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Prospects for the Use of Autonomous Underwater Vehicles (AUV) to Solve the Problems of the Mineral Resources Complex (MRC) of the Russian Federation

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ABSTRACT

Autonomous Underwater Vehicles (AUV) are one of the most advanced areas of underwater robotics development. One of the acute industry problems of the Mineral Resource Complexes (MRC) is the insufficient geological study of the territory of Russia and its continental shelf. This paper demonstrates a review of the world's experience with using AUV to solve such tasks. Also, it considers the possibility of using AUV for exploration of the MRC and escorting their extraction in the water areas of the Russian Federation by using methods of system analysis and a mathematical model. The results show that in Russia there is a shortage of specialists in the development and creation of both AUV and AUV, as well as control systems. However, it should be considered that bringing Russian research to an advanced level of development in the fields of ocean research and the exploration of mineral resources requires a significant increase in funding. Besides, the development and establishment of AUV in Russia for the resolution of MRC problems is a pressing issue that must be addressed.

1. Introduction.

Recently, most research has been aimed at ensuring the sustainable development of companies in the mineral resource complex. A significant number of scientific studies are devoted to the study of the directions for solving this problem, among which the works of Fedoseev, Pashkevich, Tsvetkova, and Plotkin et al. can be noted (Fedoseev & Xia, 2015; Pashkevich et al., 2015; Tsvetkova & Katysheva, 2019; Plotkin & Khaikin, 2017). According to the forecast of long-term socio-economic development of the Russian Federation until 2030, the contribution of the country's mineral resource base to its GDP will not be less than 10%. This will be ensured, among other things, by the sustainable development of the energy sector (Tsvetkov & Fedoseev, 2020; Resniova & Ponomarenko, 2021).

Insufficient geological study of the territory of Russia and its continental shelf are sectoral problems. On this basis, and in accordance with the state program of the Russian Federation "Reproduction and use of natural resources," the following goals are formed:

- Ensuring an increase in the fine-scale geological study of the territory of the Russian Federation and its continental shelf by an amount not less than 7% per year.
- Ensuring an increase of up to 5 percent a year in exploration of promising areas of the Russian Federation and its continental shelf.

Fulfillment of the above conditions is supported by the RF mineral resource base development strategy up to 2035 and may make a significant contribution to the development of mineral resource complex companies. This document forms the following priorities in scientific and technological development in the sphere of geological study of the subsoil, prospecting, evaluation, and exploration of mineral deposits:

- Geological data collection and interpretation will move to more advanced digital, smart, and robotic technologies.

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- Geological and geophysical research needs help with technology on the Russian continental shelf, in the World Ocean, the Arctic, and the Antarctic (Gusev, 2022; Cherepovitsyn & Evseeva, 2021).

Studies on the problems of developing information and management systems that provide solutions to various problems in the exploration and development of offshore hydrocarbon fields using methods of structural-parametric synthesis correspond to the priorities formed and can make a significant contribution to the sustainable development of mineral resource complex companies. In the study conducted by Martirosyan and Ilyushin, some of the approaches to solving such problems are presented (Ilyushin, 2022; Martirosyan & Ilyushin, 2022).

One of the promising directions for solving the above tasks is the use of AUV. Based on the use of modern intelligent and digital technologies for building control systems, these vehicles are going through a period of rapid development as automated vehicles that can do a wide range of complex tasks on their own. Modern AUV are a separate class of robotic objects with inherent functionality, technological properties, and the composition of systems and subsystems (Ageev et al., 2000; 2005; 2003).

Currently, self-propelled AUV are subdivided into two main subclasses: non-autonomous and autonomous. The class of non-autonomous underwater vehicles includes those that are towable or use a cable for control and power. They are most referred to as teleoperated submersibles. One thing that makes them stand out is that there is a communication cable between the vehicle and the control point, which gives the vehicle power and lets the operator control it remotely.

AUV represent a class of self-propelled vehicles equipped with onboard power sources, wireless control, and communication channels. The classification of AUV by the criterion of autonomy is being developed in the process of their evolution. At present, autonomy means not only the availability of onboard power sources for the vehicle but also the possibility of independent control and even decision-making by its control system.

This study assesses the possibility of using AUV for exploration of mineral resources and escorting their extraction in the water areas of the Russian Federation. It also looks at how AUV have been used in other countries and what the future holds for research in this area.

1.1. Foreign and domestic experience in the use of AUV and AUV.

Currently, the leading positions in the development and production of AUV are occupied by the USA, Canada, Great Britain, France, Germany, Japan, and Norway (Ageev et al. 2005; 2003; Illarionov et al., 2008).

The majority of AUV and their projects are created for the purposes of these states' defense departments. For example, the US Navy currently has approximately 260–300 AUV in service. The greatest development priority is given to vehicles based on small-size AUV (up to 50–70 kg). The hardware and software used in such AUV make it possible to solve a wide list of scientific and practical tasks in the range of 10 to 3000 m.

AUV are classified by different classification criteria. The most popular and generalized classification by mass-dimensional characteristics and nomination of AUV is as follows: portable AUV of the micro and mini classes; light classes; heavy classes; big classes; civil classes; and military classes.

AUV have good dynamics of development. For the past 5 years, on average, about 70 new AUV projects have been under development annually. Most of the projects under development relate to small-sized AUV (with a mass of less than 50 kg).

The main purpose of AUV projects may be military, civil, double, or experimental. Because of the modular principle of modern craft construction, distinctions between their target designations have blurred. Practically all modern AUV designs are multi-purpose. They have different levels of automation and are used for examination and search for underwater objects, hydrological and oceanological scientific works, as well as for military missions. Most operations are performed at a depth of up to 1000 m. About 30% of the AUV can dive to depths of more than 1000 m. The rest of them are less than 1000 m; deep-water AUV (with an operating depth of 6000 m and more) are very few.

AUV have several considerable advantages over vehicles of other classes: they do not use telecontrol (cable-communication) with the supply vessel. They have higher functionality when performing tasks in hard-to-reach places, higher stealth, and better mobility. It is also worth mentioning that the cost of AUV operations is less than AUV operations, as AUV do not require the constant use of carrier ships or supply vessels with specialized equipment for lowering and lifting underwater vehicles.

The practice of AUV application in the solution of various tasks testifies that, by virtue of their functional capabilities, modern AUV can successfully perform the following underwater technical works (Ageev et al., 2000; 2005; 2003; Illarionov et al., 2008; Polenin, 2015).

- conducting a search and survey of sunken objects;
- placing bottom beacon responders in strategic locations;
- surveying the bottom edges of ice fields, figuring out how thick the ice is and what kind it is, and doing subglacial hydrology;
- search for minerals at great depths and preliminary determination of geological formations' chemical composition;
- inspection and maintenance of underwater cable lines, pipelines, and other facilities;
- search and identification of underwater objects with predetermined properties;
- work in combative media;
- special military tasks, like reconnaissance, fighting against submarines and mines, acts of sabotage, tracking objects on the surface and underwater, etc.

Currently, the level of equipment and technologies used in the development and creation of AUV does not allow for the realization of all the potential capabilities of vehicles of this class. Their autonomy is low due to the low power capacity of their power sources; their manipulator system is underdeveloped; and their artificial intelligence level in using their control systems is low.

It is believed that modern AUV should have high autonomy (up to 200 hours), a developed system of manipulators, a highly organized ”intelligent” control system to be capable of solving a wide range of complex tasks and implementing such functions as pattern recognition, decision-making in conditions of partial and complete uncertainty, adaptation to external influences, etc.

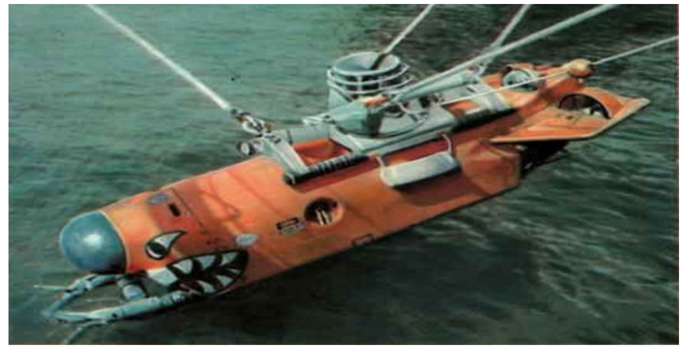
Many different firms are involved in the creation of AUV. In the United States, they are involved in more than 36, united under the auspices of the Defense Advanced Research Projects Agency (DARPA). In Japan, more than 250 firms are engaged in similar tasks. AUV, XR-21 Sea Squirt (United States), DOLPHIN, DOGGIE (United Kingdom), RTV-KAM (Japan), and ARUS (European Consortium).

Here the basic properties and characteristics of the most typical AUV of the leading developers are discussed. One of the first American AUV is the vehicle ”EX116,” which is in service on anti-mine ships of the US Navy, as shown in Figure 1. This underwater vehicle is equipped with two high-resolution TV cameras: one is used for maneuvering near the target; the other is on top of the stern of the vehicle and is used when surfacing the vehicle for precise docking with a hoist, as well as for monitoring cable status. The apparatus is powered by a cable from the carrier. This allows for almost unlimited time to solve the problem (Ageev et al., 2000; 2005; 2003).

In 1988, the US Advanced Research Projects Agency (DARPA) signed a contract with the Draper Lab for a program that envisaged the development of two experimental samples of AUV designed for anti-submarine and anti-mine warfare in the Arctic basin at depths of up to 1000 m. The SSN-21 and USS Los Angeles (SSN-688) were the carriers of the AUV. Several other firms were contracted at the same time. Aero and Naval Systems Div. of Martin Marietta (USA) was awarded 14.8 million dollars for general concept development and for development of an upper-level control system with elements of artificial intelligence providing survey and framing of minefields, placement of bottom-responding beacons, towing of hydroacoustic antennas, pattern recognition, decision-making on maneuvering, and application of a long-range weapon.

This AUV is 11 m long, 1.12 m in diameter, and weighs 6.8 tons. The apparatus is equipped with photo and video recording equipment, a set of tactile sensors, sonars, and a TV camera with a laser illumination device. The power source is a silver-zinc battery with a total mass of 2.3 tons, which gives the AUV a range of up to 360 miles at 4.5 knots. The Massachusetts Institute of Technology, in conjunction with the Draper Laboratory, was commissioned by NOAA Sea Grant to develop the Sea Squirt, a small-scale AUV designed to be used as a test platform for the AUV's artificial intelligence system. The vehicle is shaped like a cylinder with an outside diameter of 22.1 cm and is equipped with two propulsion motors for longitudinal and one for vertical movements. A silver-zinc rechargeable battery is used as a source of electric power. The vehicle's working depth is 60 m, and its empty weight is 28.6 kg. According to foreign specialists, the use of AUV as platforms for testing different equipment and systems is of sufficient interest. Thus, navigation and communication equipment, as well as systems for controlling large AUV movements, are expected to be tested using the XR-21 AUV, developed in 1988 by Applied Remote Technology, Inc. (USA). XR-21 can operate in both autonomous and tethered versions. The XR-21 operates by radar from an above-water position and by program or other means from an underwater position. For example, using the module of the XR-21's automatic control system that is being tested. The U.S. Defense Advanced Research Projects Agency is developing Hydra (Figure 2). This vehicle is a carrier for aerial drones and AUV. ”Hydra” has a special hull, structurally designed to accommodate drones of various purposes for their covert delivery to the area of operation. The AN/WLD-1(V)1 Remote Mine-Hunting System (RMS) Search and Destruction System consists of a semi-submersible vehicle and a towed AN/AQS-20 GASM, as shown in Figure 3. The apparatus has a mass of 7.3 tons and is 7 meters long. It is equipped with a 370-hp diesel engine. The mast has radio communication gear and a video camera that can be used to watch the surface visually.

Figure 1: AUV ”EX 116”.



Source: Authors Archive.

Figure 2: Hydra, an unmanned underwater transportation vessel carrier.

Source: Authors Archive.

There are some communication subsystems for the detection of underwater objects and possible obstacles. Information from the communication subsystems is continuously transmitted via VHF broadband digital channel to the carrier ship, he-

Figure 3: Remote Minehunting System.

Source: Authors Archive.

licopter, or coastal control post. Transmission of information beyond the horizon line is carried out on a low-frequency broadband radio channel. In the future, it is planned to use KB and satellite communication channels for this purpose. The AUV gets control instructions through a digital communication line, but it moves on its own according to the program that was set. Figure 4 shows the Klavesin-1P maneuvering vehicle designed in Russia.

Figure 4: AUV ”Klavesin-1P”.

Source: Authors Archive.

The Clavesin-1P is intended for survey and search operations as well as the survey of bottom objects. The apparatus can perform a mission in the program control mode and with correction through the hydroacoustic communication channel from the ship. The apparatus is used to study the Arctic shelf.

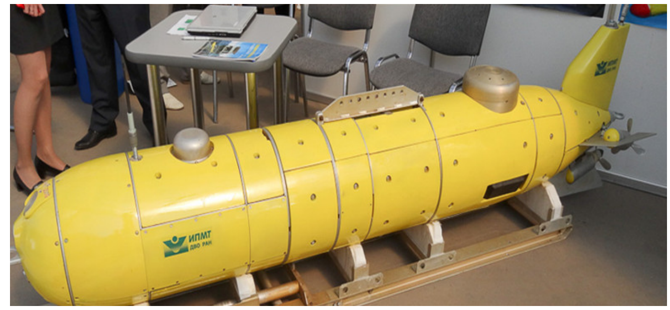
Figure 5 demonstrates a small, multi-purpose MT-2012 domestic AUV designed for deep-sea prospecting and measuring operations. It is easy to move around, has a smart control system on board, and can cover a large area.

SANPA is an autonomous unmanned solar-powered underwater vehicle (SAUV) shown in Figure 6 that has a long range and autonomous operating time in the ocean. One recharge of the batteries gives a run of 20–50 km. It is used to collect oceanological and hydrological information, meteorological observations, and environmental monitoring.

Domestic AUV are not inferior to their foreign counterparts in terms of technical characteristics, but their large weight and ”monolithic” design limit the list of possible solutions.

An example of a multifunctional AUV of modular design

Figure 5: AUV MT-2012.



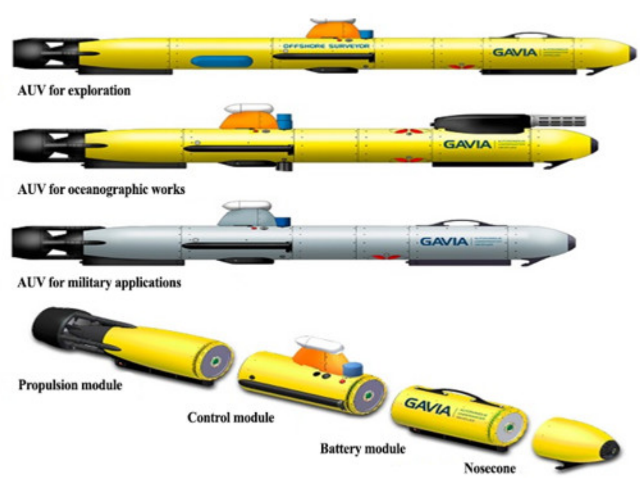
Source: Authors Archive.

Figure 6: ”SANPA” autonomous unmanned solar-powered underwater vehicle (SAUV).

Source: Authors Archive.

is the vehicle ”GAVIA” of Icelandic manufacture presented in Figure 7. The modular design of the AUV allows flexible re-equipment of it for the performance of various tasks.

Figure 7: Possible modifications of the ”GAVIA” AUV.



Source: Authors Archive.

The peculiarity of the vehicle is its autonomy and the possibility of over-the-horizon control (using the Iridium satellite communication system), as well as the considerable operational depth of immersion (up to 1000 m) at the low weight (from 49 to 79 kg) and volume (length not more than 2.7 m) of the AUV. Table 1 shows comparative tactical and technical characteristics (TTX) of the UVVs considered above.

Table 1: AUV Technical Specifications Comparison.

Country	Klavesin-1P	MT-2012	SANPA	GAVIA	Talisman L	RMS	Hydra
	Russia			Iceland	Russia		
Weight (kg)	2500	300	120	49-79	40	7000	-
Speed (knots)	3	5	2	8	5	10-16	8
Diving depth (m)	6000	3000	1000	1000	100	-	6000
Sailing autonomy (h)	48	24	6	7-10	12	24-40	-

Source: Authors.

Depending on the purpose of the vehicle, the AUV's basic performance characteristics are presented in Table 1, and the priorities in the choice of performance characteristics can be adjusted.

According to the results of the analysis, the following conclusions can be made: At present, the USA is a leader in the development and availability of operating AUV samples. Canada, France, and Japan are actively engaged in AUV development. Foreign units have more up-to-date technical equipment as compared with domestic ones, but Russian AUV are inferior to them in terms of technical characteristics. They perform a wide range of military and civilian missions. Multitask AUV with modular designs will be the most applicable and prospective soon. Currently, there are several UVV samples in operation, solving tasks in the interests of ISS. Thus, the study conducted by Gladyshev & Tamkov describes a portable complex that includes an underwater teleoperated robotic complex that can assess the ecological state of the seas and their bioresources in the context of carbon deposit development (Gladyshev & Tamkov, 2021). From the point of view of ecology, AUV are an indispensable tool to search for oil and other chemical pollution (Hwang et al., 2020a; 2020b; Tonacc et al., 2015; Wei Li et al., 2006). These devices were used to track the oil plume during the oil spill in the Gulf of Mexico (Camilli et al., 2010). Also, with the help of AUV capable of traveling long distances, they detected pollution in the Arctic (Kukulya et al., 2016). Studies of AUV to solve problems related to finding ways to use water resources in a smart way are interesting right now. Operations under ice are dangerous, so they require more thorough preparation. In a study conducted by Brito et al., the method of risk analysis was based on the experience of AUV developers, with the use of which successful works in the Antarctic were carried out (Brito, 2010). The AUV Theseus AUV is shown in figure 8. AUV have been repeatedly used in the investigation of aircraft crashes in the ocean. With their help, black boxes at great depths have been found (Sun et al., 2020). There is a unique development of glider-type AUV with a moving battery used to control them (Joo & Qu, 2015).

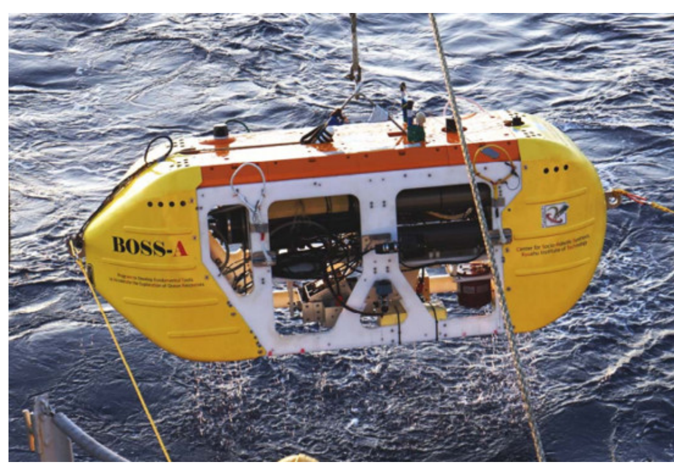
Figure 8: AUV Theseus under the ice in the Arctic.

Source: Authors Archive.

One cannot ignore the wide use of AUV by different countries (Wakita et al., 2010) for geological prospecting (Yoshida et al., 2013), the search for mineral resources (Yokota et al., 2018), seabed mapping, and seismic explorations (Martynova, 2017). It is also possible to use a camera and an acoustic sensor installed on the vehicle to detect rocks and determine the thickness of the rock (Nishida et al., 2015). Also, depending on the task, a hyperspectral camera can be used instead of a regular camera (Sture et al., 2013).

During the planning of the gas pipeline "South Stream," AUV were used for geological exploration (Lyakhov et al., 2017). One of such vehicles is shown in Figure 9.

Figure 9: AUVBOSS-A with a visual-acoustic device for inspection of manganese crusts located at 1,000 to 2,400 m depths.



Source: Authors Archive.

Thus, based on summarizing the practice of using AUV in solving tasks in various areas of application, their status, capabilities, and development trends as automated means capable of solving in autonomous mode a wide range of complex tasks. Based on the introduction of modern intellectual and digital technologies, it is possible to formulate a set of functions to be performed by AUV when exploring mineral resource complexes and supporting their production in water areas of the Russian Federation, as presented in Figure 10.

2. Materials and Methods.

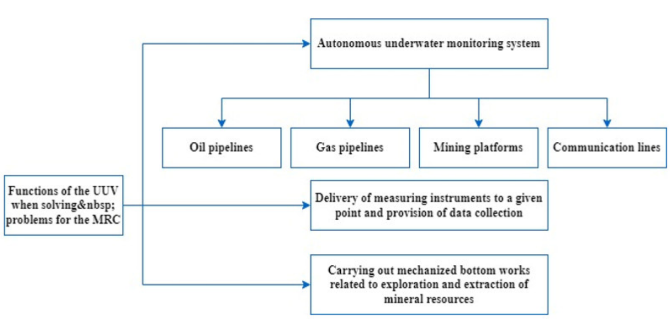
Currently, AUV are one of the most promising areas of robotics development (Bakharev et al., 2015). However, the current state of the technologies used in the development of AUV, and the modern methodology of their design do not allow for the implementation of all possible functions of AUV. The main problem associated with the development of AUV is the lack of research results on the creation of control systems that meet modern requirements for the quality of the tasks being solved.

According to experts, the most promising direction in AUV automation is a wide range of research in the field of the application of artificial intelligence in control systems.

AUV should steadily and effectively perform specified functions in an uncertain environment, which may be both partially and completely undetermined. At the same time, regardless of the functional purpose of the control system, it must fully ensure:

- quick, efficient decision-making during the problem-solving process;
- superior pattern recognition;
- choosing the best routes to take;
- correcting decisions based on the circumstances;
- complete transparency and accountability for actions taken;
- return to the beginning of the program's execution.

Figure 10: Functions of AUV when solving problems for the mineral resource complex.



Source: Authors.

Many maritime research laboratories are developing systems that will enable long-range underwater navigation in the future. Another important direction is the creation and development of small control and communication systems and power modules.

The urgency of the development and implementation of the AUV in Russia is determined by several essential factors:

- the vast, ice-covered areas of the northern seas, which are full of raw (mostly energy) resources.
- insufficient study of these territories.
- the need for scientific and practical proof that Russia is allowed to extend its economic zone into the north.
- the requirement for hydrographic support to expand the use zone of the Northern Sea Route and ensure its reliable operation.
- the prospects and feasibility of commercial development in Arctic marine territories, as well as their protection, among other things.

In a study conducted by Bozhenov, he reveals the problem of the lack of implementation of developed Russian AUV technologies and gives an overview of the use of AUV in developed western countries. He also describes the experience of their use in mapping the territory under the ice through sampling and emphasizes the fact that in Russia these areas are not developed (Bozhenov et al., 2011). The conclusions of Bardachevsky and Bezsudnov note that at present there is a high shortage of specialists in the field of the development of AUV and control systems for them in Russia (Bardachevsky et al., 2013). In another study, Laverov et al. note that Russia lags developed countries in the issues of shelf exploration and point out the lack of resources, technologies, and specialists for carrying out seismic surveys (Laverov et al., 2011).

3. Results.

Let the goal of developing a system of exploration and support for mineral resource production (SESMRP) in Russia's water area equipped with the AUV to provide solutions to tasks in Russia's mineral complex be defined.

The SESMRP may include all or part of the existing organizational structures, including organizational and technical systems, including the AUV that perform the functions of direct executive elements. The appearance of these structures and systems may be changed if necessary. Besides, the formation of new organizational structures and development of new organizational-technical and technical systems, as well as complexes, are possible for inclusion in the SESMRP. It is required to determine the appearance of such a SESMRP, which best corresponds to the set goal in the given constraints.

Mathematically, the problem of the synthesis of SESMRP is written in the following form (Mesarovich et al., 1973):

$$V^* = Arg \min_{V \in \{V_\partial\}} C(V, U); \tag{1}$$

$$\{V_\partial\} = \{V : W(V, U) \geq W_{mp}; R(V, U) \subseteq R)\},$$

where $C(V, U)$ is a function of the costs (expenses in monetary terms) for the creation, maintenance, and application of the future SESMRP, the minimum value of which corresponds to the customer's ideas about the best option of SESMRP V^*;

$\{V_\partial\}$ – the set of admissible variants of the SESMRP V_∂;

$W(V,U)$ – the performance indicator of the solution of tasks by the SESMRP Vvariant in the conditions of U;

W_{mp} – the required efficiency of solving the tasks of the SESMRP.

$R(V,U)$ – the resource required to develop, maintain, and implement a variant of the SESMRP V in in the presence of U;

R – specified resource constraints (energy, space, time, etc.) $R(V,U)$ required for the creation and application of the variant SESMRP V.

It is practically impossible to directly solve the problem of synthesizing SESMRP (1) due to its structural complexity and large dimensionality. The method of hierarchical decomposition of the problem by aspects, levels, and synthesis stages is the main method for solving this problem, as the experience of synthesizing such systems shows. Hierarchical decomposition of the SESMRP synthesis problem (1) allows not only unbundling the problem based on the "whole-part" relation but also realizing the "right of intervention of the upper level" and "dependence of the upper level on the lower levels" (Yoshida et al., 2013).

The represented image of SESMRP $V = (V^D, V^S, V^X)$as a set of descriptions of functions V^D, structureV^S, and a set of characteristics V^X is described here, i.e., as a set of organizational, functional, structural, and parametric images of SESMRP.

Depending on the state of development of the SESMRP and the goals of the research, different hierarchical relationships between the aspects of its synthesis can be established. For the case where the upper level is occupied by the organizational and functional aspect of SESMRP synthesis (that is, the main process is the organizational and functional synthesis) and the lower level is the technical aspect of synthesis, the decomposition of the general problem of SESMRP synthesis (1) will look like this:

a) The task of organizational and functional synthesis

$$V^{D^*} = Arg \min_{V^D \in \{V^D_\partial\}} C(V^D, \tilde{V}^{S^*}, \tilde{V}^{X^*}); \quad (2)$$

$$\left\{V^D_\partial\right\} = V^D : V^D \in V = (V^D, \tilde{V}^{S^*}, \tilde{V}^{X^*}),\ W(V,U) \geq W_{mp,}\ R(V,U) \subseteq R;$$

b) The problem of systems synthesis

$$V^{S^*} = Arg \min_{V^S \in \{V^S_\partial\}} C(\tilde{V}^{D^*}, V^S, \tilde{V}^{X^*}); \quad (3)$$

$$\left\{V^S_\partial\right\} = V^S : V^S \in V = (\tilde{V}^{D^*}, V^S, \tilde{V}^{X^*}),\ W(V,U) \geq W_{mp,}\ R(V,U) \subseteq R;$$

c) The problem of technical (parametric) synthesis

$$V^{X^*} = Arg \min_{V^X \in \{V_\partial\}^X} C(\tilde{V}^{D^*}, \tilde{V}^{S^*}, V^X); \quad (4)$$

$$\left\{V^X_\partial\right\} = V^X : V^X \in V = (\tilde{V}^{D^*}, \tilde{V}^{S^*}, V^X),\ W(V,U) \geq W_{mp,}\ R(V,U) \subseteq R,$$

where the symbol «~» indicates the solutions obtained from the previous iteration step. Problems of organizational-functional, system-technical, and technical synthesis (2), (3), and (4) are solved together. When it is impossible to obtain an acceptable solution to any one of these problems, the solutions to the other problems, as well as the constraints and conditions, are specified. The sequence of solutions arising because of such an iterative process will converge on the variant $V^* = (V^{D*}, V^{S*}, V^{X*})$, which is the solution to the general problem of synthesizing SESMRP (1).

At the same time, by solving particular problems of synthesis by aspects, intermediate variants are searched in advance $\{\tilde{V}^*\}^D, \{\tilde{V}^*\}^S, \{\tilde{V}^*\}^X$, as a result of repeated cyclic transitions from one aspect to another, these solutions are specified, and when "stable" sets are obtained, the iterative process stops. As a result of such a complex forward and backward movement by and within each type of decomposition, a cyclic iterative process with a non-stationary hierarchical structure is formed, which provides a gradual justification of the properties, characteristics, and order of functioning of the future SESMRP and the achievement of ideas about its expedient appearance as a result.

4. Discussion.

As stated previously, the scientific field of control systems for AUV was briefly explored.

Currently, the main vector of research in the field of AUV is the application of artificial intelligence for information and control systems (AUV). As a result, research possibilities include the following:

- integration of neural networks into the decision-making system;
- application of pattern recognition-based systems for object search and navigation;
- implementation and improvement of SLAM (simultaneous localization and mapping) algorithms;
- development of adaptive control systems.

There is little research on the modeling of both the AUV and its modules. Due to the difficulty of testing hypotheses on a real vehicle, this field of research can be considered promising in real-world conditions.

Separate research is required to review and design control systems to solve environmental problems related to the development of methods for the rational use of water resources.

Research in these areas will expand the range of AUV operations, make development cheaper (due to the appearance of multifunctional vehicles), and bring Russian research to the advanced level of development in the fields of ocean research and mineral resource exploration.

Conclusions and Recommendations.

Existing scientific achievements in the field of AUV development show great interest on the part of researchers in this field of human activity. The most elaborate areas of AUV creation and application are:

- navigation systems;
- propulsion systems and vehicle hulls.
- power supply systems;
- crafts proper for operation in middle latitudes.

These directions are well developed because of the borrowing and usage of scientific developments, schematics, and technical solutions from allied spheres of application, such as systems of submarines and manned and remotely controlled underwater vehicles.

The poorly studied areas of AUV research could include:

- control systems;
- vehicles for use in northern latitudes and under the ice.

Also, it is necessary to note the big deficiency of experts and technologies in Russia in the field of development, both in terms of actual AUV and the control systems for them.

As a result of the analysis, the following conclusions were drawn:

1. At present, research aimed at ensuring the sustainable development of MRC companies is urgent.
2. Research on the problems of developing parameters for information-management systems for the exploration and development of sea hydrocarbon fields using methods of system analysis and synthesis can significantly contribute to the sustainable development of the MRS companies.
3. One of the acute industry problems of the MRC is the insufficient geological study of the territory of Russia and its continental shelf.
4. AUV today are one of the most advanced areas of underwater robotics development.
5. The state of current technologies used in the development of AUV, and modern design methodologies do not allow for sufficient realization of all possible functions of the devices in this class.
6. Due to their autonomy, AUV are promising tools for the exploration of offshore hydrocarbon deposits, especially in ice-covered areas of the ocean.
7. The development and establishment of AUV in Russia, both for the resolution of MRC problems and those of other industries, is a pressing issue that must be addressed.
8. There is currently a shortage of specialists in the development and creation of both AUV and control systems for them in Russia.
9. AUV are currently being researched as a tool for solving problems associated with the development of methods for the rational use of water resources.
10. Bringing Russian research to an advanced level of development in the fields of ocean research and the exploration of mineral resources requires a significant increase in funding.

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