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Research Article

Overview of Remotely Operated Vehicles

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Abstract: Remotely Operated Vehicles (ROVs)fall under the category of unmanned underwater vehicles and are used to traverse through different water resources ranging from lakes to sea. This paper aims to provide an overview of the evolution of ROVs from their inception in 1953 to modern adaptation. ROVs have grown in popularity as a result of their ability to dive to the deepest depths of the ocean and perform complex scientific tasks ranging from discovery to inspection for much longer periods of time while working in hazardous environments. ROVs are categorised based on various factors such as design, size, capacity, strength, and weight. The aim of this paper is to review and address various design parameters that have previously been considered by researchers. Advantages, drawbacks, and applicability ranges have been addressed based on the observations of several researchers.

Keywords: Remotely operated vehicles, underwater robotics, Autonomous underwater vehicle

1. Introduction

Oceans hold 96.5 per cent of the water on earth, and water occupies about 70% of the planet's surface [1]. The oceans are also responsible for more than half of the total oxygen production, thanks to the oceanic plankton [2]. On the other hand, oceans remain a mystery, with more than 80% of these water bodies unexplored [3].

To tackle the harsh conditions and various challenges of underwater exploration, the use of ROVs has burgeoned, with its ability to dive into the ocean's deepest end and carry out intricate scientific tasks ranging from exploration to inspection for a much longer duration while operating under hazardous conditions in different water resources from lakes to sea. ROV's come under the category of unmanned underwater vehicles [4]. ROVs can either be controlled by a tether cable or be connected to the operator by a wireless medium [5]. A majority of the ROVs are stocked with a camera relaying images and video to the operator [6]. Additional sensors to measure different parameters such as water clarity and temperature can be added to the vehicle to allow sample collection [7]. During the 1970s, ROVs were used in various rescue operations. Most famously, the "Cable-controlled Undersea Recovery Vehicle (CURV)" was used to rescue drowning submarine Pisces [8].

While initially ROVs were developed to recover torpedoes by the US Navy, during the 1970s, they found a new purpose. The oil and gas industries came calling for ROVs' prowess to inspect the underwater pipelines [9]. Later, with a growing need to inspect a ship's hull without sending a human diver [10], ROVs expanded their horizons. Since then, ROVs have found numerous fields of application. ROVs have helped scientists study different water bodies and assisted in climate change studies, with ROVs being deployed in polar regions studying history and characteristics of ice mass [11] by observing the melting of ice and its varying density. They are used in studying various underwater life forms and water characteristics.

Recently ROVs have found a new application. With the rise of underwater photography, ROVs are being sold commercially to photography enthusiasts[12], which has made ROVs easily accessible to people.Worldwide, various Governments have recognised the potential of utilising ROVs by incubating them for various applications ranging from surveying dams to nuclear reactors[13].With the advancements in computing and technology, ROVs can perform complex tasks independently without human input, resulting in the emergence of Autonomous Underwater Vehicles (AUVs) [14], which has allowed ROVs to travel independently without the operator's instructions and carry out their given tasks.

2. History

Luppis-Whitehead Automobile of Austria in 1854 developed a PUV (programmed underwater vehicle) which was a torpedo [15]. Later, in 1953, famous French pioneer Dimitri Rebikoff developed the first Remotely Operated Vehicle named "POODLE" with tether cable and surface controls, which was an unmanned adaptation of his "dive scooter" [15].Fig.1. shows the world's first ROV, the Poodle.

Fig.1. "POODLE", worlds first ROV.(Credit:Rebikoff-Niggeler Foundation)

During the 1960s, the United States NAVY started to work towards developing ROVs [16]. As a result of research by US NAVY, a remotely operable underwater camera system which eventually was known by the name of "Cable Controlled Underwater Research Vehicle (CURV)", was developed mainly to recover torpedoes that went missing on the seafloor [16].In 1966, at the coast of Spain during the Palomares B-12 crash, an atomic bomb that went missing was successfully recovered with the help of the US NAVY's CURV [16]. Later, in 1973, with the help of US NAVY's CURV III, an eminent deep-sea submarine "Pisces" was saved at the coast of Ireland [15]. The US Navy adopted the CURV III into more complex vehicles, such as the huge "Pontoon Implacement Vehicle (PIV)," which was developed to aid in the search for sunken submarines. They also produced the first portable ROV, "SNOOPY," which was hydraulically controlled from the surface, followed by an "electric SNOOPY," which extended the ROV's capability with a fully electric vehicle; later, other sensors such as pressure sensors, depth sensors, proximity switches, and so on were added to it [16]. Fig.2. shows the image of the US NAVY's CURV.

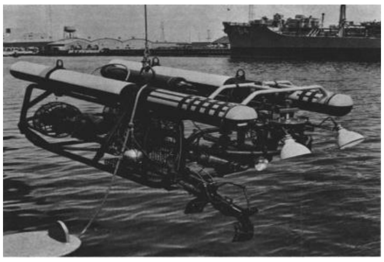

Fig. 2. 1965 – "CURV Cable-controlled Underwater Recovery Vehicle" (Credit: Popular Science, June 1966)

Fig.3. CURV III developed by the US NAVY

Among 20 ROVs constructed in 1974, 17 ROVs were funded by various governments [16]. In 1975, 229 out of the 340 ROVs were produced by North American firms [16], but the market was highly competitive. The ROV technical centre was moved to the United Kingdom to assist in oil and gas production in the North Sea due to the dollar to the pound exchange rate. It became more cost-effective to produce vehicles in the UK once the dollar and pound exchange rates were equalised [16]. As this technology started gaining more significance further from 1974 to 1982,350 vehicles were produced, funded, and constructed. Some Notable ones are RCV-225, which eventually was developed to RCV- 150, developed by HydroProducts in the USA, specifically for offshore work [14](shown in Fig 5). During the years from 1982 to 1989, the ROV industry flourished.

Fig.4. RCV-150 and RCV-225 [14]

In 1970 the oil and gas industries manufactured work class vehicles to strengthen their offshore fields utilisation [16]. However, they were seen as an alternative to divers until the 90s, when the ROVs covered most of the underwater work, minimising divers' risks. This improvement was made to solve the difficulties of sending divers to work at depths greater than 200 metres [17]. Few firms, however, chose to advance this technology by shrinking the ROV into a new class of lightweight, reliable observation class vehicles. When compared to the larger offshore vehicles that were manufactured earlier, these vehicles were much more compact. Chris Nicholson developed the first actual economic observation class ROV named "Mini Rover", which found application in the civil engineering industry, surveying dams, inspection of tunnels, defence operation, ocean studies, nuclear plant inspection, and many more [16].

In 1990, the United States Navy set a goal of developing underwater vessels capable of achieving a depth of 6096 metres (20000 feet)[16]. CURV III, which reached a depth of 6128 metres (20105 feet) [16], and the Advanced Tethered Vehicle (ATV), which could achieve a depth of 6279 metres (20600 feet) [16], were the vehicles that accomplished the goal. In 1995, JAMSTEC's KAIKO ROV broke the record by diving to a depth of 35791 feet in the Mariana Trench's "Challenger Deep" [19]. It has been the world's only full ocean depth survey since 1995. It has performed more than 20 dives to a depth of approximately 11000 metres in the Mariana Trench's "Challenger Deep" [18].

Fig.5. KAIKO ROV developed by Japan's JAMSTEC [19]

In the present day, with advancements in technology, ROVs have become more efficient and cheaper, making them more commercial hence expanding their applications into various new fields. Underwater photography has been one field that recently came into the limelight thanks to ROVs' application allowing photography enthusiasts to capture 4K images and videos underwater [17]. DTG3, developed by Deep Trekker, is one of the many ROVs used in this field with a 4K quality camera and can operate at a maximum depth of 200 meters with a battery life of up to 8hrs [17].

3. Classifications Of ROVs

ROVs can be classified into five categories, which are Class 1 (Pure Observations Vehicle), Class 2 (Observation Vehicle with Payload Capability), Class 3 (Work Class Vehicle), Class 4 (Towed or bottom crawled vehicle), and Class 5 (specialised prototype or development vehicles) [16].

The smallest ROVs are Class 1 ROVs, also known as surveillance vehicles. They can dive up to a maximum depth of 300 metres, for example, the subsea tech observer XT, ECA group's H300-V, Seaeye Falcon, and others.

Class 2 ROVs, such as the ECA group's H1000, Seaeye Cougar XT, and others, go deeper than 300 metres and weigh between 100 and 1000 kilogrammes.

Class 3 ROVs are known as heavy electromechanical vehicles (WCROV), which require high voltage (>3000 V) and possess high-powered tooling capabilities, like the Nexxus ROV, Perry XLX EVO, etc.

Both Class 2 and Class 3 ROVs are deep-rated vehicles that can be used for deep-water operations, but Class 3 ROVs are capable of carrying out heavy tasks.

Class 4 and Class 5 vehicles are special purpose vehicles; they do not swim in water but crawl. Hence, they are known as crawling underwater vehicles or structurally compliant vehicles like the Greensea's hull crawler.

Table I. Comparison of different classes of ROVs

Category	Input Power	Power	Telemetry Type	Maximum Depth	Deployment Method	Tether Management System
OCROV (Observation ROV)	110/220 VAC 1Φ (1 phase)	Low-Voltage DC	Copper only	+/- 300m	Hand deploys	No
MSROV (Mid-sized ROV)	440/480 VAC 3Φ (3 phase)	Medium-Voltage DC or AC	Copper or Fibre	>1000m	Crane or A-frame	optional
WCROV (Work-class ROV)	440/480 VAC 3Φ (3-phase)	High-Voltage AC	Fibre only	>3000 m	A-frame	Yes

Based on ballast configuration ROVs are classified into two types, fixed and variable ballast. In a fixed ballast configuration, the ballast of ROV is constant. Therefore, propellers are used to generate thrust for diving and depth control like theSealion-2 by JW fishers, while in variable ballast thrusters are not required for controlling depth like JAWS [20].

ROVs can be characterised depending on their design and size into two categories, Intervention-class & Inspection-class.[21]

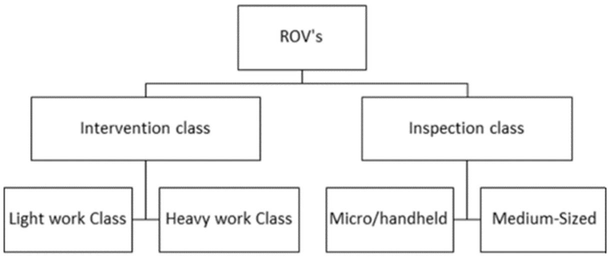

Fig.6. Flowchart of Classification

The majority of intervention-class ROVs, also known as work-class ROVs, applications are in the offshore oil and gas sector [22].This category is further divided into medium work-class and heavy-duty work-class models.

Standard light workROVs, such as the Super Mohawk and the ROV Sirio, weigh between 100 and 1500 kilogrammes and are used in survey and inspection activities.

Fig.7. Sirio ROV

Heavy-duty work-class ROVs are more durable and versatile vehicles, weighing up to 5000 kg and propelled by hydraulically actuated devices.These systems can excavate, support, and construct construction activities at depths of up to 6000 meters.[23] Their ability to perform heavy-duty work is mainly because of their strong hydraulic actuation. Some commercially available models of this category are Millennium plus ROV, Maximum ROV.

Fig .8. Millennium plus ROV

Inspection-class ROVs, also known as observation-class ROVs, are usually smaller than Intervention-class ROVs.In addition, inspection-class ROVs are classified as medium-sized or micro/handheld ROVs.

- Inspection-class ROVs weigh between 30 and 120 kg and can be launched and recovered by hand, but larger ROVs require the use of a Launch and Recovery System (LARS).They are generally open-frame models that allow for the addition of additional sensors and small equipment.
- They have precise navigation systems and high-resolution cameras that aid in mapping. They will execute specific minor tooling procedures, such as latching, in addition to navigation. They are usually operated by a DC supply with a voltage of up to 600 VDC [24] and have power specifications of up to 6 kW [25,26], such as the Deep Ocean Engineering Phantom T5 and SeaBotix L200-4.

Fig.9. Phantom T5 by Deep Ocean Engineering

Micro/handheld Micro Inspection-class ROVs weigh between 3 kg to 20 kg and can be dispatched andretrieved by labour alone. They are designed to complete the task efficiently with diminished operational costs [27] and system complexity coming in many configurations like cube-shaped variants and more streamlined shapes, requiring less power, mostly between 300 watts & 1800 watts. The contact signals are sent via the umbilical's copper cores.According to the criteria for low density, low cost, and total system portability, their depth rating is typically less than 300 m. Pressure housing wall thicknesses are reduced to minimise mass and expense, as seen in Teledyne Benthos' MiniROVER and JW Fishers' Seaotter-2.

Fig.10. Sea otter 2

Weight, ability, and power are also used to classify submersible ROVs [16] into Micro, Mini, Light Work Class, and Heavy Work Class [28].

- Micro-class ROVs are compact and light, weighing up to 3 kg, and are used in areas where a human diver would struggle to enter, such as sewers, pipelines, and small cavities.
- ROVs in the Mini-Class would weigh up to 15 kg.They can be used as a diver substitute and can perform a task without any external assistance.
- ROVs of the Light Work-Class are used for more demanding tasks, and the majority of them are equipped with manipulators (small three-finger grippers).Polymers or aluminium alloys make up their frame.
- ROVs in the Heavy Work-Class will dive to a depth of 1000 meters.Work-Class ROVs are used by offshore oil producers, and they have at least two manipulators and a sonar unit.ROVs for Trenching and Burial can hold a cable laying sledge and operate in depths of up to 6000 meters[29].

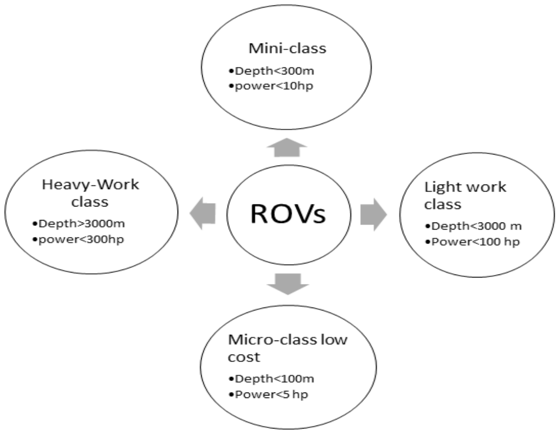

Fig.11. Classification of different classes of ROV

4. Applications

During recent years, ROVs have broadened their area of application with the inclusion of wireless connectivity, autonomous control systems, and better battery performance; they have found applications [31-37] in

- In the Aquaculture field, where fish farmers can track the fishes to get a better harvest.
- Inspection of underwater pipes, tanks, and open water applications such as hull inspection.
- The defence industry, where they are used to track anything suspicious in the water bodies, is also used to track weapons lost underwater.
- Environmental research and surveying of oceans and other water bodies.
- Municipal bodies for a routine inspection of dams and water bodies.
- Underwater photography and cinematography

5. Review of ROVs from different research papers

Contriving of ROVs [38]

ROVs are used to perform various tasks like measuring suspended particles in water, oceanographic investigation, water contamination, assessing marine territories, and operating in harsh conditions where human divers may not go. Therefore, it is a safer alternative to human divers. The ROV designed uses a copper or optic link, also known as the umbilical link, for remotely controlling it. In this, a person or administrator has control over the ROV while he is operating it from a shore-based controlling station or a boat. The ROV uses a turbidity sensor that can measure the turbidity level and the haziness of water. It also uses a GPS to keep track of its location. They have developed an android based app that can track the ROVs location and operate it with the help of an antenna fixed on the ROVs. A cloud environment is incorporated for storage and access to the data collected by ROVs. A node MCU (Microcontroller Unit) turbidity sensor, turbidity driver, is used for measuring water quality. This ROV has three thrusters; one is placed on top to control depth, while the others are used for horizontal motion. They have found out turbidity levels of water in different waters. It is established that water with turbidity values below 450 is safe to drink.

Their plans include improvising the projects by reducing the ROV's weight and using better sensors and better hardware. They hope to be able to change batteries, transfer data, and communicate new instructions without bringing the ROV to the surface

One of the limitations of this ROV is that the remote-control range is limited as the signals or waves do not travel well in water, and therefore high data transfer is not possible, resulting in a loss of contact with ROV. The use of optic fibre cable is not feasible as it cannot be used for deep waters. This method is expensive and not as effective as in deep waters. It is tough to communicate with ROV.

"Simplified Modelling and Identification of an Inspection ROV"[39]

ROVs are primarily used in the offshore industry, and their use continues to rise in this industry every year. They are usually used for underwater welding and assemblies but are also used for mapping and surveying.

The given paper looks into a control-aligneddynamic model structure gleaned from physical assumptions. It explores the option of including automation in the process of controlling ROVs. A Video Ray Pro 4 ROV was used, which belongs to the inspection class. They take an approach of incorporating the results of experiments in model studies. They consider some of the formulas and then estimate parameters based on their experimental data and perform various experiments, e.g., heave, surge, yaw, thruster parameter, drag coefficients, couplings.

Furthermore, the experimental data are compared with theoretical results. It was observed that theoretical data were close to experimental data for steady-state. Still, there was a significant variation for the transient state, therefore to correct them, two parameters were introduced as corrections in the transient state. These parameters were introduced based on experimental results. This way, they improved the overall model accuracy.

Some of their shortcomings are that they did not consider coupling effects that were significant in the model. Assuming the velocity in a given direction to be equal to the opposite, the analysis and experiments were conducted for a maximum depth of 3 m. "Experiments showed that there indeed was a great amount of coupling present between the surge and pitching motion at the large thruster actuation" [33]. Further, they want to include coupling effects in their model studies. Also, they want to include disturbances in their study in the future.

A Novel Low-Cost ROV For Aquaculture Applications [40]

This paper presents an ROV development for aquaculture inspection to provide data for Fishing and other associated aquaculture fields. The ROV is protected by a floating platform that can be used to recover it if it malfunctions. The ROV can be sent down the water body and lifted out using a winch on the deck. The proposed project aims to create a low-cost ROV that can be built with inexpensive and easily produced components. The ROV composes of three wings with a thruster embedded into each wing to provide the thrust. These thrusters govern the ROV's Mobility, and in this ROV the thrusters are configured such that it has omnidirectional movement.

The proposed ROV is designed for use in aquaculture environments, environmental investigations, providing advanced technology to the local aquaculture industry, and improving technology to support environmental exploration monitoring.

The project's main goal was to install a camera to inspect the aquafarm's net, use an umbilical for energy control and video signal, and provide versatile motion control, friendly GUI.The whole system is easy to use. In addition to scientific use, it could be of interest to consider the possibility of commercialising this ROV design. The whole project comprises a movable sea farm inspection platform, the ROV, and a supporting winch.Presently, the sea farm inspection platform is under testing. Furthermore, they aim to integrate the three subsystems and commence system testing soon.

A Customisable Underwater Robot [41]

Some of the various ROV applications in this paper are underwater exploration, archaeology, marine geoscience, and boat maintenance. The ROV designed has a fixed ballast configuration; in this case, the ascent and descent are achieved using vertical thrusters. During a power failure, due to its positively buoyant nature, the ROV resurfaces. They have enclosed their electronics in a watertight container that prevents water infiltration. They have incorporated a unique safety solution of moving the propeller inside the watertight container by using magnetic coupling using a motor. A customisable ROV model was proposed, which was claimed to be compatible with hardware components available readily in the market. The 3D printing technique is not a very common method employed to manufacture ROV components because of their challenges as the holes could be stripped very easily. However, the existing models could not address these problems. Therefore, to address the problems of 3D printing, they had to remodel and make changes in the existing model to make it suitable for 3D printing. They have explored the possibility of 3D printing components for ROV and have successfully tested it.

In this paper, researchers have successfully used 3D printed components to build a functional prototype and successfully tested it. Some of the ROV's drawbacks are that the model was tested only in shallow waters and 3D printed materials are not reliable for underwater applications. They want to test this model in deep waters in the future and hope to have different frame configurations.

6. Conclusion

This paper presents the historical development in the field of ROVs from their inception in 1953 to their modern-day adaptation.This paper contributes to our understanding of ROVs and their applications in various fields. Different designs and parameters of classification were discussed. Few prominent research papers dealing with different topics ranging from the application to design were reviewed.

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