Development of Intellectual Support System for ROV Operators

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Abstract. The article describes the system of intellectual support for remotely operated vehicle (ROV) operators, which provides the precise movements control of the ROV and its depressor-weight along the specified trajectories, even in the case when the supporting vessel has no a dynamic positioning system. Proposed system provides operators with visual recommendations and warnings, which are formed in real time on the basis of expert evaluation of the information obtained from various sensors and navigation systems. Software and hardware implementation of the system was carried out for the working class ROV Comanche 18. Experimental studies of the developed system were carried out during an expedition to the Bering Sea on board of the research vessel Akademik M.A. Lavrentyev.

1. Introduction

Today, underwater robotic complexes are actively being developed and used to solve certain types of deep-sea operations for the effective exploration and development of the World Ocean. When the research is carrying out in the fields of hydrography, geophysics, hydrobiology, biochemistry, and exploration of oil and gas fields, there is an important task of large deep-water polygons investigation with the need for the high-quality video and photography, profiling, object detection, and the sampling of water, soil, animals and gas all along the route [1-5]. The performing process of these operations in real time should be controlled by the specialists who determine the purposes and places of sampling, and also correct the movement route. For the effectively solving of this task, it is advisable to use ROVs, but the capabilities of these vehicles are greatly limited by the presence of a flexible communication cable, which is under the significant hydrodynamic and hydrostatic influences from the surrounding water environment.

To solve the mobility limitation problems, an intermediate depressor-weight [2, 6] is used, which connects the thick reinforced cable of the lifting device with the flexible communication cable of the ROV. This common scheme ensures high mobility of the ROV within its working area limited by the length of the flexible communication cable. However, the depressor-weight can often collide with the sea bottom, creating an emergency situation, threatening the breakage of the flexible cable. At the same time, operators experience sensory, emotional and intellectual overloads, as they have to make decisions, analyzing a large amount of information and taking into account the features of several dynamic objects at the same time, as well as the conditions for performing underwater works: the current, the relief in the work area and the desired route for the ROV motion. As result, the human factor often becomes the reason for the quality decrease and the increase in the time for performing the research and technological underwater operations or even the emergency situations.

An intelligent control and alarm system of autonomous underwater vehicles was proposed in [7]. However, it cannot be used for intellectual and informational support of the ROV operators. In the work [8], an intuitive interface of the ROV operators was developed. But this interface does not provide the underwater complex coordinated movements for a comprehensive survey of the large deep-water areas. In the work [6] the control system, which allows to the simultaneous and coordinated control of the ROV and the supporting vessel, was proposed to exclude the emergency situations and provide the high-precision ROV motion along the given route. This system also allows to control the length of the reinforced cable, constantly monitoring the relative position of the ROV, its depressor-weight and completely avoiding the collision of this depressor-weight with the bottom.

Wherein, the current work describes the software implementation and full-scale tests of this system of intellectual support for the operators' activities, intended for the accurate and accident-free moving of the supporting vessel Akademik MA Lavrentyev, the ROV Comanche 18 and its depressor-weight.

2. The control of the ROV and the depressor-weight coordinated movements

The Modern specialized supporting vessels for the ROVs, for example, research vessels Akademik Golitsyn and Mstislav Keldysh, are equipped with dynamic positioning systems, which provide an automatic positioning of the vessel at a given point in space with the required heading angle at the calculated maximum parameters of the external environment. The ROV operating is possible only if the object of work or the destination point of the route is located in the working area of the vehicle, the dimensions of the area are determined by the length of the flexible communication cable, and the area location in space is the location of the depressor-weight held by the reinforced cable. For the high-precision ROV movement along long routes, it is necessary to use the control system [6]. This system allows to calculate the desired size and direction of the vessel movement, as well as the length of the reinforced cable, so that the ROV depressor-weight provides the greatest maneuvering freedom of this vehicle. However, if the carrier vessel is not equipped with the dynamic positioning system in space, the control of its movements is significantly complicated.

At present, research vessels, for example, Akademik M.A. Lavrentyev and Akademik Oparin, are actively used to work with ROV. These vessels have only limited means of positioning (the main engine and bow thrusters), which allows the ship to move with unavoidable positioning errors, especially in the conditions of currents and wind effects. Therefore, when the ROV is moving along long routes and its supporting vessel has no a dynamic positioning system, there is advisable to set the desired direction and speed of the vessel movement and move the ROV following this vessel. In this case, the ROV has to always be in the front hemisphere of its working area (see figure 1). This relative location of the ROV and its depressor-weight allows to make the stop near the detected object and perform the specified operation without requiring an immediate stop of the supporting vessel. In addition, this relative location allows to avoid the entanglement of the floating communication cable and the collision of the depressor-weight with the bottom.

The relative location of the ROV and its depressor-weight is defined by means of the beacons of a hydroacoustic navigation system with an ultrashort base. The antenna of this sonar system is fixed on the supporting vessel. The navigation system defines the coordinates x_v, y_v and z_v of the ROV, as well as the coordinates x_d, y_d and z_d of the depressor-weight in a right rectangular coordinate system rigidly connected to the vessel. The origin of coordinates is located in the vessel center of buoyancy C, Y axis coincides with the horizontal-longitudinal axis of the vessel, Z axis coincides with the vertical axis (directed down), X axis is right-handed (see figure 1).

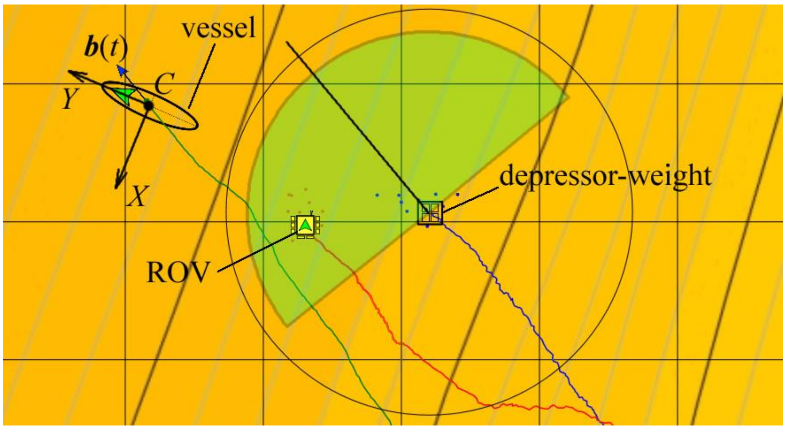

Figure 1. The ROV working area.

If the ROV is in the desired segment of its working area, then the angle between the unit vector $\boldsymbol{b}(t)=[\sin(\beta_r), \cos(\beta_r)]^T$, which determines the current direction of the vessel motion, and the vector $\boldsymbol{c}(t)=[(x_v-x_d), (y_v-y_d)]^T$, which connects ROV with its depressor-weight, does not exceed 90° in the XY coordinate system. In this case, the following condition is satisfied:

$$\arccos\frac{\boldsymbol{b}(t)\boldsymbol{c}(t)}{\|\boldsymbol{b}(t)\|\|\boldsymbol{c}(t)\|} \leq \frac{\pi}{2},$$

where β_r is the current heading angle that defines the supporting vessel movement direction in the XYZ coordinate system. This angle is measured by the vessel GPS system and, in conditions of wind and (or) currents, may differ from the angle of course β_0, which determines the spatial orientation of the vessel longitudinal axis. If this condition is not satisfied, an alert is generated to move the ROV to the desired segment of its working area.

3. The software implementation features of the proposed intellectual support system

The architecture of the intellectual support system for the ROV operators (see figure 2), which provides operators with visual recommendations and warnings, is proposed in the paper. They are formed in real time on the basis of expert evaluation of the information obtained from various sensors and navigation systems from different manufacturers. The software implementation of this system was developed based on the approach [2], wherein its architecture has several changes.

For the convenience of connecting of the various sensors and devices to the system, it includes the External devices communication module that asynchronously transfers and processes data. The internal software implementation of this module makes it easy to create classes of individual devices and run their internal methods in separate threads using the Task manager. This allows to minimize the process time spent for the data waiting, as well as control the performance of methods for processing the data.

The processed data of the devices enter to the Data management unit (see figure 2), which redistributes them to other units. So the coordinates of the sonar beacons and the supporting vessel are transferred to the Maps, tracks, target points and routes formation unit. This unit forms tracks and performs their filtering for further transfer to the communication unit with a User interface, and also draws the work area maps, determines and schedules the ROV and supporting vessel motion routes. The Data management unit also generates information about the relative position of the supporting vessel, ROV and its depressor-weight for further transfer to the Expert system. The User interface communication unit provides the processing of the operator commands, when he interacts with the User interface, and updating this user interface during the operation of the system.

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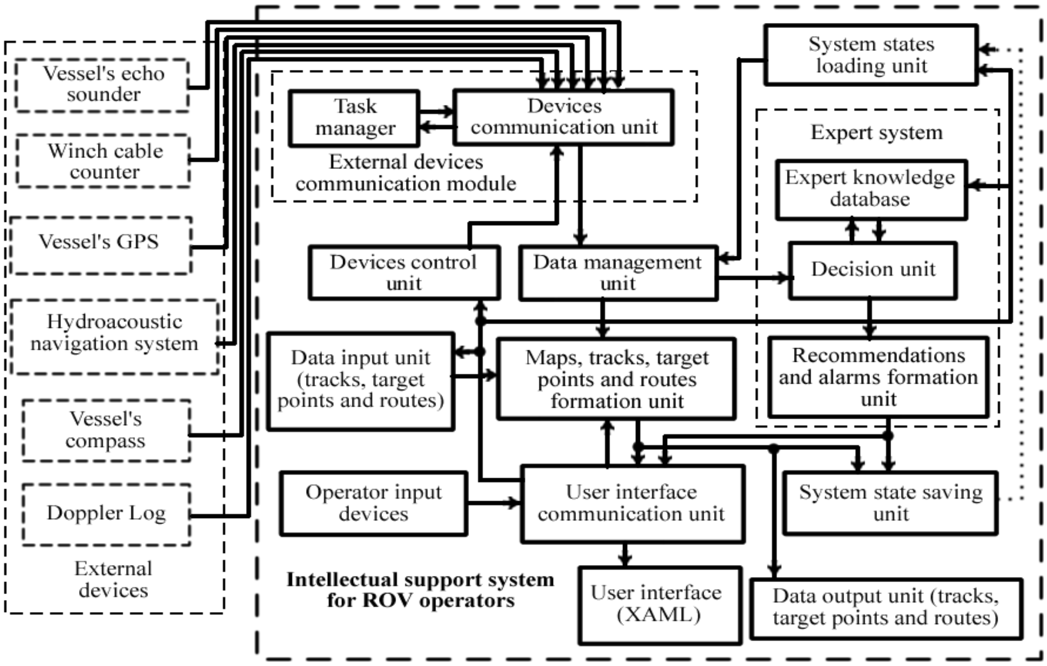

Figure 2. Generalized structural scheme of the intellectual support system for the ROV operators.

The algorithm for the controlling of the coordinated movements of the ROV and its depressor-weight [6] is implemented in the Decision unit. Herewith, the calculation of the values that determine the desired relative location of these objects is carried out on the basis of the formal estimates of the conditions for the performing of the underwater operation stored in the Expert knowledge database. These estimates are set by the operators or can be determined automatically based on the information from the sensors. In addition, according to the scheme shown in figure 2, the Decision unit compares the current data received from the sensors and external devices with the formalized security concepts from the Expert knowledge database. These formalized concepts can reflect the emergency tension of a flexible communication cable, the complex relief of the bottom surface, the possible contact of the depressor-weight to the bottom or to the ROV, the ROV is out of the desired segment of its working zone, etc. At the same time, the possibility of an emergency situation is revealed and the recommendations and signalling for the operators are formed.

Additionally, the ability to save and load the system states was implemented in the System states saving unit. Moreover, each change in the state of the system like the arrival of device data, commands of ROV operators, signalling, etc. are automatically saved to a file. The full playback of the saved system states is performed as the result of the reading of the saved file using the System states loading unit. This feature allows to analyse the process of performing already completed ROV dives in order to detect the system errors and the errors in the operators' actions.

4. Experimental research of the system

Experimental studies of the developed system were carried out in 2018 during a deep-sea research expedition to the Bering Sea on board of the research vessel Akademik M.A. Lavrentyev with the ROV Comanche 18. In the process of the underwater operations performing, the system was actively used to mark the found underwater objects and taken marine organisms by adding markers and entering signatures identifying underwater objects. The user interface displayed an added numbered marker with the current coordinates of the ROV on the working area map, as well as an item with an identifying signature in the list of target points (see figure 3). These capabilities allowed ROV to return to the previously discovered underwater object during the dive for its taking or studying, as well as to simplify the registration of detected objects.

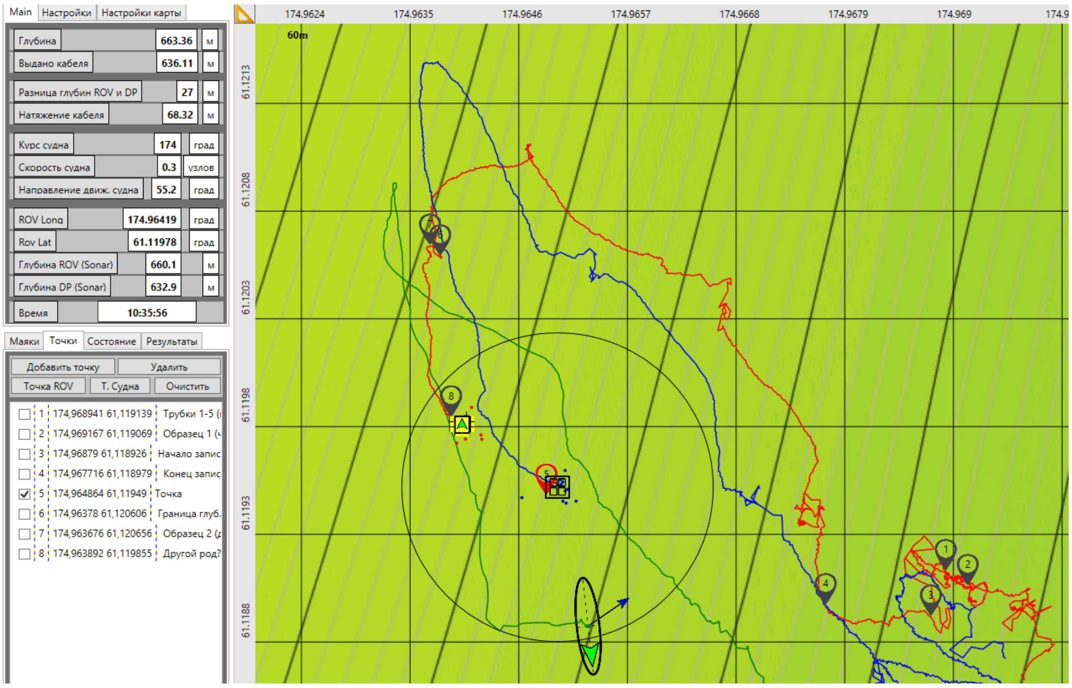

Figure 3. The user interface in the process of the underwater operation performing.

Also the developed system displayed tracks of movements of this vessel, ROV, and its depressor-weight on the basis of information obtained from the Sonardyne Fusion acoustic navigation system, as well as the GPS system of the vessel. At the same time, the system implements the possibility of the tracks filtering using an exponential filter, as well as the manually adjustment of its filter coefficient. During the underwater works, the tracks were saved to the log files, the format of which allowed them to be easily downloaded to various programs for the constructing of three-dimensional surfaces and reliefs, including the seabed. Figure 4 shows a three-dimensional model of the surface of the underwater volcano Piipa constructed using the software package Surfer 13, and also tracks of movements of the ROV Comanche 18 during the study of this volcano.

Generated by the program, warnings and recommendations for the operators have made it possible to completely avoid accidents and ROV damage. Also, the system feature of the saving and loading of its states allowed to analyze system errors and operators' errors with the subsequent exclusion of these errors.

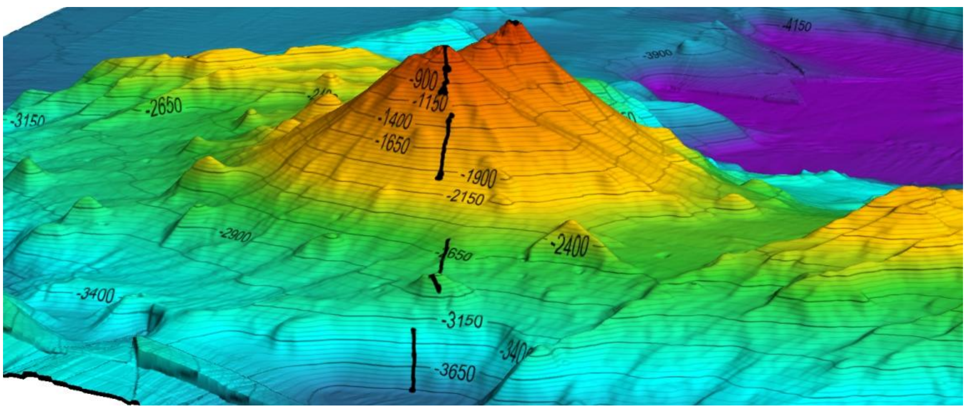

Figure 4. The surface model of the underwater volcano Piipa with tracks of the ROV Comanche 18.

In total, in the solving process of the expedition tasks, 21 dives of the Comanche 18 were performed. This ROV spent more than 150 hours underwater and passed over 53 km near the sea bottom. Underwater works were carried out at depths from 345 to 3880 meters and included a survey of the slopes and peaks of the Piipa volcano and underwater slopes near the coast of Chukotka, searching for various objects, video shooting, selective taking of marine organisms, and sampling of bottom water and geological rocks. The developed system increased the performing speed and quality of the expensive underwater works, allowed to avoid emergency situations, to simplify the construction of tracks of movements of the ROV and the registration of detected underwater objects.

5. Conclusion

It is important to note that the presented system was developed with the active participation of the team of engineers of the deep-water equipment department of the National Scientific Center of Marine Biology FEB RAS. Thanks to the close cooperation with these engineers and operators of the ROV Comanche 18, as well as customers of underwater operations, it was possible to create an easy-to-use software and to provide it with the functionality for effective and trouble-free performance of complex technological and research underwater operations.

6. References

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