Review: Remotely operated underwater vehicles with autonomous operation

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Abstract: Most actions that Remotely operated underwater vehicles (ROVs) perform are employed by operators, but with the rise of technology making it possible to accomplish autonomous tasks, these vehicles are getting able to perform some actions without human interference. This material is a review of ROVs that are able to execute some autonomous actions. This work started with the application BiLi Method to find relevant publications and work around the theme. Beyond showing some ROVs with autonomous actions, the main details and characteristics of control, sensors, and perception are presented and discussed.

Keywords: ROV; Autonomous actions; Control.

Revisão: Veículos submarinos operados remotamente com ações autônomas

Resumo: A maioria das ações que os veículos subaquáticos operados remotamente (ROVs) executam são empregadas pelos operadores,mas com a ascenção tecnológica tornando possível a realização de tarefas autônomas, esses veículos estão conseguindo realizar algumas ações sem interferência humana. Este material é uma revisão de ROVs que são capazes de realizar algumas ações autônomas. Esta revisão começou com o aplicativo BiLi Method para encontrar publicações relevantes e trabalhar em torno do tema. Além de mostrar alguns ROVs com tarefas autônomas, são apresentados e discutidos os principais detalhes e características de controle, sensores e percepção.

Palavras-chave: ROV; ações autônoma; Controle.

1. INTRODUCTION

The oceans, for the most part, are unknown especially the underwater depths, making research laborious. Such as interventions in submersible areas and the need for submarines in order to carry out monitoring, exploration and maintenance.

In the twentieth century, according to Bogue, american and british army was the first to use and design Remotely operated underwater vehicle (ROV) mainly for underwater military activities [1]. Today, the use of ROVs is still growing and large industrial groups that have oil and gas exploration in submerged areas are the main users.

Usually, at least one human operator is required for ROV actions. Commands are generated by operators through joysticks that are configured as teleoperation. As Schjølberg afirm, Tasks that use ROVs are costly, as well-trained professionals in vessels are required to execute the operations [2]. According to Albiez, currently, due to advances in automation techniques, perception, and control, the ability to perform tasks semi-autonomous is getting possible and broader. In the last decade, the underwater robot FlatFISH was able to execute all missions without any human interference, in other words, a fully autonomous robot [3].

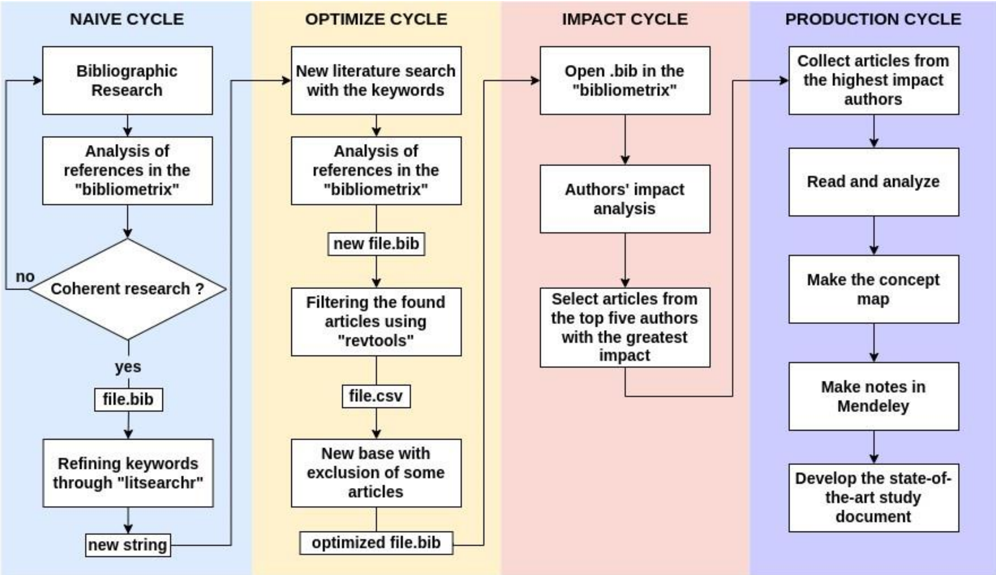
Underwater vehicles are capable of semi-autonomous operations or autonomous actions, resulting in increasing repeatability and reproducibility, as autonomous generally result in better results as compared to humans, and the same should occur with ROVs. The main objectives of this research are to carry out a review and discussion of applications, control, perception, and localization that are attributed to ROVs with autonomous operation.

2. METHODOLOGY

To execute this review, it was necessary to carry out a bibliographic study based on the BiLi methodology which includes bibliometric laws and principles[4]. The main bibliometric laws are Bradford's law which deals with the productivity of articles developed; Lotka's law which aims at authors' scientific productivity and Zipf's law which deals with the frequency of words in the text.

The BiLi method consists of using R language tools and code to refine publications searches on specific topics and, finally, produce concept maps to help make connections with primary and conceptual information. The method is divided into 4 cycles, as can be seen in Figure 1. The naive cycle consists of performing a simple search on an academic basis and thus exporting a .bib file. Then, used the Bibliometrix library, a package in R language dedicated to data analysis, from which information such as co-citation network, annual scientific production, historical, and word map is extracted [4]. If the search result is consistent, keyword refinement will be performed using the Litesearchr code and thus generate a new search string. If the result is not consistent repeat the cycle.

Figure 1. Bili Method.



With the development of the new search string created by Litesearchr [4], the process of the previous step was repeated, generating a new .bib. With the refined .bib, the Revtools library was used, which was made a new filter by title and abstract [4]. At the end of this choice, some articles were discarded, an optimized file was generated, and an optimized cycle was performed.

In the impact cycle, a new one was performed in Bibliometrix, the .bib file optimized by the previous cycle was analyzed, which aims to analyze the five authors with the greatest impact, as well as their respective articles. All articles that were used on this method were from 2016 until the 2021 year. In the production cycle, the scientific articles produced by the authors found in the previous cycle were collected and, thus, the complete reading and analysis were carried out. With the reading of the articles, the concept map was made, to effect interconnections of the main concepts that involve the theme and produce notes in Mendeley [4]. Finally, the elaboration of the state-of-the-art study was carried out.

3. RESULTS

According to Antonelli underwater robotics are vehicles that perform actions in underwater environments without a human presence, in other words, unmounted underwater vehicles [5]. ROVs are underwater robots that have human intervention, executed mostly by teleoperation. Some ROVs have the capability to execute autonomous actions such as hovering, autodepth, autoheading, autoaltitude, go to goal and obstacle avoidance because of their controller strategies that act mainly on thrusters and make the vehicles able to perform actions without human presence.

Control strategies are used to implement the ROVs movement actions. The data collected for these systems is obtained through the use of sensors and cameras with SLAM techniques. The data is mostly focused on the location of the vehicle.

3.1 Vehicles

Beyond the different autonomous tasks that ROVs can execute, these vehicles can differ in the control strategies that were implemented, element of perception, amount of thrusters, and other features. The vehicles: DexROV, SAGA, ROV-BWSTI, and SMU II are able to execute the autonomous operation. These vehicles are on papers that were used to compose this review. Table 1 shows some details about these vehicles such as the company that has developed them, sensors, actuators, control strategies, and autonomous tasks. The autonomous actions that these vehicles perform are aimed at movement such as hovering and auto depth which are present in all ROVs.

3.1.1 DexROV

The DexROV, developed by the European Commission, is a vehicle focused on teleoperation over long distances involving variable communication latencies with advanced handling capabilities [6]. It presents Ultra Short Base Line (USBL), Depth Sensor, Attitude, and Heading Reference Systems (AHRS) as its main sensors. Beyond being equipped with thrusters and manipulator actuators, the DexROV also features a Proportional Integral (PI) controller, which allows it to perform autonomous tasks.

3.1.2 SAGA

The unmanned underwater survey vehicle SAGA, was developed by Desistek group for the purpose of seabed exploration. It includes a camera and two-dimensional sonars. For actuation, it has two horizontal thrusters and one vertical thruster as its main actuators. There is also a Proportional Integral Derivative (PID) controller, which enables it to perform autonomous actions, the same as DexROV. It is possible to obtain navigational data and high-resolution video, as regards underwater operation, from this vehicle [7].

3.1.3 ROV-BWSTI

The ROV-BWSTI, was designed by the Fraunhofer Institute in Ilmenau, which is a remotely operated, highly maneuverable vehicle capable of performing various sensing tasks. Compared to other underwater vehicles, it is equipped with internal energy storage, which allows communication between the ROV and the control station via a special lightweight optical fiber with a length of 800 m [8]. This ROV also includes four horizontal thrusters and two vertical thrusters for motion and a Proportional Integral Derivative (PID) controller, which is capable to execute autonomous tasks.

3.1.4 SMU-II

The SMU-II ROV, which is present respectively in Figure 3, was designed by the National Natural Science Foundation of China to highlight engineering features for underwater applications, such as continuous working hours, simple crawling function, and perception of the environment [9]. Its main sensors are a digital compass, depth sensor, ranging sonar, angular rate sensor, and cameras, there are also main actuators such as two horizontal thrusters, two vertical thrusters, and one manipulator which allows a good motion and interaction with the underwater environment. To achieve autonomous tasks, a PID control was designed for this ROV.

Table 1. ROVs comparison.

ROVs	Company	Main Sensors	Actuators	Control Strategies	Autonomous Actions
DexROV	European Commission	USBL, depth sensor, AHRS and stereo cameras	thrusters, manipulators	Proportional Integral controller (PI)	hovering, autodepth, autoheading, autoaltitude and go to goal
SAGA	Desistek	camera, sonar	2 horizontal and 1 vertical thrusters	Proportional Integral Derivative (PID)	hovering, autodepth, autoheading, autoaltitude and go to goal
ROV-BWSTI	Fraunhofer Institute of Optronics	camera	4 horizontal thrusters and 2 vertical thrusters	Proportional Integral Derivative (PID)	hovering, autodepth, autoheading, autoaltitude and go to goal
SMU-II	National Natural Science Foundation of China	Digital compass, depth sensor, ranging sonar, angular rate sensor and cameras	2 horizontal, 2 vertical thrusters and 1 manipulator	Proportional Integral Derivative (PID)	hovering, autodepth, autoheading, autoaltitude and go to goal, obstacle avoidance

3.2 Autonomous Actions

The autonomous actions that these vehicles are able to execute are aimed at movimentation or holding the current pose to aid the human operators as [6], [7], [8] and [9] present. There are some simple tasks auto diving and auto depth that acts on the depth position of vehicles. Hovering is designed to hold the ROV's position and orientation. The auto heading is focused on orientation.

More complex actions consider the vehicles to move in an operation environment on all six-axis, as Go-to-Goal. This task is performed when a pose is selected on the environment and the ROV must move to it without any human intervention. Another task, which was implemented by Deng, is obstacle avoidance which is the capacity to overtake some objects that may appear in the underwater environment[9].

3.3 Control Strategies

The application of control is essential to the implementation of autonomous tasks. There are a variety of strategies that are applied to underwater vehicles aimed at autonomous tasks. The target of the Control is on vehicle's motion.

According to Ludvigsen, the motion controls that are usually applied in ROVs are aimed at developing handling capacity and depth tracking. In the DexROV vehicle, proportional integral control was used at six functionalities aimed at navigation: Hovering - dynamic position; auto-depth; auto-heading; auto-altitude, and go-to-goal[10]. These functionalities were classified as the basis for the control of the guidance system. The use of these functionalities, disregarding obstacles, enables the implementation of DexROV autonomous navigation. The development of the controls was done in a simulated environment and the delay of the signals that report vehicle dynamics to the operators. Implementing the delay makes the control simulation more similar to applications in real environments.

With Proportional Controllers and, also in a simulated environment on Gazebo software and Robot Operation System(ROS), Oliveira has implemented the functionalities of go-to-goal and executed a comparison with teleoperation[11]. The result of this comparison was that the automatic controller showed a better result than the teleoperation.

Also with the aim of developing autonomous functionalities, Kartal using optimal PID control in ROV simulations in the software Matlab-Simulink[7]. Due to the number of thrusters present in this vehicle, the control was developed just for surge, heave, and yaw using PID control. As there are no dedicated thrusters for roll and sway, it was not possible to implement a control strategy for them. Focusing on the development of a trajectory control through the intermediary, Rojas built PID controls for developing the ROV-BWSTI capable of performing the trajectory[8]. For control aimed at the positioning of underwater vehicles, the application of the PID control strategy and its simplest versions meets the objective of control very well.

The implementation of control is important for the realization of autonomous operations of ROVs as automatic control performs the actions that a human operator would perform, manual control. The junction of automatic controller applications with the data provided by sensors, localization strategies, and thrusters' actuation provides the main basis that makes ROVs capable of performing operations without direct dependence on human actions. There is a diversity in the data type, there are several sensors to collect it.

3.4 Sensors and localization

The presence of sensors in a system allows data collection. The measure of sensors can be directed to the dynamics of a system itself and localization. As well as classified by [10], sensors that are commonly used in ROVs can be distinguished into two groups: payload and navigation sensors.

Payload sensors are measurement units intended to collect data from the environment, some examples of these sensors are: sensors CTD, designed to measure conductivities, temperature, and depth, sensors ADCP (Acoustic Doppler Current Profiler), which are used to measure the velocity of chains and cameras to obtain visual data. Navigation sensors are implemented with a focus on vehicle navigation, so data about localization and speed are the main ones to be measured. Some navigation sensors are pressure sensors and DVL which measure the Doppler shift in the input signal reflected from the seabed to obtain linear velocity data and inertia sensors. With the increase in computer vision applications, digital cameras can also be used to obtain vehicle localization data through the application of SLAM techniques, as shown by [12]. Some SLAM techniques that use visual data are ORB SLAM, RGBD SLAM, and S-PTAM.

The ROV developed by [9] has 5 sensory elements: a digital compass, pressure sensor, sonar, an element dedicated to the vehicle's angular variation rate, and a camera. The data acquired by the sensors are used by the operator to assist in manual control.

Another sensor that is used in ROVs is the USBL (Ultra Short Base Line). The use of this element is mainly directed to the positioning of the vehicles on the NED (North-East-Down) reference frame. In [5], a USBL model was used in the simulation to measure the position. In this application, it was considered a problem that the USBL faces, the delay of signal. When the reference is too far from the vehicle, the answer about the current position takes a while to obtain. In addition to USBL, the vehicle simulated by [5], have more sensory elements: depth sensor and AHRS (Attitude and Heading Reference System). The AHRS was used to obtain data about the roll pitch and yaw of the ROV, although it can also measure depth. With the combination of these three sensors, it was possible to obtain data on the position and orientation of the underwater vehicle and perform some simple autonomous operations. The acquiring of data is very important in autonomous systems.

4. CONCLUSION

The objective of the present material was achieved. A state-of-the-art study was able to discuss and address the ROVs that have the ability to perform some action with low or no human intervention. It was observed that there are already some projects that have already been implemented on simulation environments. The architectures consider the implementation of automatic control to replace human actions. The control strategies are diverse, but there is a significant presence of PID control and its derivations. The use of sensors and cameras has great value. Visual data from the environment can also be used to detect the vehicle's pose in the driving environment operation.

To verify if these strategies can really be used, it is necessary to carry out developments of functionalities in a real environment.

5. ACKNOWLEDGMENTS

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