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A Study of the Feasibility of Autonomous Underwater Vehicles and Remotely Operated Vehicles in Black Sea

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Abstract. An underwater vehicle designed for industrial use in the Black Sea has to tackle two specific characteristics of it, given by its enclosed nature: the strong vertical stratification and the high content of hydrogen sulfide at greater depths. These particular environmental conditions impose also new approaches of design and technology for construction. The innovation foreseen of our study is the very concept of a universal underwater vehicle, based on modular design. Currently, unmanned underwater vehicles are controlled in two main ways, either autonomously (AUV) or by data transfer through an umbilical cable (ROV). Despite the fact AUV and ROV have many common characteristics they are used separately and are disjoint throughout their life cycle. To increase the technical performances and economic efficiency of such vehicles, we planned to design a universal carrier platform able to support different modules. Based on the common carrier sub-system, DCUV (**D**ual **C**ontrolled **U**nderwater **V**ehicles) can be assembled as an AUV, controlled autonomously and by radio when surfaced. After its recovery and transfer of the sea data recorded during its evolution as an AUV, the specific modules (sensors and battery) are replaced with functional modules needed to change it into an ROV, which can be then remotely controlled towards the contacts of interest. The concept of providing DCUV with a common propulsion unit will be eased by designing of an innovative multi-control system that will integrate data from sensors and human operator with the propulsion motors and end effectors, based on state-of- the-art micro-controllers and their appropriate programming.

1. Introduction

The general objective of our study is the design and development, in a new concept, of an underwater vehicle’s physical model that will validate the new scientific approaches planned. The DCUV system will consist of the modular vehicle itself, supported by a bottomed/anchored dock station and the control &communication station located on a platform, afloat or onshore. DCUV is destined to contribute to the implementation of sub-sea technologies as a whole for the benefit of the economic and social development of the Black Sea basin area. As offshore industry and environmental research in the Black Sea have a great potential but are still underdeveloped, a vehicle like DCUV meets the specific operational requirements of a tool which may determine a genuine “blue growth” in the area. In order to efficiently respond to these requirements, we are committed to design a new type of underwater vehicle that encompasses the characteristics of both Autonomous Underwater Vehicles and Remotely Operated Vehicles. The challenges of DCUV come from the universalization of such vehicles, philosophy that will need to take in account the modular design and the new theoretical and technological approaches this concept involves.

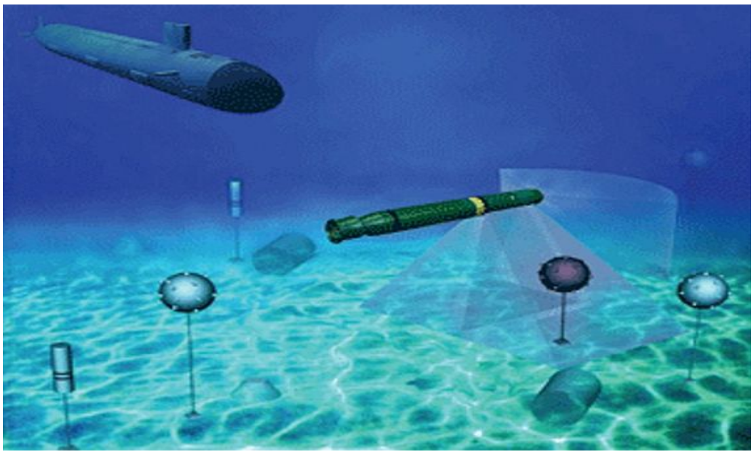
The specific objectives of the project will consist of theoretic research of new or innovative functional sub-systems of the DCUV, as well as their near-to-operation testing and validation. We envisage work packages dedicated to the following critical sub-systems:

- A watertight streamlined hull for the DCUV, able to carry the inner devices down to a depth of 500 meters in a corrosive environment, due to the presence of H_2S in the Black Sea's waters. The body is to be modular and consists of the common propulsion module and specific sensor and power modules that can be inter-changed for the two alternative configurations, as an AUV or an ROV.

- The propulsion system, based on newly developed thrusters. The innovations will be aimed towards reduction of power consumption for a given "underwater time" of the DCUV. In order to enhance also the maneuverability of the vehicle, optimization of the classical electric propulsion will be considered, but in addition research on directing the thrust forces, based on the principle of vector thrust jet propulsion will be carried out.

- The sensors system will allow measurements of the internal functional parameters (position in space, velocity, accelerations, power supply, temperature, humidity, etc.) and external, environmental ones, needed for detection of targets and operation onto them (scanning sonar, high resolution sonar, camera, metal detector, robotic arm). DCUV will also be fitted with environmental sensors which will reveal water's density, salinity, hydrogen sulfide concentration and other chemical compounds, temperature, geophysical data, etc.

- The control system will achieve the integration of main sub-systems of DCUV and permit the operator's input. It will have a common core ensuring the control of the underwater trajectory, at which specific hardware will be added according to the module the carrier platform is equipped with. The control system will be based on dedicated software that will be also differentiated for the two types of employment of the DCUV. The ROV configuration of the DCUV will contain automated functions for relieving the human operator as much as possible. Physical integration and programming will be supported by solid-state micro-controllers, actuators and drives.



- Fig. 1. The role of AUV/ROV in Black Sea

- The data transfer system will consider another innovative approach. A docking station for the AUV configuration will be developed. As it lies on the sea bottom, it allows recharging the sweeping vehicle and the transfer of the data acquired (sea floor images). This docking station increases substantially the underwater time of the DCUV in AUV configuration, because initiating of a new mission does not require its return to the mother ship/onshore platform.

2. The purpose

The DCUV system encompasses technical and operational features that meet the newest requirements of the sub-sea industry development, tailored especially for the basin of the Black Sea. For determinate the DCUV design we must take into consideration the following criteria:

a) The particular hydrology of the Black Sea, given by its enclosed nature. The low level of water exchange with the ocean and the massive fresh water intake from the rivers determine the presence of well-defined layers of water. The inhomogeneous environment will pose specific challenges to be solved, because it will influence the static and dynamic features of the vehicle during its operation. The submarine currents' disposition is also not very well known in the Black Sea, so they should be also charted first by the DCUV or other means in order to set further the necessary trajectory corrections for a long-range use, autonomous configuration of it. Another specific challenge to be solved is the high content of hydrogen sulfide - H_2S - in the water, generated by the decomposing sea life of the Black Sea. Accompanied by the low level of oxygen present in the seawater, the hydrogen sulfide demands particular approaches for the man-made structures that are to be installed on the bottom of the sea. It is recommended to know the exact concentration of H2S in different periods of the year at various depths is an operational requirement for any offshore or environmental protection equipment in the sea. In addition, the acidic nature of the water has to be carefully tackled when designing the watertight hull of DCUV.

b) Universalization of the previous AUV and ROV types of unmanned underwater vehicles, based on a versatile, modular design. The common functions and common operational parameters of these can be obtained by a generalized propulsion segment, which can serve as a transporting platform of two kinds of payloads. Thus, two different configurations can be assembled one after another in a very short time, depending on the type of control needed - autonomous or remote. This design criterion will decrease dramatically all the costs of its life cycle - construction, maintenance, repairs, operation, training, etc. Even though DCUV is a sophisticated automated vehicle, an underwater robot, the scientific and technical capabilities of integrating two vehicles in one are mature now, making this conceptual leap very feasible, while necessary.

c) Innovative structural, propulsion and control characteristics for the DCUV. The sealed hull modules can carry instruments and devices that do not need any extra pressure or chemical protection. A streamlined body also gives the highest dynamic performances and power efficiency needed for a prolonged operational duration, with minimum human intervention. The dedicated software used for design and laboratory testing and validation will be used for an optimal shape and dynamic features of the hull. New approaches for enhancing the thrusters' efficiency will be undertaken, in conjunction with the hull's geometry. Vector thrust propulsion will be also studied. Autonomous and remote control will be based on the use of powerful micro-controllers which will integrate the information from the sensors with the propulsion unit. Some decisions, belonging to the human operator, will be made by the automated control system for the ease of operation. A well programmed control sub-system will also allow the use of a docking station for both approaching maneuvers and data transfer.

3. The concept

The overall concept of the DCUV system consists of a modular, multi-functional and multi-controlled underwater vehicle. Moreover, such vehicle designed for industrial use in the Black Sea must tackle two specific characteristics of it, given by the sea's enclosed nature: the strong vertical stratification of the body of water and the high content of hydrogen sulfide at greater depths. These specific environmental conditions also impose new approaches of design and technology for construction. In addition to the specific operational requirements of a Black Sea underwater vehicle, the technical innovation foreseen by the partners of the DCUV project is the very concept of a universal underwater vehicle, based on modular design. Currently, unmanned underwater vehicles are controlled in two main ways, either autonomously (AUV) or by data transfer through an umbilical cable (ROV). Despite the fact AUV and ROV have many common characteristics they are used separately and are disjoint throughout their life cycle. To increase the technical performances and economic efficiency of such vehicle, is recommended to design a universal carrier platform able to support different modules. Based on the common carrier sub-system, DCUV can be assembled as an AUV, controlled autonomously and by radio when surfaced. After its recovery and transfer of the sea data recorded during its evolution as an AUV, the specific modules (sensors and battery) are replaced with functional modules needed to change it into an ROV, which can be then remotely controlled towards the contacts of interest. The concept of providing DCUV with a common propulsion unit will be eased by designing of an innovative multi-control system that will integrate data from sensors and human operator with the propulsion motors and end effectors based on state-of-the-art micro-controllers and customized programming.

The needs of sub-sea exploration and operation, the complexity of tasks and the reduction of life cycle costs ask that DCUV should be considered as an integrated system, in which the functional subsystems are closely inter-dependent. The research will aim to develop the specific subsystems, which share some design requirements. For example, in the case of automated functioning as an AUV, the electric propulsion subsystem will receive commands from the control system consisting of microcontrollers in response to data obtained from the sensors. The overall motion and the meeting of requirements imposed by trajectory mobility and stability will take account, among others, of the hydrodynamic characteristics of the vehicle. The individual disciplines which contribute to the synthesis of the DCUV prototype and to the fabrication technology ranges from mechanical engineering, fluid mechanics, 6 degree of freedom body dynamics, electrical engineering, electrical power sources, electronic sensor equipment, information technology and computers, automation and programming to the study of underwater explosions and tactical use of the product in combat.

The main milestones foreseen for the research and development of the DCUV system are:

- Literature survey and distribution of the main findings in electronic format.
- Establishments of the components, weights locations, price range and availability.
- Development of design algorithms design and optimization software including expert system application and artificial intelligence applications.

- Simulation of the platforms in Black Sea environment, integration of the motion and control algorithms with the simulator environment.
- Design of the model, its simulation by CFD, FEA, confirmation and preparation of the model for wind tunnel and towing tank testing.
- Design of thrusters having an integrated duct that directs the flow efficiently and increases the push force at a noteworthy rate. The propulsion design is integrated to the underwater vehicle body, so it does not form any fixation resistance.
- Hydro-acoustic sensors needed for navigation, sea bed charting and detection of contacts of interest
- The docking station, which will improve the capacity of data to be surfaced at a single dive.
- Delivery of the physical model for testing in laboratory and near to operational conditions.

A pattern of technological advancement can be observed in the history of civilization. Technical inventions appear to meet a specific challenge. Subsequently, it is necessary to integrate more technological products and to gather more research materials, which leads to the emergence of several scientific and technological spaces that allow the integration of several specific solutions into a single high-functionality product. This pattern of technological evolution can be easily recognized since the end of the eighteenth century, when the industrial revolution began. For example, we mention the history of steam engines, or that of the internal combustion engines, which gradually came to today’s standard form, or the development of the surface and anti-submarine torpedoes into one universal type, etc. In the modern era, the most relevant example is the space shuttle, which meets the requirements of an atmospheric flying vehicle as well as those of a spaceship.

Similarly, the DCUV is aimed towards the research and development of an innovative concept, that of a universal product. The DCUV proposes a standardization of a carrier platform capable of being configured with minimal effort into two versions of underwater vehicle, with complementary purposes, the AUV and the ROV.

Worldwide, underwater unmanned vehicles, alongside their logistic support systems, operate mostly in high depth or dangerous areas which are inaccessible to divers or manned submersibles. On the other hand, acquisition, maintenance and operation costs are far lower in comparison with any other method of working under water. Currently, the most popular unmanned underwater vehicles are those controlled via umbilical cable - ROV - and those that are autonomous - AUV. Both varieties are used in military and civil industry applications. ROVs were initially designed and developed as vehicles to search and destroy mines found in seas and rivers, therefore at first, they had purely military applications. With the advancement of construction technologies of the vehicle itself as well as the sensors and controllers with which it was equipped, fabrication costs dropped so much that ROV started to be used more and more in a large variety of civil activities. The operator monitors the data coming from the sensors (movement parameters, environment parameters and optical or acoustical images of the targets) and controls the propulsion system to obtain the desired trajectory. The typical ROV employment is exploration of an underwater area limited to the length of the control cable and performing, with the aid of a robotic arm, an appropriate action on the discovered target.

ROV used in oceanographic industry applications are mostly constructed in the “open frame” system, meaning that the sensors, effectors and other equipment are mounted on a chassis, functioning in the open aquatic environment. The construction of ROV used to fight against sea mines is based exclusively on the use of a hydrodynamic efficient, sealed body, which houses the functional subsystems.

AUV are vehicles with autonomous control over trajectory, with the aid of automated course and pre-programmed immersion tracking systems. The main sensor is long range sonar which scans the body of water underneath the vehicle, towards the seabed. The ultrasonic picture thus obtained is recorded and downloaded when the AUV is recovered. Subsequently, an analysis of the seabed map is performed alongside identification of salient features and classification of targets. The rated operating range of a military AUV is between 10 and 60 hours, and up to 75 nautical miles. Total patrolling area varies between 10 and 500 square nautical miles. Current AUV modern trends include obtaining precise underwater maps by increasing sonar performance, rechargeable energy sources, synthetic diaphragm sonars for long range high fidelity classification, etc.

A feature of the current global development stage of ROVs and AUVs is that, up to this point, they are designed as different types of systems and are used for different missions - exploration of a large maritime area and acting on local targets respectively. Due to the large number of manufacturers and technical solutions implemented so far, there are dozens of operational types available on the global market, which leads to severe fragmentation regarding production, maintenance and operating technologies. That determines the increase of associated costs throughout the product life cycle.

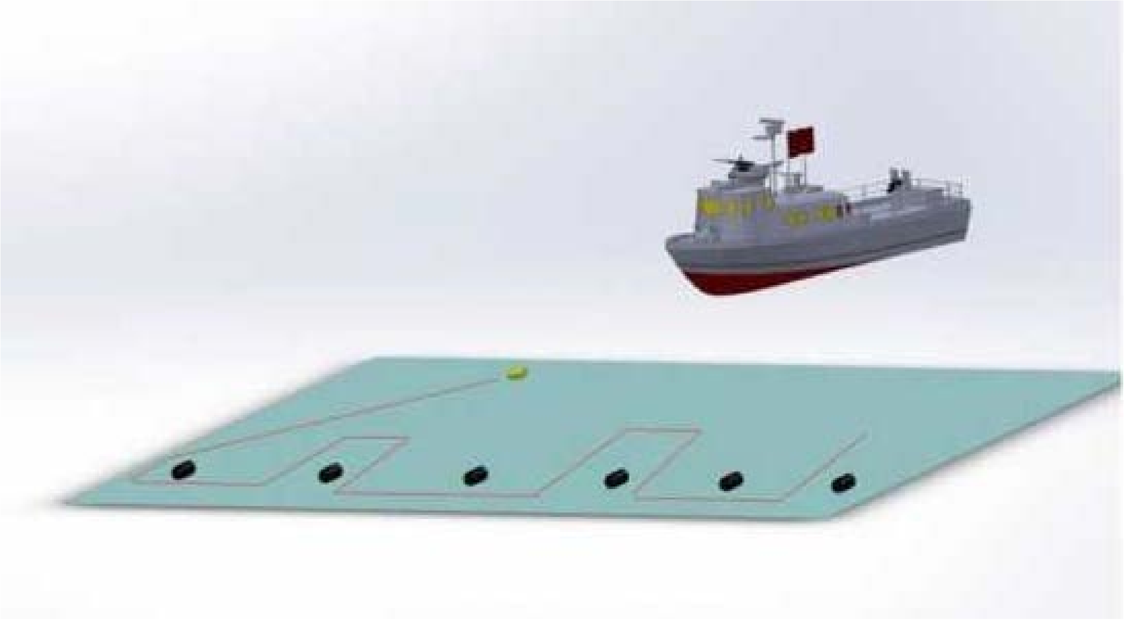


Fig. 2. DCUV in AUV configuration

Fig.3. DCUV in ROV configuration

A multi-purpose DCUV system, operationally versatile and flexible in terms of possible configurations would remove all these disadvantages.

The two configurations the DCUV can be transformed into are presented in the pictures below:

As described in the preceding paragraph, the milestones of the proposed project are planned to solve the scientific and technical challenges posed by its innovative concept. According to these, the super-efficient thruster offered to be integrated into DCUV, has a special routing path for the entering water flow into the propulsion system. The objective of this innovative propulsion system is to increase the efficiency and lower the amount of power source on board the vehicle. Away from manipulators and other mission modules, the highest energy consumer of underwater vehicles is the propulsion unit. The minor improvement on the efficiency of this unit has leveraged effect on the amount of energy source (battery) that needs to be carried in the AUV configuration. Hundreds, even thousands of different propeller or water-jet designs have been developed in the history for surface or underwater vehicles. Each design has pro’s and con’s, but the real important consideration should be the compatibility of the vehicle with the propulsion system. This means that each vehicle needs its own, custom design propulsion unit. The proposed propulsion thrusters will be designed in an exact compatibility with increased efficiency gained from the innovative flow path.

All types of underwater vehicles need physical interfaces for positioning, data transfer and charging. The “underwater time” is one of the most important specifications that an underwater vehicle can have. The longer underwater time is always preferred due to cost effects during operation. Suggested docking system does not increase these two capabilities but makes them limitless. Bottomed underwater vehicles equipped with this option can stay underwater as much as required without and charging or data transfer requirement. Several docking stations have been studied and suggested by different scientists and designers but most of them are far away from being practicable.

The ultrasonic imaging sensors will consist of a complex array of sonars which include a sonar for bottom surveillance and charting (based on side scan sonar or development of an interferometric synthetic aperture sonar concept). For control of trajectory, DCUV will be equipped with a navigational sonar multi-beam Doppler velocity log (DVL) for underwater column AUV position estimation and speed measurement. Other ultrasound devices that can be utilized in the sensor module of the AUV configuration are: sonar for forward obstacle (objects) avoidance, high resolution sonar for near surveillance of bottom objects, an acoustic pinger for AUV (ROV) designation, USBL acoustic tracking system and acoustic underwater modem for control and telemetry. The determination of the AUV's position and commands to modify its trajectory are done through a radio communication system between the vehicle and the station found on the control platform.

The automated control sub-system is also a critical part of the DCUV system. The information compiled in deliverable results will be used as input data for the specification of requirements. Consequently, the design of the automated control systems for the DCUV is addressing the integration of sensors for monitoring position and movement (constant course, constant immersion, tilted trajectory, horizontal and vertical preprogrammed trajectory, automatically floating at fixed point without operator intervention), for sensing marine pollution - biological or chemical, etc. Last but not least, it can research on implementation of artificial intelligence techniques in the identification and classification of specific items for underwater exploration missions.

4. **Conclusion**

In conclusion, the ambition level of the DCUV system project is a high one, emerging from the regional economic/social development trends, the highly scientific and technological requirements self-imposed.

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