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# Autonomous Underwater Vehicles - achievements and current trends

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**Abstract**. The field of underwater robotics has reached an impressive technological momentum over the past decades by merging areas such as electrical, mechanical and systems engineering. A particular interest is presented by autonomous underwater vehicles (AUV), given the progress in the implementation of revolutionary technologies to overcome the challenges associated with autonomous operation in the underwater environment. The purpose of this paper is to present a synthesis of what has been achieved so far with regard to AUVs, from the factors and conditions that underlie their operation on issues related to different models and implemented technologies, up to current development trends.

## 1. Introduction

As soon as Romania joined NATO in 2004 the national defence strategy from the perspective of foreign policy stated that one of our country's national security objectives is ensuring security in the Black Sea region. Lately, the Black Sea region is a priority on the international agenda and is considered both a strategic and sensitive area due to the three principal actors that influence security policies in the region. In the maritime security issues NATO started to implement the concept of unmanned underwater vehicles (UUVs) as part of ensuring its maritime borders security policy. Some of the most common military applications for AUVs are mine countermeasure (MCM), antisubmarine warfare (ASW) and harbor protection. A chart regarding the global AUV demand by sector for from 2011 and forecast to 2020 is presented In Figure 1.

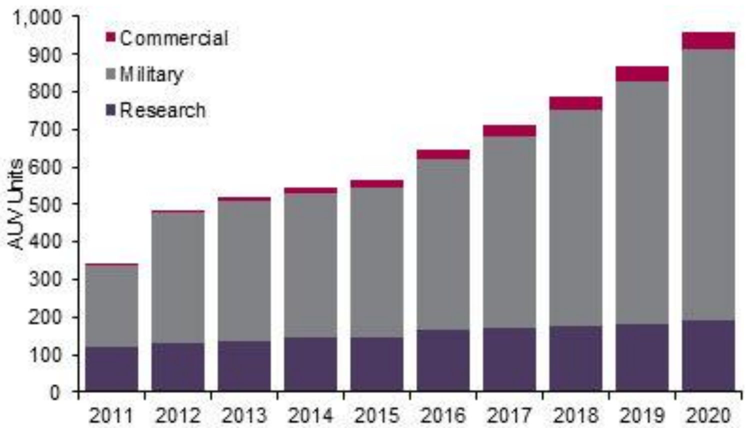


**Figure 1.** Global AUV demand by sector, 2011–2020. *(*Source: Douglas-Westwood's World AUV Market Forecast 2016–2020*)*.

This paper presents a state of art regarding the achievements and trends of one of the two main types of UUVs- AUVs (autonomous underwater vehicles). An AUV is a underwater robot that operates in six degrees of freedom (6DOF) and can conduct planned missions by using its own propulsion system controlled by an on board computer. The payload of an AUV includes, beside the CPU and the electro-energetic system, different types of sensors and technology like navigation, system and communication.

The development of AUVs started in the 60s in the USA, when the first torpedo- shaped AUV was build. All the theoretical and experimental work was used later in the 80s and 90s in building AUV prototypes, and in testing and experimenting in real underwater environment. From the golden era in the history of chronological development of AUVs [8] to their commercialization was just a step. After 2000 there were organizations which succeeded in producing and selling AUVs. From 2000 until now the underwater vehicle industry pursued technologies like cooperative motion, simultaneous localization and mapping (SLAM), path planning, sensor fusion and so on.
The overall market for this breed of vehicle is expected to grow at a CAGR (Centre for the Study of Globalisation and Regionalisation) of 20.65% from 2014-2019, thanks to advances in technology, miniaturization, improved endurance, and enhanced payloads. A representative chart regarding the market values is presented in figure 2.

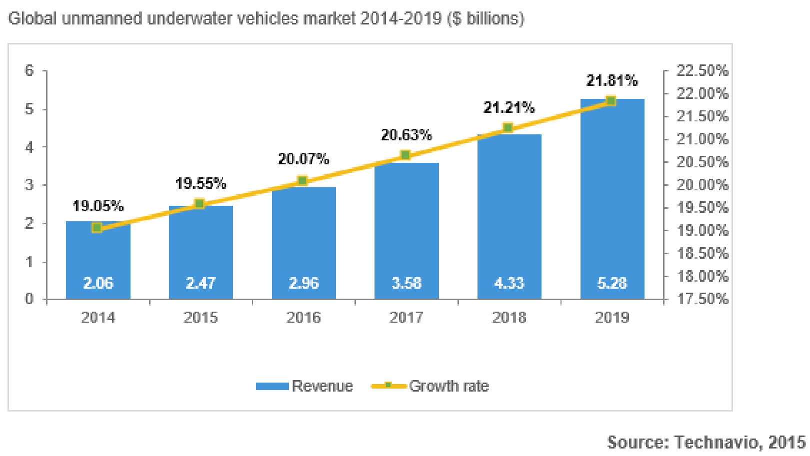


**Figure 2.** Global UUV market, 2014–2019.

## 2. Background theory

The main issue of AUVs is the nature of the underwater environment and its dynamics which makes navigation a problem when a vehicle is submerged. Due to the fact that navigation accuracy is critical in military applications, there were developed several different methods for navigation [4].

### *2.1. Factors affecting AUVs*

In order to adjust to the underwater world the AUV must be watertight, actuated and equipped with suitable sensors. Some of the factors affecting an AUV are visibility under water, gravity and buoyancy, stability, hydrodynamic damping, hydrostatic pressure and environmental forces.

The visibility underwater is affected by different factors like the absorption of light travelling through and the amount of particles in the water.The relation between the buoyancy and weight, the stability of the AUV, the dragging force, the Coriolis and the pressure are the key in navigating at a certain depth level. Last but not least factors to be considered, affecting both stability and motion of AUVs, are the surface waves and wind, currents and turbulences, and high or low temperatures.

### *2.2. The AUV reference frames*

An underwater vehicle has 6DOF; three spatial coordinates: x, y and z; and three attitude defining Euler angles: roll, pitch and yaw. Figure 3 shows the AUV coordinate System and its DOFs.

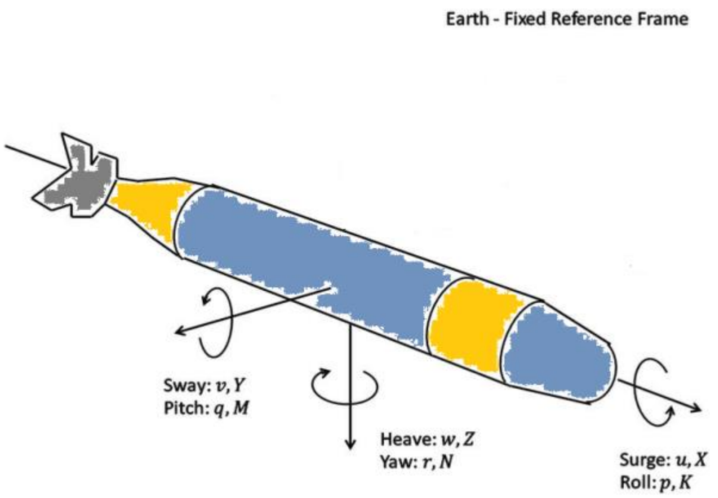


**Figure 3.** AUV coordinate System and its DOFs.

In order to keep an AUV stable, each degree of freedom must be controlled for obtaining a high range of motion.

## 3. AUV Technology

### *3.1. Electro-energetic System/Energy management*

In the propulsion matter, it's common for AUVs to use thrusters because they provide more accuracy and a faster response. Relying on the autonomy characteristic, the AUV must provide its own power for long term operation. Since all the systems onboard the AUV are electric, batteries are the choice for the power supply. Electric propulsion comes with the advantages of silent operation, ease of speed control and simplicity.

AUVs use secondary batteries, meaning rechargeable ones, lithium-ion being the most common choice nowadays. There is also a trend to combine solar power with lithium-ion batteries for very long operation. Another new idea is to achieve neutral buoyancy by adding extra batteries instead of dead weight therefor increasing the autonomy in order to operate more time than a given application requires.

### *3.2. Navigation*

For accurate navigation purpose, it's recommended for AUVs to work in conjunction with surface vessels. In these cases the location of the underwater vehicle is calculated by measuring the acoustic range relative to the known GPS position of the surface support ship.

If the mission scenario does not include a surface support ship, the AUV will take its own GPS position when at surface and when submerged it will use its inertial navigation system onboard to measure acceleration and velocity, therefore the rate of travel, in order to determine a final navigation solution.

The calculated position can be absolute, meaning that it does not depend on the previous position (e.g. the GPS), or relative, meaning that a drift error must be taken into consideration and apply the dead-reckoning method in order to find the AUV position.

Considering that in literature [9] exist three navigation methods known as (1) dead-reckoning and inertial navigation, (2) acoustic navigation, and (3) geophysical navigation techniques the configuration of navigation sensors must take into consideration the mission needs.

### *3.3. Sensor System and Processing*

The AUV platform is equipped with a sensor and sensing systems to perform static and dynamic experiments, to navigate autonomously and map feature of the ocean. The main sensors to estimate its position are a depth sensor, a compass and a speed sensor but a Doppler velocity log is recommended to increase the accuracy of the estimates. Instead of simple speed sensors, it would be recommended to install an inertial navigation system with laser or fiber optic gyroscopes. Sonar and underwater cameras are used for obstacle detection and classification.

### *3.4. Communication*

It's a known fact that the underwater environment imposes electro-magnetic constraints both on communications as it does to navigation. The most common application that involves AUV communication is done at surface by radio for mission upload, status and monitoring or data download. When submerged, an AUV mission involves minimal or no communication because of the limitation of the underwater environment. In these cases acoustic means are employed even though they have limited range or bandwidth and very limited data rate and depend on factors such as depth, bottom type, temperature, salinity, and sea state.

## 4. AUV simulators

With the increase of AUV missions' complexity, there comes the necessity of developing control algorithms that need validation. Given the risk involved in testing the algorithms in real –life test of the vehicles, the necessity for simulators started to impose. Safer and cost effective graphical simulators played a key role in AUV development. Obviously there were developed different types of simulators where the end user can vary the type of AUV, world, environment and sensor models they use.

Depending on the application, they can perform indifferent ways: offline, online, hardware in the loop (HIL) and hybrid simulation (HS). Graphical simulators can also be used as monitoring systems and/or mission playback or for operator training [5].

## 5. Researches on AUV around NATO countries

As part of NATO and its common policy regarding the implementation of unmanned underwater vehicles (UUVs) for ensuring its maritime borders security, the member countries started to develop AUV technology and to provide it worldwide. Some of them are: the USA, where most of the research and development work on AUVs were supported by the Defense Advanced Research Project Agency (DARPA) and US Navy, Canada, with a private production company Hyland Underwater Vehicle (HUV), Denmark, with biomimetic AUVs developed in the Technical University of Denmark, Iceland, with the well-known GAVIA AUV, Norway with the famous underwater vehicle HUGIN off Kongsberg Maritime and France with ECA Group.

Another country in NATO conducting research in this field is the UK, with the Aberdeen University, Cranfild University and Heriotwatt University.

## 6. Future perspectives of AUV researches

All future development perspective in the AUV research field must regard the issues of the autonomy, energy, navigation, sensor and communication. Autonomy increasing is mandatory for obtaining a longer mission and it could be done by implementing a hybrid energy source with both lithium-ion batteries and solar cells.

The solution for obtaining longer mission durations and a higher level of autonomy is path planning (the core and crucial components to improve AUV persistence). This means that an AUV must be capable of finding a trajectory that safely leads from its initial or current position to its destination with the optimization of time or energy consumption. This will lead to the capability to adapt to changing ocean environment, mission goals and system status.

Regarding the navigation and localization aspects, the trend implies simultaneous localization and mapping (SLAM), a process where an AUV can autonomously build a map of its environment and, at the same time, while localizing itself within that environment. Another perspective, in cooperative navigation (CN), follows the idea of AUV teams' localization using proprioceptive sensors, as well as communications updates from other team members. Implementation of cooperative path planning will make fleets of autonomous robots cooperate in order to achieve a desired goal.

Another technology that is desired to be implemented is multi sensor data fusion (MSDF), which means synergistic use of the information provided by multiple sensory devices to assist the accomplishment of a task by the system. This technique will reduce the uncertainty, reject the noise, tolerate sensor failure, increase resolution and extend the coverage of the sensors.

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