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# Overview on ARC Unmanned Surface Vehicles

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*ABSTRACT*

Unmanned naval vehicles, surface (USV), submarines (UUV), and aerial (UAV) for military operations are appearing in an exponential way, making the actual warships designs, based on multi-mission spaces, to obtain modular capabilities and specific spaces to launch and recover them quickly, while these operations are developing. Focusing on the USV, its use extends to operations as diverse as the perimeter defense of the ship or the fleet, search and clearance of routes, anti-submarine warfare based on towed sonars, support to marine forces, environmental monitoring, seabed mapping, R&D in robotics, infrastructures inspection, electronic warfare and information, ISTAR tasks of intelligence, surveillance and reconnaissance, operations against piracy and illegal traffic, communications relay, etc. It is understandable that the different Armed Forces, such as that of Colombian navy (ARC) are making budgetary efforts to equip themselves with these vehicles. Throughout this paper, the aim is to describe the technological developments carried out by the research groups Naval Design and Engineering Program (PRODIN) of COTECMAR shipyard, and the Naval Control, Communications and Design Research group (GICCDN) of ENAP University.



## 1. Introduction.

The current global security context (Ballesteros, 2012). can be characterized by being involved in a series of complex conflicts (Alvargonzález, 2012) where the ability and speed to adapt to new circumstances is a key element, which has led USVs to gain a deserved prominence in the different operations despite the inherent difficulties in the environment in which they operate (meteorological conditions, communications, logistics, positioning, autonomy...).

The different navies (U.S. Navy, 2006a) have opted, as shown in Fig. 1, on these unmanned vehicles in the performance of tasks that have been considered too dangerous for their manned ships, mainly associated with high-risk missions, such as the tracking or detection and mines neutralization (U.S. Navy, 2006b). And also, because if an operation can be carried out by a USV, saving to move a ship to the objective and its costs, so the Navy logistics (Clark, 2002) see the USVs as a reduction in operating expenses. Both factors show the actual interest in the acquisition of this equipment in all of them.

This type of vehicle is, once again, an example of how scientific-technological knowledge is rapidly incorporated into the systems of the dual civil-military world (Marketwatch, 2021), and how the necessary synergies between defense and security applications are developed in the military and civil spheres (Riola, 2011; Orenes, 2012). In the civil field, we can cite already common jobs for the surveillance of critical infrastructures in ports, infrastructures installed on the seabed, floating offshore platforms, gas pipelines, electrical cables, fiber optic cables, etc. With the same idea applied to the development of USV control, we should highlight the gyroscopic needle and the positioning systems for electromagnetic and acoustic signals (Kayton, 1990).

The movements of a USV have greater complexity than its counterparts on land or air platforms, due to the fact that it acts between two fluids, air and water, so in addition to the dynamic equations of a rigid solid, it is necessary to add the different hydrodynamic phenomena that can affect it, and which in turn

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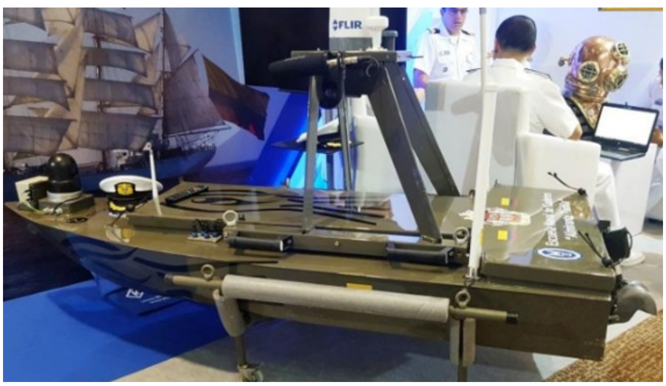
depend on the different environment variables such shallow waters navigation, obstacle proximity, confined space confined or working in a swarm. In any case, when studying it theoretically we always begin to consider it in the ideal conditions of an infinite fluid to which we will impose boundary conditions that facilitate its development, such as considering working with USV speeds below 45 or 50 knots, trying to avoid the frequent phenomenon of cavitation (González-Adalid, 2005).

Figure 1: ENAP-COTECMAR USV.




Source: ENAP.

Mathematically, to define a USV, we usually start using the equations proposed by Kirchoff, for example in the quote by Gutiérrez et al (2014), which presents the variables f and M as force and moment of a solid movement in a fluid without friction, its linear and angular velocities being represented by the variables v and w respect to an inertial system considered if the letter T represents kinetic energy. This results in the following expressions:

The dynamic equations are presented in vector form:

$$f = \frac{d}{dt}\frac{\partial T}{\partial v} + w\frac{\partial T}{\partial v} \tag{1}$$

$$M = \frac{d}{dt}\frac{\partial T}{\partial w} + w\frac{\partial T}{\partial w} + v\frac{\partial T}{\partial v} \tag{2}$$

The kinetic energy T can be presented in its form:

$$T(v, w) = \frac{1}{2}v^T M v \tag{3}$$

The dynamic equations are presented in vector form:

$$Mv + C(v)v = \tau \tag{4}$$

M can be expressed as a symmetric matrix and C, and according to Fossen (2002), to include the centripetal and Coriolis acceleration. It can be written as an antisymmetric matrix by matching the center of the reference system with the center of gravity of the USV, considering the value m as its mass and Jg as the inertia matrix of the vehicle with respect to its center of gravity:

$$M = \begin{bmatrix} mI_{3x3} & 0_{3x3} \\ 0_{3x3} & J_g \end{bmatrix} \tag{5}$$

Specifically, in order to take into account all external forces and moments that would affect the USV, we should consider the hydrostatic and hydrodynamic forces, particularly those caused by the different navigation appendages such as rudders, keels and flaps, in addition to the propulsive own actuators and the forces induced by waves, current and wind. When talking specifically about the control of these ships, Elmer Sperry (1911) is often cited, who in 1914 launched an autopilot system based on his gyroscopic patent and Nicolás Minosky (1922) with his proportional, integral and derivative (PID) controls.

Basically, the control is composed of 3 systems: guidance, navigation and control. The guidance system continuously provides the control system with the necessary references to be able to carry out a route, containing the limitations and characteristics of the USV. This system receives information from the navigation system and meteorological variables such as drift, waves, geolocation data, reference points, etc. The control system is also usually made up of 3 sub-systems: central controller, state observer and system for distributing the forces in the actuators.

The propulsion of the USV usually works with one or two shafts and their corresponding propellers or waterjets which permit excellent maneuvering. It can also consist of azimuth impellers and any other type of appendage, such as stabilizer fins, which will determine the possible movements and the different and constant needs of the control system. An example is the use of azimuth thrusters if we want to achieve adequate dynamic positioning but that is not useful if we want high-speed performance.

The autopilot is in charge of getting the established route defined in a plane and gives the control signals of the rudder or its equivalent in the steerable waterjets to achieve both the heading and the engine revolutions that offer the speed you need to achieve. Thus, the autopilots control the course of the USV, as its changes, with respect to an angle that the speed vector at which it is ordered to maintain, a geographical axis, some reference points on the plane that it must reach, a certain route that has to be traced and also achieve the appropriate speed to arriving at the right time, stays at constant speed or decreases according to the operation convenience.

As first control steps, the usual PIDs usually have sensors that report heading and speed, and that by comparison with the desired values for their heading, speed and acceleration, which includes the state observer, the filter of movement induced by the swell and the feedback of heading, wind function as a mechanism of adaptation to the environment. In addition, they usually have an action proportional to the acceleration of the heading angle to increase the vehicle inertia and minimize the disturbances.

In this control area developments, we can cite authors as van Ameroengen (1984) with his adaptive autopilot model, Källström et al (1981) with his self-tuning heading regulator and a Kalman filter, and Fossen (2002) with non-linear models with linearization techniques by feedback, Girón et al (2011) with an iterative method based on CFD data to obtain the effects in the domain of frequencies to decrease pitch, yaw and balance, Zhang et al (1998) with neural networks, Esteban (2000) and

Aranda (2004) with the control for damping of movements and Velasco et al (2010) that works the hydrodynamics of UUV and USV for its application in the academy.

## 2. Plan 2042.

The ARC has presented in November 2020, the Naval Development Plan 2042 (Armada Nacional, 2021) (Fig. 2) as an implementation guide linked to its vision and strategic objectives. The 4.0 technologies possibilities offer for the development of these vehicles is exposed literally "*The fourth industrial revolution, defined as the process in which intelligent devices will replace humans in the roles of administration, optimization and control of machinery also applies to the maritime sector, specifically, in the emergence of intelligent ships that will bring the next great technological revolution in the shipping world*". And "*a direct consequence of this technological development will be the emergence of fully automated ships, which do not need human crew on board, and whose control is carried out remotely on land.*"

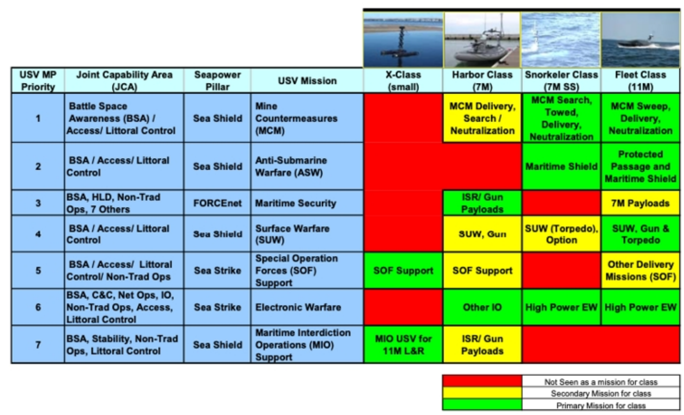
Figure 2: Plan de Desarrollo Naval 2042.


Source: ARC.

Internationally, the great technological USV programs carried out by USA and EU stand out. It published in 2006 the USV Navy Master Plan (Fig. 3) and Navy Large Unmanned Surface and Undersea Vehicles: Background and Issues for Congress and also the Unmanned Maritime Systems (UMS) (Riola and Díaz, 2011) program of the European Defense Agency (EDA) in 2010.

A good conclusion of the US Navy work is the need to have different types and sizes of USV for their different operational uses, presenting from disposable vehicles of little bit more than one meter, as are necessary in anti-mine operations, in which the USV to detect the mine, identifies and impacts causing the explosion, even the USV of electronic warfare, with a very sophisticated and bulky equipment, which seems not will be below of 11 meters in length.

Figure 3: Missions/lengths.



| USV MP Priority | Joint Capability Area (JCA) | Seapower Pillar | USV Mission | X-Class (small) | Harbor Class (7M) | Snorkeler Class (7M SS) | Fleet Class (11M) |
|---|---|---|---|---|---|---|---|
| 1 | Battle Space Awareness (BSA) / Access/ Littoral Control | Sea Shield | Mine Countermeasures (MCM) | | MCM Delivery, Search / Neutralization | MCM Search, Towed, Delivery, Neutralization | MCM Sweep, Delivery, Neutralization |
| 2 | BSA / Access/ Littoral Control | Sea Shield | Anti-Submarine Warfare (ASW) | | | Maritime Shield | Protected Passage and Maritime Shield |
| 3 | BSA, HLD, Non-Trad Ops, 7 Others | FORCEnet | Maritime Security | | ISR/ Gun Payloads | | 7M Payloads |
| 4 | BSA / Access/ Littoral Control | Sea Shield | Surface Warfare (SUW) | | SUW, Gun | SUW (Torpedo), Option | SUW, Gun & Torpedo |
| 5 | BSA / Access/ Littoral Control/ Non-Trad Ops | Sea Strike | Special Operation Forces (SOF) Support | SOF Support | SOF Support | | Other Delivery Missions (SOF) |
| 6 | BSA, C&C, Net Ops, IO, Non-Trad Ops, Access, Littoral Control | Sea Strike | Electronic Warfare | | Other IO | High Power EW | High Power EW |
| 7 | BSA, Stability, Non-Trad Ops, Littoral Control | Sea Shield | Maritime Interdiction Operations (MIO) Support | MIO USV for 11M L&R | ISR/ Gun Payloads | | |

| | |
|---|---|
| (red) | Not Seen as a mission for class |
| (yellow) | Secondary Mission for class |
| (green) | Primary Mission for class |

Source: US Navy.

Regarding the EDA UMS program, a total of 14 technological R&D programs were developed within it (De Miguel, 2012). The main objective was to improve European operational capabilities in a wide number of naval tactical applications through the use of USV and UUV, providing conditions of standardization, interoperability and modularity to their designs, and also addressing aspects related to regulations of military applications. This program addressed various areas such as sensors, platforms, communications, command and control, launch and recovery systems, simulation, standards, etc., and that included as main projects:

1. Network Enabled Cooperation System of Autonomous Vehicles (NECSAVE) - Develop and evaluate tools and methodologies related to swarm technologies (swarms) of unmanned naval vehicles under the NEC philosophy (Fig. 4).

2. Systems Integration (SI) - Examine technologies for systems integration.

3. Standard and interfaces for more interoperable European Unmanned Maritime Svstems (STANDIN) - Addresses interoperability problems, under the aspects of standardization and modularity.

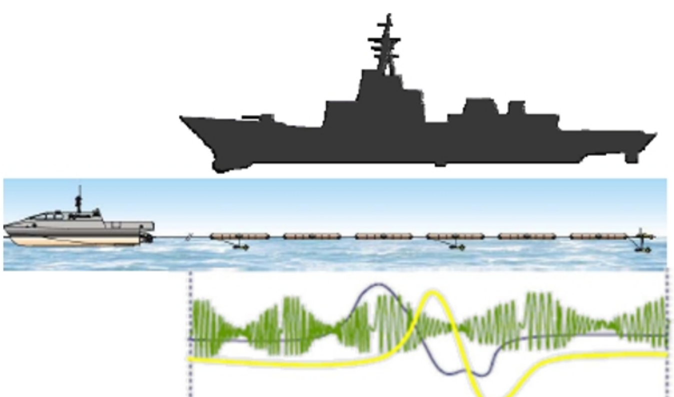
4. Signature Response Analysis of Multi-influence Mines (SIRAMIS) - Response and emulation of influence signals.

Figure 4: UXVs net operation concept.

Source: EDA.

Due to its technological interest and directly focused on the operational capacity of "stelth", the UMS project entitled Remote Control Influence Mine Tracking System (Fig. 5) has the objective to develop a prototype of a mine tracking system can be highlighted of influence (magnetic, acoustic, electrical, and any combination of them) by remote control.

Figure 5: Tracking System.



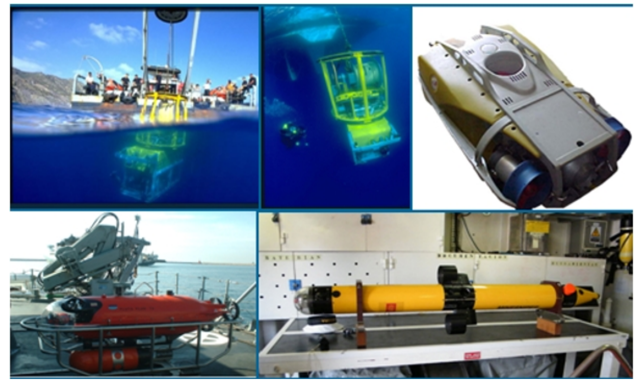
Source: MDE.

The naval interest has been expressing in various forums the need to have a great number of these unmanned platforms, USVs or Remote Operated Vehicles (ROVs), for example, SCORPIO and NAVAJO in security and submarines rescue missions at great depth or PLUTO and MINESNIPER in the location, identification and neutralization of mines (Fig. 6).

### 3. R&D programs.

As an example of the interest that these media arouse for the ARC and the Ministry of Science, Technology and Innovation (Minciencias), the following R&D programs have been selected in their respective calls for Francisco José de Caldas program can be cited: "*Development of the navigation control system for unmanned surface vehicles SABALO (Fig. 7) for*

Figure 6: USVs & ROVs.



Source: MDE.

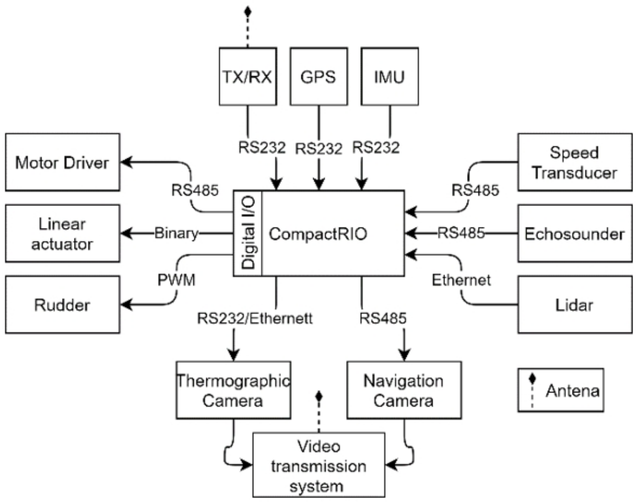
*its implementation in maritime and river patrol operations" in 2018 and "Development of a technology demonstrator (TRL5) for the unmanned surface vehicle for the Strategic Surface Platform (PES), focused on the system of communications and its integration with the navigation control developed by ENAP for its future implementation in the USV of the PES*" in 2019.

Figure 7: SÁBALO prototype.

Source: ENAP.

These programs have a wide academic representation and whose objective is to develop, acquire capacities and show the national naval advances of unmanned surface vehicles, and to disseminate the knowledge into national research sector. An example of this is presented in Fig. 8 with the results obtained is the USV general scheme.

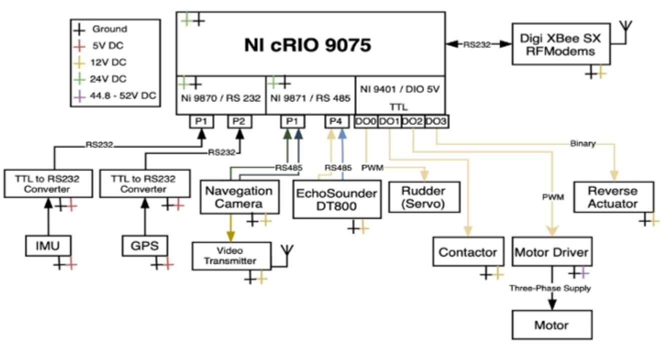
Figure 8: SÁBALO general scheme.




Source: ENAP.

A more detailed schematic of the National Instruments driver used in this USV prototype is also presented in Fig. 9:

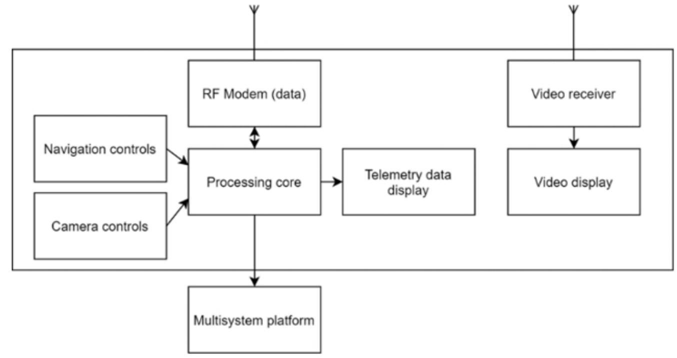
Figure 9: SÁBALO detailed scheme.




Source: ENAP.

Once the first project was completed, the program continued with the development of a technology demonstrator (TRL5) for a USV for the Strategic Surface Platform (PES), focused on the communications system and its integration with the control of navigation developed by ENAP. Actually, the system contains the LINK-CO naval tactical network and an encrypted communications system that allows the transmission of data and information from different platforms to the network in order to create a common tactical panorama that allows the conduct of operations in a more effective and efficient way. The research project is looking for the adaptation capabilities already developed for LINK-CO and for navigation control, so that they can be integrated into a demonstrator that sets the technological base for the USV prototype. The following Fig. 10 shows the basic preliminary diagram of the control station:

Figure 10: SÁBALO control station.




Source: ENAP.

## 4. Figures, Tables y Equations.

The alliance ENAP-COTECMAR considers the maritime aggressive environment in which these systems must operate. Due to this, the first technological challenges to be faced are those associated with communications, especially when USVs must transmit underwater, being necessary to optimize the data transmission speed and conditions. We can highlight the NATO-BRASS Broadcast and Ship-Shore system (Rhode-Schwarz, 20-18), an automatic process system that allows the NATO HF maritime Communications centers to establish control and management of communication resources between the commands and their Forces deployed through services such as broadcast, ship-shore, and maritime real link.

Another technological challenge is associated with the development of obstacle avoidance algorithms, such as the one developed for the C'inspector by the University of Cantabria (Riola, Velasco, and Revestido, 2017; López et al., 2004) (Fig. 11) sailing on the surface, since an effective route planner in scenarios with obstacles it may be too slow when they increase. Nowadays, there are route planners that require a complicated preparatory phase, but once executed, the calculation of a valid trajectory is immediate, even if the starting and ending points are varied. If we add the kinematic or dynamic restrictions to this operation in the marine environment the problem becomes more complex, since obstacles that varying their position over time, requiring adaptation of the initially calculated trajectory.

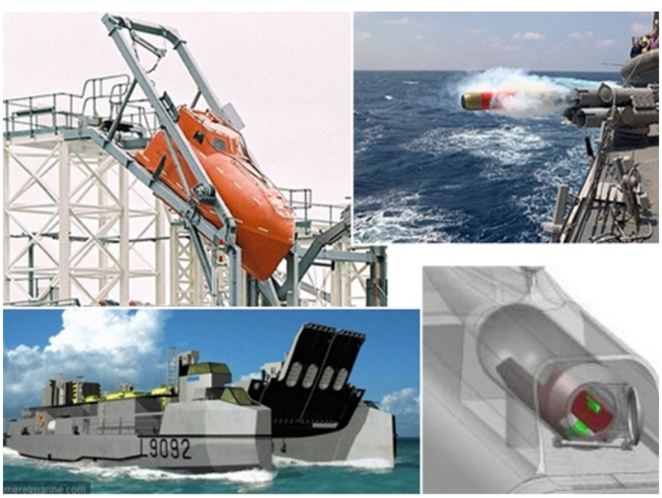
Figure 11: UUV sailing.

Source: Unican.

In the dynamic positioning (Moreu, 2020; UST 2020) maneuvering the USV must autonomously maintain position and heading with its own propulsion system. It must be connected to different position reference sensors combined with wind, current, gyrocompass or inertial boxes that feed precise information to the navigation system, anticipating the magnitude and direction of the environmental forces that affecting its position.

Another critical issue is the launching and recovering vehicles (Chen et al., 2018) from ships (Figure 12) in which speed and safety must prevail. Today the widely maneuver is launching by gravity, launching through an opening in the hull, a structural ramp in the ship, torpedo tubes, catapult, cranes, davits, pressure chamber, etc. When thinking about how an unmanned vehicle should be launched and picked up, we must take into account certain factors that will delimit the options, such as (Fig. 13): speed, weight, size or volume, ruggedization… It is important to consider the control of noise and vibration (Riola et al, 2019) from the beginning of the design. And this will be more complicated in the near future with the development of the theory of automation and control known as swarms (Cuevas et al., 2018).

Figure 12: Launch systems.

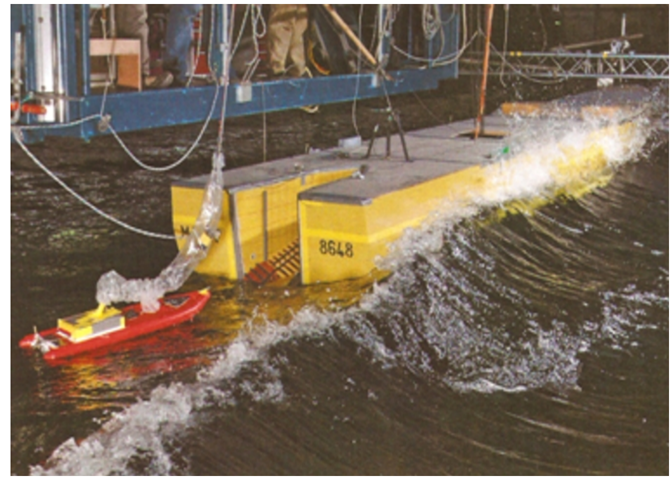


Source: EMSA.

And finally, with the idea of reducing the cost of the life cycle (Fernández Jove et al, 2019), it's necessary to carry out R & D programs for the development of new generation and storage systems of energy that provide a greater autonomy of the USV operation.

Hydrogen technology is widely considered (Álvarez and Martínez, 2018) one of the most promising in the USV, so in this area the works are being done mainly in fuel cells, although today there are great limitations due to the storage space needs of the reagents. They have important advantages over others such as the non-use of moving parts, their high efficiency, low noise emission, low polluting emissions, adaptability… (Fig. 14). The use of hydrogen has important environmental and economic benefits, once its production, storage, transport, distribution and use costs have been reduced. It is emphasized that for the production of hydrogen to be free of polluting emissions,

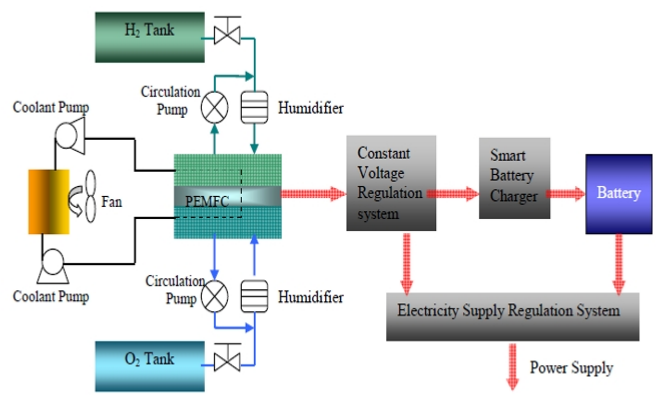
Figure 13: Hydrodynamics testing on waves.



Source: CEHIPAR.

this will only happen if the energy used in the production process comes from renewable energies.

Figure 14: Fuel cell-based system architecture.




Source: JALVASUB.

**Conclusions.**

- The Sábalo prototype presents the requirements of the ARC needs and its performance continues to improve with the different R&D projects underway. ENAP and COTECMAR have a strong research alliance to continue the development of the USVs.

- Developing technologies will allow the USV will have greater autonomy, automatic target recognition, obstacle and collision prevention, automated target recognition, increased payloads and attached weapons, improvements in launch and recovery to the ship and hydrodynamic, mechanical and electrical improvements.

- The hydrogen economy is reaching a sufficient degree of maturity to be able to compete with the economy based on fossil fuels whose massive use generates large amounts of carbon dioxide (CO2), and sulfur oxides (SOx) and nitrogen (NOx), that get trapped in our atmosphere. The use of hydrogen as an energy vector reduces the emissions of polluting substances and is presented as a solution to the propulsion of the USV.The figures and tables must be original, that is they must not be copies of other publications, but are rather devised by the authors themselves. If it is indispensable to copy, reference must be made to the authorship.

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