Four propellers architecture proposed for the Submarine Drone

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Abstract - *The use of underwater vehicles, which was once an option, has become a necessity in many cases such as research, mapping or monitoring of sea depths. Also, the hostility of the underwater environment made these missions more difficult and more expensive, even impossible in certain cases. The use of these mobile robots offered a very advantageous alternative compared to Human intervention and often more to what the mission requires* [1].

Architectural and control solutions generally optimized the choice of these machines. In this paper, we will focus first on the history of the main underwater devices and on the architecture of our machine, which will draw from the maneuverability of aerial drones with four rotors for its evolution in the marine environment; what will be the object of this work and also to study after the behavior of this robot with this type of propulsion by modeling and simulation[2]*.*

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)

Key Words: Mobile robot, underwater vehicle, Propellers, Modelling, Simulation, command thrusters, Propellers arrangement.

1. INTRODUCTION

Underwater vehicles have become increasingly present in many areas related to the seabed. They are used in both the civilian and military sectors, starting with the oil industry and marine cartography and going through the rescue and mine search [3].

Several models and technologies of these machines were appeared, at their beginning, they were remote controlled with the humane presence in the chain of decision, after they created autonomous variants AUVs (Autonomous Underwater Vehicles) which filled the limitations of Remotely Operating Vehicles (ROVs) [4]. All these submersibles have been able to assert their importance and consolidate their position as an indispensable tool to avoid endangering humans and to reduce operating costs by automating some repetitive or reduced-decision tasks in relation to the fields aforementioned.

This article is organized as follows: After an introduction in the first Section, the classification of underwater vehicles is presented in Section 2. The state of the art is set out in Section 3. Section 4 presents the proposed submarine model inspired from the drone. Section 5 "Study of propulsion configurations" describes and compares the propellers configurations. The conclusion is given in the last section.

2. UNDERWATER VEHICLES CLASSIFICATION

"Underwater Vehicle" refers to any craft that can navigate below the surface of the water. There are several variations of these machines [5] and are classified according to several criteria depending on:

• Their energy or decision autonomies,

• Their range action or operational depth,

• Their dimensions or architectures,

• Their propulsion mode,

• The nature of the missions to be performed,

• Whether they are occupied by humans or not occupied.

In this part, we will present a classification according to the decisional autonomy.

2.1 Human Operated Vehicle

All type of vehicle whose human factor appears in the control chain [6], such as:

• HOS or HOV (Human Occupied Submersible / Vehicle): totally controlled by an on-board pilot, it can also contain more researchers. It is equipped with high-definition cameras, projectors and robotic arms to collect bottom samples and marine wildlife. Therefore, this category also includes military submarines.

• ROV (Remotely Operated Vehicle). With no crew, it is totally remote controlled from the surface by a series of cables, it can have the same equipment as the HOS and can perform similar missions and reach greater depths.

• UUV (Untethered Underwater Vehicle): it is a gear operating without attachment to the surface, but there is an acoustic link between the surface and the submarine to allow control and data exchange.

2.2 Autonomous Underwater Vehicle

The Autonomous Underwater Vehicle (AUV) can operate completely without human control, which is important during long-term or repeated missions. They can, according to the implemented program, follow a race or interact with the environment to make their own decisions [7]; for example:

• AUG (Autonomous Underwater Gliders): is distinguished by the ability to use ballasts for diving and wings to glide under the surface of the water for long-term missions (Fig. 1).
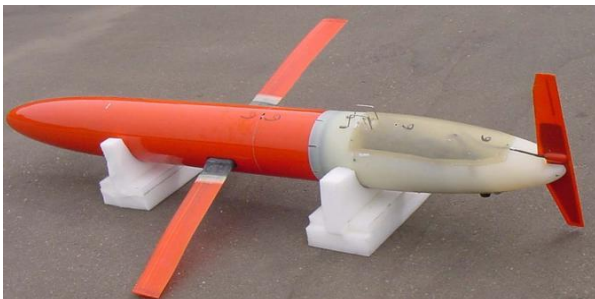

Figure 1: Spray Glider (Bluefin Robotics)

• BUVs (Biomimetic Underwater Vehicles): They are distinguished by their resemblance to living creatures that have been inspired for their way of moving.

• Micro Autonomous Vehicles (MUVs): a very important variant of AUVs, they find their applications in the military sector for recognition missions, anti-submarine warfare or mine search and can also be used to inspect submarine pipelines. [8].

3. STATE OF THE ART

Several submarine propulsion processes and architectures are used and have become standards in this field. They are generally based on one or more propellers combined with rudders and dive bars to ensure the evolution of the submersible in surface and in diving.

Many forms of outer hulls are made. The most known is the shape of the torpedo, it is aerodynamic and intended to reach relatively high speeds compared to other existing forms. The other solutions are far from common and so diversified that they cannot be classified according to a clearly distinct form, they generally obey the mission to be carried out and the technological solution available and sometimes to the imagination of the engineers [9].

Some examples of the most answered forms of underwater robots are:

• « AsterX » robot

Figure 2: AsterX (IFERMER)

The robot "AsterX" is an autonomous underwater vehicle dedicated to scientific recognition, can reach a depth of 2800m [6].

• Victor 6000.

Figure 3: Victor 6000 (IFERMER)

Ifremer's ROV is a teleoperated submarine robot that can work up to 6000 m deep for several days [6].

• Tuna robot

Figure 4: Tuna robot (M.I.T)

The autonomous underwater robot tuna, was chosen as a model for its speed and accelerations [4].

Vehicle	Depth (m)	Institution	Manufacturer
Hyperdolphin	3000	JAMSTEC[a]	ISE
Dolphin 3K	3000	JAMSTEC	JAMSTEC
Quest	4000	MARUM[b]	Shilling
Tiburon	4000	MBARI[c]	MBARI
ROPOS	5000	CSSF[d]	ISE
Victor	6000	IFREMER[e]	IFREMER
Jason	6500	WHOI[f]	WHOI
ISIS	6500	NOC[g]	WHOI
UROV 7K	7000	JAMSTEC	JAMSTEC
Kaiko	11000	JAMSTEC	JAMSTEC

Table 1: ROVs for scientific use. [10].

Architectural and control solutions optimized the choice of these machines. The solution proposed in this study is an original architecture inspired from the aerial drones that have recently emerged with their four or six rotors offering unmatched aerial surveillance capabilities.

4. PROPOSED MODEL

Conventional propulsion systems usually consist of a rear propulsion unit, one or more shaft lines coupled with propellers. The power developed by the propeller with fixed or controllable pitch is directed by rudders to control the direction of this thrust. The tunnel thruster that is also answered, looks like a tunnel with a propeller inside that produces a transverse force with direction fixed or steerable according to the architecture of the tunnel. [11]

This section presents the realization of a submersible with four propellers and without rudders or dive bars, using the drone's resources for its evolution in the aquatic environment.

This model has several advantages starting with the aerodynamic aspect, as there will be no protruding parts that will impede the flow. then the absence of rudders and dive bars will present a significant saving in energy, space and control system and especially will help avoid sealing problems. Also note that the ROV will gain speed and manoeuvrability especially the static. Finally, in case of failure of one engine, the others can compensate for this defect[12].

The proposed model must take into account the following general conditions:

• Use drone technologies for this submersible,

• Like any conventional submarine, it will need a ballast for any static dive,

• At least three immersed propellers are required for a dynamic dive,

• If needed, a weight compensator will be is installed in the rear to compensate the weight of the front and thus balance the submersible.

4.1 Architectural Solution

The underwater vehicle must navigate on the surface and under the water level, also dive and rise to the surface. But, without the help of rudders, the evolution of the submersible in its environment is totally "blind". The idea that is already used as rescue means by the old navies in ships with two lines of propulsion, is to unbalance the thrust of one of the two propellers to turn in one direction or the other.

The same three-dimensional generalized principle is otherwise used by aerial drones. Once enslaved by a control card, it allowed the drones to perform spectacular aerial flight by the effect of the controlled imbalance of the thrusts of the rotors.

The use of this propulsion solution and its application to underwater vehicles is by no means accidental, because it offers several advantages acquired by aerial drones [13]. But above all, we must overcome the incompatibilities of forms and environments that differentiate the two machines.

Below, we will present some advantages and difficulties of using drone's technology:

• Advantages:

- Already experienced and functional solution;

- Great maneuverability;

- Increased speed;

- Absence of the rudders.

- Wide range of hardware and software tools available for adaptation;

• Difficulties:

- Rotors vertical plan;

- Sensors not adapted to the aquatic environment;

- Weight distribution;

- Hull waterproofing;

- Very unfavorable environment (corrosion, short circuit, fluid resistance);

In the next section, we will propose a solution to resolve the difficulties cited above. This solution is based on propellers arrangement.
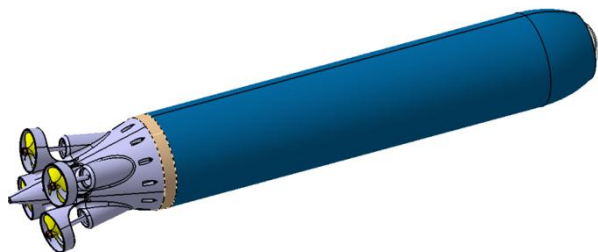

Figure 5: Isometric view

4.2 Propellers arrangement

On a conventional aerial drone, the rotors are placed horizontally, however on this drone they will be placed vertically, and like all floats, the submarine must take a fixed initial position that will be its static stability position, with the use of four rotors two main configurations of the propellers are required (view of the rear of the submarine):
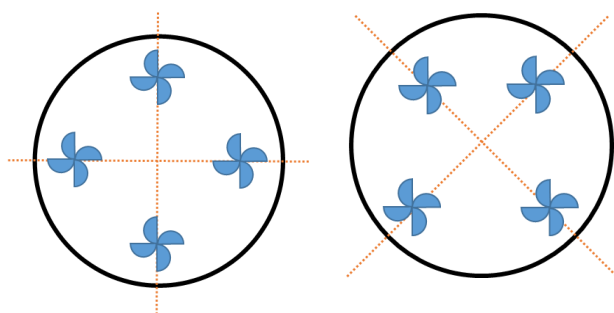
"+" Propellers;   **"×" propellers;**

Propulsion configurations Study will be developed in the next section.

5. PROPULSION CONFIGURATIONS STUDY

Choosing one of the configurations will directly affect:

• The control sequence of the propellers,

• The initial immersion ratio,

• The speed of immersion.

5.1 Waterline with Initial Immersion Ratio

Based on the fact that the only propellers will provide surface navigation and submarine diving, they must be immersed to produce the thrust required to operate the craft.
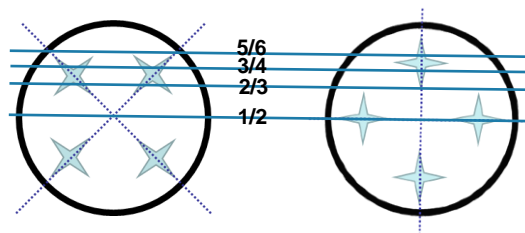

Figure 6: Different waterlines

This figure shows the rear of the submarine according to the two possible propeller arrangements with the important immersion ratios schematized by different waterlines:

Table2: Effective propellers.

Configuration	« × »	« + »
Line $^1/_2$	2	1
Line $^2/_3$	2	3
Line $^3/_4$	4	3
Line $^5/_6$	4	4

The table above shows the number of effective propellers able to producing thrust.

5.2 Advantages and disadvantages of the two configurations

The advantages of each configuration are presented below:

Table3: Configuration advantages.

In "×"	- Low ratio for surface navigation.
	- Most power for manoeuvring.
	- Classic propeller layout in surface navigation
In "+"	- Diving is possible with 3 propellers.
	- Surface manoeuvring from line 2/3 of immersion.
	- Relatively low immersion ratio for diving

The disadvantages of each configuration are presented below:

Table4: Configuration Disadvantages.

In "×"	- Large immersion ratio for diving.
	- Requires 4 propellers for diving,
	- Low spacing of propellers for surface

	manoeuvring.
In "+"	- Large immersion ratio for navigation. - Minimum 3 propellers for surface navigation. - Minimum 2/3 Ratio for the surface manoeuvre.

6. CONCLUSION AND PROSPECTS

According to the Comparison of the two tables above, the "×" arrangement seems to be a very good compromise in that, with this configuration, the ROV has the powerful difference of the thrusters and from the 3/4 line the four propellers are practically usable.
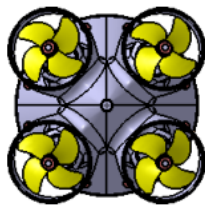

Figure 7: back view "x" configuration

In the next study we will approach the kinematic and dynamic study of the ROV to move on to the simulation part.

Figure 8: Prototype realization

REFERENCES

[1] Russell B. Wynn, Veerle A.I. Huvenne, Timothy P. Le Bas, Bramley J. Murton, Douglas P. Connelly, Brian J. Bett a, Henry A. Ruhl, Kirsty J. Morris, J. Peakall, Daniel R. Parsons, Esther J. Sumner, Stephen E. Darby, Robert M. Dorrell, James E. Hunt, Autonomous Underwater Vehicles (AUVs): Their past, present and future contributions to the advancement of marine geoscience, Marine Geology, Vol. 352, 2014.

[2] E. Miftah, A. Sayouti, H. Medromi, Multi-agent Systems and its Application to Control Vehicle Underwater, International Journal of Applied Information Systems, Vol. 9, n. 7, September 2015.

[3] A. HATTAB, Modélisation et commande robuste d'un robot, Ph.D. Thesis, Dept. Electrotechnique, Université des Sciences et de la Technologie d'Oran Mohamed Boudiaf, Alger Oran,2016.

[4] A. KHADHRAOUI, ''Modélisation et simulation interactive pour la navigation d'un robot sous-marin de type ROV Observer'' Ph.D. Thesis, Dept. Sciences et technologies de l'information et de la communication, Université Paris-Saclay, Paris, France, 2015.

[5] B. S. Seifallah, Conception d'un algorithme decoordination hybride de groupes de robots sous-marins communicants, Ph.D. Thesis, Ecole Doctorale Santé, Information, Communications, Mathématiques, Matière, Université De Bretagne Occidentale, Brest, France, 2016.

[6] P. Van Rie, Les Sous-Marins Autonomes, EPMI ecole d'ingenieurs, Rapport de TIPE - 2005/2006.

[7] V. CREUZE, B. JOUVENCEL, Seabed perception and following for autonomous underwater vehicles, Traitement du Signal, Vol. 20, n. 4, 2003.

[8] N. BOËLY, Modélisation non linéaire et contrôle linéaire par retour entrée-sortie linéarisant d'un drone sous-marin quadri hélices à poussée vectorielle, école de technologie supérieure, university of Québec, Montreal, MAI 2010.

[9] V. CREUZE, Robots marins et sous-marins - Perception, modélisation, commande, Techniques de l'Ingénieur, 2014.

[10] B.Siciliano, O. Khatib, Springer Handbook of Robotics, Springer-Verlag Berlin Heidelberg Deutschland 2008

[11] Asgeir J. Sorense, Marine Control Systems: Propulsion and Motion Control of Ships and Ocean Structures, Department of Marine Technology, Norwegian University of Science and Technology, Report UK-13-76, 2013.

[12] M. Moustanir, K. Benkirane, A. Sayouti, H. Medromi, Submarine Drone, First Edition of the Doctoral Days on Engineering Science ENSEM, Hassan II University of Casablanca May 2018.

[13] M. MOUSSID, A SAYOUTI, H. MEDROUMI, Dynamic Modeling and Control of a HexaRotor using Linear and Nonlinear Methods, International Journal of Applied Information Systems, Vol. 9, n. 5, August 2015.

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