left(\frac{\lambda_{se}^2}{cos^2\gamma_s}+2\right)}\cos\gamma_s+2.6}(\varepsilon+\delta)+2.1(\varepsilon+\delta)^3$$

$$Cx_s = 0.01 - 0.7\lambda s_e\,(\varepsilon+\delta)^2$$

Or,

- $\lambda_{se}$ is the actual lengthening of the wing : $\lambda_{se} = 2\lambda_s = \frac{b_s}{c_s}$ ,with $b_s$ the size (length) of the wing and the chord (width) of the wing,
- $e_s/c_s$ refers to the relative thickness of the wing,
- $\gamma_s$ is the deflection of the wing, assumed to be zero in this study,
- ε represents the main body of the vehicle the angle of incidence,
- δ characterizes the deflection of the wing, and the control element.

In referring to the landmark vehicle axes, we get the lift and drag forces (Fig.8):

$$X_{uGouv} = -0.5\rho S_s V_0^2(C_{Z_s}\sin\delta + C_{X_s}\cos\delta)$$

$$Z_{uGouv} = -0.5\rho S_s V_0^2(C_{Z_s}\cos\delta - C_{X_s}\sin\delta)$$

$$M_{uGouv} = Z_{uGouv}\,(0.2C_s\cos\delta - d_a\sin\delta) + X_{uGouv}\,(0.2C_s\sin\delta)$$

with,

- $S_s$ is the wing's surface defined by, $S_s = b_sC_s$
- $V_0$ is the flow module of the fluid around the wing,
- $0.2C_s$ is the distance of the leading edge of the wing at the application of hydrodynamic forces.

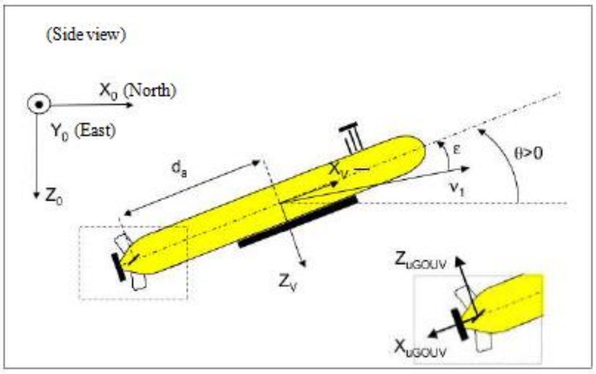



**Fig.8: Lift and drag forces reported the vehicle marker**

**Propellan**[...] a rotating shaft, which generates a thrust force in the axis of rotation of the shaft.

An approximation of the thrust $T_p$ and torque resistant Q generated in the case of a propeller to a propeller is:

$$X_{uprop} = T_p = \rho D_p^4 K_T(J_0)\,|\,n_p\,|\,n_p$$

$$K_{uprop} = Q = \rho D_p^5 K_Q(J_0)\,|\,n_p\,|\,n_p$$

Or,

- $n_p$ is the speed of rotation of the propeller,
- ρ is the density of sea water,
- $D_p$ is the diameter of the helix,
- $J_0$ is the propellant Progress coefficient in water, it is defined by: $J_0 = \frac{V_a}{n_p\,D_p}$

With, $V_a$ the average velocity of the water around the propeller, defined by: $V_a = (1 - w_a)V_0$,

Or, $V_0$ is the axial component of the velocity of the water upstream of the propeller, and $w_a$ is a coefficient in [0.1; 0.4] characterizing the wake of the vehicle.

- $K_T$ is the thrust coefficient which is equal to:

$$K_T = Ct_0 + Ct_1J_0 + Ct_2J_0^2 + Ct_2J_0^3 + Ct_3J_0^3$$

Or, the constants $Ct_i$ are given in the table (1)

- $K_Q$ is the coefficient of torque equal to:

$$K_Q = Cq_0 + Cq_1J_0 + Cq_2J_0^2 + Cq_2J_0^3 + Cq_3J_0^3$$

Or, the constants $Cq_i$ are given in the table (1)

| i | $Ct_i$ | $Cq_i$ |
|---|---|---|
| 0 | 0.50539 | 0.090271 |
| 1 | -0.088971 | -0.013470 |
| 2 | -0.29960 | -0.023529 |
| 3 | 0.046836 | -0.0020050 |

- **Disturbances**

The underwater environment introduces disruptive nature:

- *Non-additive*, by modifying the hydrodynamic coefficients related to the marine environment. The main hydrodynamic coefficient may introduce significant perturbations is the density of seawater, or equivalently its density.

- *Additive*, by the action of a movement or an additional force on the original vehicle dynamics. This is the case of ocean currents, waves, and to a lesser extent to the movement near the surface, wind.

**Sea water density** The density of seawater environment within which the torpedo is a factor which is involved in the determination of the hydrodynamic coefficients of the vehicle. This is to present the range of variation of this disturbance through the variable that is the equivalent density.

The density of sea water θ depends on salinity Se, temperature Te and the pressure Pe at the point considered. An underwater vehicle, even perfectly balanced, operates in an environment where the density may increase or decrease slightly depending on the salinity gradient and temperature of the sea water.

In conclusion, we will retain the hydrodynamic coefficients of a submarine evolve according to the geographical location of the device (North Pole or Mediterranean, for example) and depth.

**Ocean currents** Ocean currents are the results of a number of factors including:
- The gradients of temperature and density of the sea water,
- The tide,
- The rotation of the Earth,
- The effects due to solar activity,
- Winds.

They are also influenced by the proximity of the coast and the topography of the seabed.

- **General relationship dynamics**

Dynamic modeling of a type of torpedo underwater vehicle in Rv landmark, leads to the following general equations:

$$M\dot{\nu} = C(\nu)\nu + D(\nu)\nu + \Gamma_g + \Gamma_p + \Gamma_u$$

With,
- $M$ is the inertia matrix, symmetric and positive definite. It is equal to:

$$M = M_{rb} + M_a$$

Or, $M_{rb}$ and $M_a$ are previously determined.
- $C(\nu)$ is the vector of Coriolis forces and added water, defined as:

$$C(\nu) = C_{rb}(\nu) + C_a(\nu)$$

Or, $C_{rb}$ and $C_a$ are being the matrices as determined in the previous section.
- $D(\nu)$ is the matrix of damping coefficients. It is equal to:

$$D(\nu) = D_P(\nu) + D_t(\nu)$$

Or, $D_P$ and $D_t$ are respectively the lift and drag matrices also determined in the previous section.
- $\Gamma_g$ is the vector of forces and moments due to the action of gravity and buoyancy.
- $\Gamma_p$ gathers disruptions due to the environment, such effects due to sea currents, waves ... These phenomena are described in chapter 5.2.
- $\Gamma_u$ is the vector of forces and moments generated by the vehicle actuators. Hypothetically, let us assume that it is determined by adding the effects of each individual actuator (see chapter 5.2).

It is also possible to describe the vehicle model in the absolute frame:

$$M_n\ddot{n} = C_n(\nu,n)\dot{n} + D_n(\nu,n)\dot{n} + \Gamma_{ng} + \Gamma_{np} + \Gamma_{nu}$$

with the following relationships:

$$M_n = J_c^{-t}(n) M J_c^{-1}(n)$$

$$C_n(\nu, n) = J_c^{-t}(n) [C(\nu) - M J_c^{-1}(n) \dot{J}_c(n)] J_c^{-1}(n)$$

$$D_n(\nu, n) = J_c^{-t}(n) D(\nu) J_c^{-1}(n)$$

$$\Gamma_{ng}(n) = J_c^{-t}(n)\Gamma_g(n)$$

$$\Gamma_{np} = J_c^{-t}(n)\Gamma_p$$

$$\Gamma_{nu} = J_c^{-t}(n)\Gamma_u$$

Or,
- $n$ represents the position and orientation of the vehicle,
- $\nu$ is the vector overall speed,
- $J_c(n)$ is the mark of the transformation Jacobian vehicle inertial frame.

In order to validate the kinematic and dynamic modeling we presented in the next section the implementation of our architecture.

## 6. IMPLEMENTATION AND EXPERIENCES

The core capabilities of our architecture include modularity, encapsulation, scalability and parallel execution. Therefore, we decided to use multi-agent approach that naturally suits our needs encapsulation in independent modules, asynchronous and heterogeneous [11]. Communication between the agents is performed by messages. The C ++ language features with integration capabilities of agents is absolutely suitable for programming agents. We use threads to represent each agent in the global architecture process. The robot used in both indoor and outdoor experiences is a robot submarine Open Source (OpenROV) wire-guided and equipped with a mini-PC BEAGLEBONE Linux, a mini HD camera, three brushless motors with three propellers, etc. (See Fig.9).

We are in the final phase of the assembly robot submarine to implement our proposed architecture and perform simulations and real tests at the Computer Laboratory (LISER) of the School (ENSEM) (see Fig.10). These tests were conducted in remote operation mode to achieve the control in standalone mode.

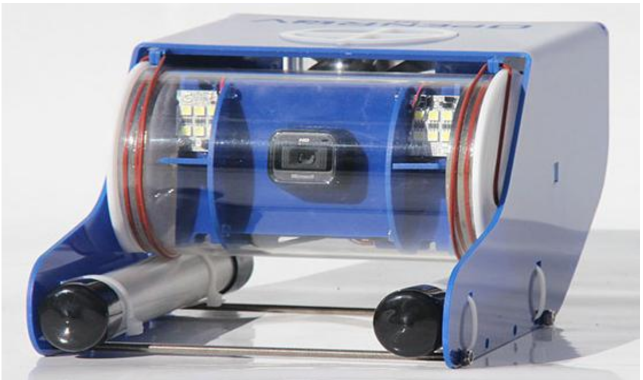


**Fig.9 : underwater vehicle OpenROV with mini HD camera**

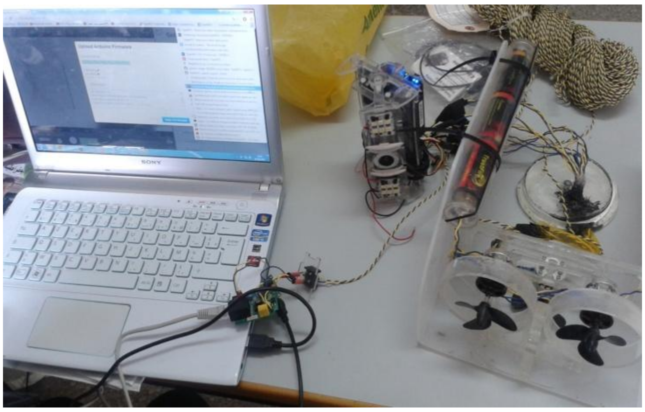


**Fig.10 : BEAGLEBONE configuration and camera OpenROV**

## 7. CONCLUSION AND PERSPECTIVES

In this paper, we presented our work focuses on the study and implementation of control architecture of a vehicle submarine torpedo. A state of the art on control architectures and multi-agent systems was presented.

This study allowed us to offer the first version of the architecture based multi-agent and modeling of underwater vehicle systems. the operation of various agents of this architecture will be developed and on the next step this one will be developed and deployed on a miniature submarine robot (OpenROV) to conduct a real simulation at sea.

## 8. REFERENCES

[1] S.J. Russell, P. Norvig. “Artificial Intelligence: A Modern Approach”. Englewood Cliffs, NJ: Prentice Hall, 1999.

[2] Dalgalarrondo, A. "Integration of perception function in an autonomous mobile robot control architecture" , PhD Thesis , University Paris-Sud , Orsay, France, 2001 .

[3] Sayouti, A. " Design and Realization of a Control Architecture in Via Internet Distance Based Multi -Agent Systems " . PhD thesis, ENSEM , University Hassan II, 2009 .

[4] Ferber, J. "The multi-agent systems " toward a collective intelligence (Paris, InterEditions 1995).

[5] H. S. Nwana. “Software Agents: An Overview”. Knowledge Engineering Review, 1996.

[6] Sayouti, A. Medromi, H. “Chapter Title: Autonomous and Intelligent Mobile Systems based on Multi-Agent Systems, Book Title: Multi-Agent Systems - Modeling, Control, Programming, Simulations and Applications”, INTECH, http://www.intechweb.org, 2011.

[7] Sayouti, A., Medromi, H. “Multi-Agents Systems for Remote Control on Internet”, International Journal of Applied Information Systems (IJAIS), USA, July, 2012.

[8] A. Hentout, B. Bouzouia and Z. Toukal. “Multi-agent Architecture Model for Driving Mobile Manipulator Robots”, *International Journal of Advanced Robotic Systems, CDTA, Algeria, 2008*.

[9] Arnaud Degroote . " A distributed control architecture for the autonomy of robots" , PhD , Institut National Polytechnique de Toulouse ( INP Toulouse) , France , October, 2012 .

[10] Isabelle LEONARD. " Recognition of manufactured objects in underwater videos ", PhD thesis, University of Western Brittany , Brest, France , in September 2012 .

[11] Ahmed Benzerrouk. " Hybrid control architectures for mobile multi-robot systems," PhD thesis, Université Blaise Pascal, Clermont II , France , February 2012.

[12] Novales, C., Mourioux, G., Poisson, G. “A multilevel architecture controlling robots from autonomy to teleoperation”, Proceedings of the First National Workshop on Control Architectures of Robots. Montpellier (Year of Publication: 2006).

[13] Inaya Lahoud. " A multi-agent system for the management of heterogeneous and distributed knowledge. " PhD thesis, University of Technology of Belfort- Montbéliard, France, 2013.

[14] Jean-Mathias SPIEWAK. "Contribution to the coordination of vehicle fleet autonomous underwater", PhD thesis, University of Montpellier II, France , September 2007.

[15] Jawhar Ghommam. "Nonlinear Control and navigation of watercraft underactuated". Automatic. National Engineering School of Sfax, France, January 2008.