Underwater vehicle – their past, present and future development

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Abstract. Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) have many applications in a large variety of submarine areas. In the last period, they are used to replace different missions in rivers, lakes and oceans. Named also underwater robots, both tethered and untethered, they are an integral part of scientific equipment to explore the seas and oceans field. The underwater robots, ROVs and AUVs, are useful in many fields and for a different application such as inspection, bathymetry or mapping. However, we must keep in mind that according to their capabilities they can operate at different depth limit. For example, Hugin 3000 sensor of Knogsberg Maritime, Remus 3000 from Institutulul Woods Hole Oceanographic (WHOI), Sea Orache of Bluefin`s Robotics and Alistar 3000 of ECA can reach depths of 3000 m.

1. History

The first world’s American submarine vessel was named Turtle. It was built in 1775 at Saybrook, Connecticut, by David Bushell and his brother, Ezra. The missions of Tutle was to attaching explosive charges to ships in a harbor and also for against Royal Navy vessels occupying North American harbors during the American Revolutionary War. The pear-shaped vessel was made of oak reinforced with iron bands. The submarine measured about 2.3 m (7.5 feet) long and 1.8m (6 feet) wide. Turtle was equipped with a mine able to attach the hull of an enemy ship [1]. The design was a clam like shape which could only accommodate the captain and no passengers. The design focused the basic requirements; being able to submerge, have enough air, being able to maneuver underwater.

The submarine could be submerged by letting water into a tank beneath the captain which could be pumped out with a hand pump to resurface. In case of emergency a load of lead could be released to resurface quickly. The turtle had enough air to stay submerged for about twenty-five minutes and could maneuver with a rudder at the back and a paddle propeller blade at the front. While the Turtle only had a speed of 5 km/h and never managed to sink a ship it was the first step towards a military submarine.

2. Introduction

In the last few years, the underwater vehicles have known an increasing interest from research and in industry. An important role it is played by the manned underwater robotics systems which realized
different missions at sea bottom, for example, maintenance and monitoring cable, pipeline, offshore structures, collect and inspect different biological surveys [2].

According to Figure 1, the underwater vehicles divide into two basic categories: manned underwater vehicles and unmanned underwater vehicles (UUVs) or autonomous underwater vehicles (AUVs). [6]

![Underwater vehicles diagram](image)

Figure 1. The underwater vehicle category

The unmanned undersea vehicle is a self-propelled submersible whose operation is mainly fully autonomous or under minimal control. The unmanned vehicle divided into tethered (ROV) or non-tethered vehicle (AUV).

The difference between the AUV and the remotely operated vehicle (ROV) is the presence (or absence) of a direct hardware (for communication and/or power) between the vehicle and the surface. However, AUVs can also be connected to the surface for direct communication through an acoustic modem, or via an radio frequency or an optical link. Simplistically, an ROV is a camera mounted in a waterproof enclosure, with thrusters for maneuvering, attached to a cable to the surface over which a video signal and telemetry are transmitted information.[5]

ROVs can be largely classified as open frame structure or closed frame structure. An ROV with an open frame structure has stable three DOF motions based on a large metacenter. This type of structure has various additional advantages. This structure is well known and generally adopted by most ROVs. It is convenient for large payloads. Inspection and cleaning equipments can be easily attached to or removed from the body. However, ROVs with this structure have difficulties with motions that require more than three DOFs. Due to these advantages and disadvantages, open frame structure is mainly applied to ROVs for general works.

3. ROV categories based upon size and capabilities

ROVs can be described as tele-operated free-swimming robotic unmanned underwater vehicles.[3] The applications in which they are used are varied for diver support to heavy marine subsea construction. Below it is presented four broad categories of ROV’s based upon vehicle size and capabilities:

1) Observation class ROVs (OCROV) – “low-cost ROVs”
The vehicles from these categories go from the smallest micro-ROV to a vehicle weight of 100 kg (200 pounds.). Vehicles are used in shallow water inspection tasks because are limited to depth rating of less than 300 m (1000 ft) of seawater and one atmosphere pressure – which imposes limitations upon the vehicle size (it is necessary to maintain the buoyancy). In Figure 2 is presented a OCROV simulated in SolidWorks Software. The OCROV it is a BlueROV. This king of OCROV is the most capable, flexible, and affordable ROV on the market. The 6-thruster vectored configuration, coupled with strong static stability, provides a vehicle that is smooth and stable. The BlueROV2 provides the capabilities of a high-end mini-ROV at the price of the most basic commercial ROVs.

![OCROV](image1)

Figure 2. OCROV [7]

2) Mid-sized ROVs (MSROV): - “light work class” vehicles

![MSROV](image2)

Figure 3. MSROV

The vehicles from this categories weigh from 100 kg (200 pounds) to up to 1000 kg (2000 pounds). These vehicles (Figure 3) are generally a deeper-rated version of the OCROVs. The difference between those two categories is that the MSROVs operate with sufficient AC power delivery components than OCROVs. Also, the MSROVs have sufficient pressure housings capable of achieving deeper depths over the longer tether/umbilical lengths. The moving of these vehicles is based on a tether management system (TMS) [4]. In Figure 4 are presented a TMS system necessary in case of a long cable length.
3) Work class ROVs (WCROV):

The particularity of this category is that the vehicles are generally heavy electromechanical working on high-voltage (3000 V) AC circuits from the surface to the vehicle. The power delivered to the vehicle generally is changed immediately to mechanical (hydraulic) power at the vehicle for locomotion as well as all manipulation and tooling functions.

4) Special-use vehicles:

The vehicles from this category are not falling under the main categories of ROVs due to their non-swimming nature such as crawling underwater vehicles, towed vehicles, or structurally compliant vehicles (i.e., non-free-swimming).

In Table 1 are presented the vehicle characteristics according their classification. In table are presented the vehicle power and the depth of working depending the launch method and TMS.

| Size Category | Vehicle Power | Depth Rating | Launch Method       | TMS | Thruster/ Tooling          |
|---------------|---------------|--------------|---------------------|-----|---------------------------|
| OCROV         | Low-voltage DC| +/- 300m     | Hand deploy         | No  | Electric/ electric        |
| MSROV         | Medium-voltage DC or AC| >1000m    | Crane or A-frame | Op  | Electric/ hydraulic       |
| WCROV         | High-voltage AC| >3000m      | A-frame             | Yes | Hydraulic/ hydraulic      |

4. Size versus ability to equip with sensors

Generally, any ROV can be equipped with any sensor or tooling package. The size needs to vary to optimally accommodate the thrusters, tooling and sensors while still powering these items and moving the package. The communications capabilities played an important role because must to ensure enough data to transmit the telemetry to the operator station for controlling the tooling package. Table 2 present some examples of sensors along with their data transmission requirements. Every closed frame structure must have some sort of navigation system, propulsion system and a dry,
A watertight environment to house onboard components. In addition, an closed frame ROV will usually possess the following systems and components as seen in Figure 5.

Table 2. Sensors ROV and transmission requirements

| Sensor Type           | Bandwidth        | Protocol          | Telemetry Type       |
|-----------------------|------------------|-------------------|----------------------|
| Single beam sonar     | Low              | RS- 232/422/485   | Copper or optical fiber |
| 2D multibeam sonar    | Medium to high   | Ethernet          | Copper or optical fiber |
| 3D multibeam sonar    | High             | Ethernet          | Optical fiber        |
| UT metal thickness    | Low              | RS- 232/422/485   | Copper or optical fiber |
| Standard def. video   | Medium           | Composite         | Copper or optical fiber |
| Radiation sensor      | Low              | RS- 232/422/485   | Copper or optical fiber |
| Pipe tracker          | Low              | RS- 232/422/485   | Copper or optical fiber |

Figure 5. System and Components

The sensor packages aboard an ROV system are divided depending on responsibility into two categories: survey sensors and vehicle sensors. The vehicle sensors are the responsibility of the ROV team, during the survey sensors are for the survey team. The vehicle sensors are integrated through the vehicle’s telemetry system.

For example, the navigation sensors are integrated into the vehicle’s telemetry system and are used to manage the position, orientation and physical status of the vehicle. Table 3 details the sensors by ROV classification. The WCROV is the most complex type of underwater vehicle, because have incorporated all type of sensors.

Table 3. ROV sensors

| Sensor                      | OCROV | MSROV | WCROV |
|-----------------------------|-------|-------|-------|
| Single channel video        | X     | X     | X     |
| Compass                     | X     | X     | X     |
| Depth gauge                 | X     | X     | X     |
| Tether turn counter         | X     | X     | X     |
| Rate gyro                   | X     | X     | X     |
| Lighting level adjustment   | X     | X     | X     |
| Ground fault interrupt      | X     | X     | X     |
| Multiple channel video      | X     | X     |       |
| Camera zoom/focus           | X     | X     |       |
| Obstacle avoidance sonar    | X     | X     |       |
| Altimeter                   | X     | X     |       |
| Motor current draw          | X     | X     |       |
| Tether in/out               | X     | X     |       |
5. Vehicle stability

The role of an ROV is to act as a delivery platform (both for sensors and tooling) to a remote work site. It is necessary that all items and subsystems of the vehicle to support this function. It is necessary that the vehicle to power itself.

In the case of a dynamic underwater body, stability is affected not only by the centres of mass and buoyancy, but also by factors such as external forces and centres of drag.

Environmental disturbances can affect and influence the motion and stability of a underwater vehicle. This is the reason that waves, currents can perturb the underwater vehicle. When the vehicle is submerged, the effect of wind and waves can be largely ignored not having an important influence. The most significant disturbances along the body of underwater vehicles are currents. In a controlled environment such as a pool, the effect of these environmental forces is minimal.

The Reynolds number plays an important role considering the effect of the skin on the drag of vehicle. Near the surface, the fluid velocity increase with the distance from the surface.

The Reynolds number is a dynamic factor for fluid flow and is used for determining the flow characteristics around the vehicle. The flow characteristics affects directly the drag equation.

The Reynolds number effect of a fluid flowing around a cylinder can be calculated using the formula (1):

\[
Re = \frac{\rho V l}{m} = \frac{V l}{v}
\]

Where:
- \( \rho \) – density of fluid (slugs/ft\(^3\))
- \( V \) – velocity of flow (ft/s)
- \( m \) – coefficient of viscosity (lb-s/ft\(^2\))
- \( v = \frac{m}{\rho} \) – kinematic viscosity (ft\(^2\)/s)
When an object is immersed in a liquid, the liquid generates a force that tends to push the object towards the surface, known as the buoyant force.

The immersion system facilitates the vertical motion of the ROV in the water. The existing ways for implementing the immersion system are:

a) Mechanical method by using propellers to achieve the displacement, and

b) Hydraulic method by using ballast tanks which can be filled with water or air in order to submerge or emerge.

The autonomous underwater vehicle needs to have some navigation modes such as autonomous navigation mode and acoustic remote control mode for many scientific survey requirements.

The concept is shown in Figure 7. According the mission type, there are chosen the modes of navigation. Until now, in world exist two navigation mode.

The Autonomous Navigation Mode: The work schedule is preset on the vehicle's computer some time before the observations start. In terms of component, the program includes cruise and device observation. The carrier ship carries the vehicle to the observation area and is used to launch and recover the vehicle left in the water. The vehicle independently cruises without any information from the support vessel. When the vehicle detects some obstacles along the scheduled course, it needs self-avoidance actions. In the case of long range cruising, some acoustic transponders are arranged along the cruising course for reference. The vehicle can correct its position by communication with transponders, making positioning accuracy better.

Another navigation mode, it is represented by the acoustic remote control mode: the support vessel follows the vehicle and they communicate with each other during the operation. Although the working schedule is preset in the same manner as for autonomous navigation mode, a new schedule can be downlinked from the support vessel by acoustic telemetry. Images can be sent acoustically, and side-scan sonar and TV camera data can also be uplinked from the vehicle by acoustic telemetry. The images are transmitted at an interval of a few seconds. Acoustic control is able to be employed inside a 30 degree angle of conic area under the support vessel.

6. Conclusion

Figure 7. The concept of navigation mode
Submersible ROVs are the best tools for inspection and survey of natural as well as artificial water bodies. The smaller ROVs can be used to gain knowledge required by local fisherman and acquisition of required data for scientific purposes.

In this study was presented the general difference between the OCROV, MSROV and WCROV. In conclusion, the difference between the OCROV and MSROV is represented by the power transmission and depth rating. The general difference between the MSROV and the WCROV is represented by the size of the hydraulic power pack and the horsepower rating for the operation of manipulators and tooling. Both the MSROV and the WCROV are deep-rated vehicles and both can be delivered to deep work sites. Furthermore, on the other hand, the WCROV, can perform heavier tasks than the MSROV can achieve on the strength of the added muscle of hydraulic actuation of its components (versus the electrical actuation of the MSROV). The MSROV has additional deepwater capabilities along with fiber optic telemetry for full gigabit sensor throughput. On the other hand, the WCROV hold all of the attributes of both the OCROV and the MSROV along with high-powered hydraulic manipulators and tooling capabilities.

Also, the authors present the vehicle submersible stability and the possibility to navigate underwater in case of autonomous underwater vehicle. In this paper, was compared the two mode of navigate for vehicle, with their advantages and disadvantages.

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