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REFINING THE CLASSIFICATION OF UNDERWATER MISSIONS PERFORMED USING UNDERWATER COMPLEXES WITHFLEXIBLE CONNECTIONS

УТОЧНЕННЯ КЛАСИФІКАЦІЇ ПІДВОДНИХ МІСІЙ, ЩО ВИКОНУЮТЬСЯ ІЗ ЗАСТОСУВАННЯМ ПІДВОДНИХ КОМПЛЕКСІВ З ГНУЧКИМИ ЗВ'ЯЗКАМИ

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Abstract. The concept "underwater complex with flexible connections" has been introduced to the field of marine robotics. Advanced underwater technologies that are implemented with the help of underwater vehicles and complexes with flexible connections are considered, and the main features of their operation are established. The existing systems for classification of tethered underwater vehicles are supplemented with classification features that take into account basic underwater technologies, surface conditions for underwater works, characteristics of underwater space, and intended purpose.

Keywords: underwater complex; flexible connection; classification; tethered underwater vehicle; underwater works.

Анотація. Для галузі морської робототехніки введено поняття «підводний комплекс з гнучкими зв'язками». Розглянуто сучасні підводні технології, що реалізуються за допомогою підводних апаратів і комплексів з гнучкими зв'язками та встановлено основні особливості їх експлуатації. Існуючі системи класифікації прив'язних підводних апаратів доповнено класифікаційними ознаками, які враховують базові підводні технології, надводні умови проведення підводних робіт, характеристики підводного простору та використання за призначенням.

Ключові слова: підводний комплекс; гнучкий зв'язок; класифікація; прив'язний підводний апарат; підводні роботи.

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Problem statement. WTo date, the world has been experiencing a rapid development of marine engineering and technology. One of the directions for the development of marine engineering is creation of underwater complexes with flexible connections (UCFC). The UCFC is a set of marine mobile objects (MMO), such as surface or underwater vessels, underwater vehicles, etc., which are directly or indirectly linked via flexible connections and designed for a joint implementation of a specific underwater mission. As tethered means of marine robotics, the UCFC are developed and actively employed by the world's leading maritime countries for a wide range of search, emergency and rescue, inspection, research and specialized underwater missions. Configurations of the UCFC and tethered underwater vehicles (TUVs) as their part are extremely diverse, which is primarily caused by the range of underwater missions such complexes are created for.

Ukraine as a maritime state needs to develop brand new and elaborate the existing marine technologies dealing with underwater inspection, geological, archaeological, search and rescue works. Various underwater works are an integral part of national, sectoral and regional programs of Ukraine [1–4]. Therefore, development and improvement of the theoretical foundations for the UCFC creation with the purpose of enhancing the overall performance of underwater missions is a relevant applied problem.

Latest research and publication analysis. The UCFC comprise a large class of marine robotic equipment, including tethered self-propelled, towed and submersible vehicles and systems. The tethered underwater vehicles and systems (TUS) which are constitutive of the UCFC are well studied and described in the scientific and technical literary sources. Their classification is given in [5–7]. Moreover, they served as a basis for creation of numerous TUVs and their introduction into maritime practice [8–11]. A number of research papers consider towed underwater vehicles and systems [12–14]. These and other scientific publications render the functioning of the UCFC quite thoroughly and provide an opportunity for the creation of such systems for particular underwater missions.

However, the issue of classification of underwater missions for the UCFC as a special type of marine robotic equipment that has considerable working space limitations is currently covered unsystematically in scientific papers.

THE ARTICLE AIM is to refine the system of classifications of underwater complexes with flexible connections as design objects and to determine the areas of their preferred application.

Basic material. Works with the use of UCFC involve the implementation of a specific underwater technology, which in turn is part of a more general complex of works performed within the framework of an appropriate underwater mission. Underwater activities (scientific research and other tasks) are realized on the water surface, in the water column, and on the sea floor. The underwater missions performed by the UCFC are usually divided into underwater search throughout large areas, works on extended objects, and works on point underwater objects. Such missions are carried out using four basic underwater technologies presented in Fig. 1 [1, 8].

The above-mentioned technologies are realized through interaction of an UV and a support vessel (SV).

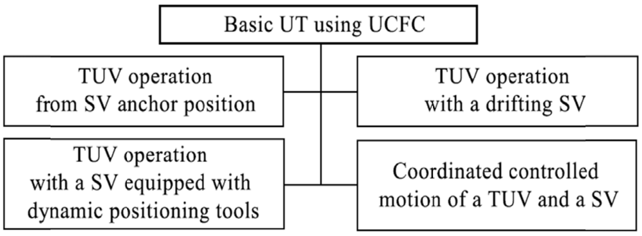


Fig. 1. Basic underwater technologies implemented with the use of UCFC

The underwater technologies under study have the following peculiarities. In the first case, the task of UCFC control resides in moving the SV to new anchor positions; in the second case, the task is to stabilize the SV at a given point on the water surface; in the third case, the SV is to be returned to the drift starting point; in the fourth case, the control task is vessel navigation along a given route.

Works with the use of UCFC involve the implementation of a specific underwater technology, which in turn is part of a more general complex of works performed within the framework of an appropriate underwater mission. Application of the UCFC elements should be considered as inextricably linked with hydrometeorological conditions, navigation circumstances, and movement of all the UCFC elements. Underwater works employing UCFC are classified according to their surface conditions as presented in Fig. 2.

It is essential to consider the above conditions both when organizing the works and designing the UCFC, as well as selecting the SV.

For example, under limited navigation conditions (such as water areas with vigorous ship traffic), one of the measures to be provided is the minimal length of the released part of the flexible connection (FC).

Works at night require illumination of the deck and a large overboard area in order to control the released part of the FC. Meanwhile, works in the presence of drifting ice require providing for the safety of the FC. At submersion under the ice, the submersion site is to be arranged properly (a hole is to be drilled, etc.).

The classification of underwater works performed by the UCFC according to the working space is shown in Fig. 3.

The listed features are important for the formulation of the UCFC specifications, the process of its design, and the efficient movement control.

According to the complexity of underwater works, they are divided into the following four types:

– simple works include video inspection and measurement of hydrophysical and hydrochemical water parameters, speed of sound propagation in water, physical fields of underwater objects;

– medium-complexity works include photo and video shooting of the sea bottom surface and underwater objects with a geodetic reference and parameter measurement, mapping, work with add-on underwater tools (cutters, manipulators), and search works;

– complex works involve sharp hydrometeorological conditions (currents, wind wave effects, diving in the presence of the floating ice, diving under the ice, large variations in water and air temperatures), complex underwater navigation, limited duration of the works, manipulator operations of enhanced accuracy, operation under unpredictable underwater conditions, search and identification of underwater objects, maintenance of underwater technical devices;

– especially complex (unique) works take place in an aggressive environment (with a radioactive or chemical contamination), precision positioning, going inside the sunken objects, work with dangerous underwater objects, search and identification of underwater objects with given properties.

The complexity of underwater works defines the requirements for the UCFC specifications and the quality of appropriate automatic control systems.

Depending on whether there are any people under water, the works are divided into those with and without human participation; the former are conducted with the help of divers or aquanauts of inhabited UVs. This feature is crucial for the design of a particular UCFC, since the presence of a human being under water imposes a number of restrictions on design solutions and control algorithms for an inhabited UV.

From the point of view of the UCFC design and equipment with appropriate devices and tools for underwater works, it is important to distinguish underwater works according to their purpose (see Fig. 4).

The search works are conducted using hydroacoustic systems and devices that measure the physical fields of a sought-after underwater object. In some cases, the search follows a chemical or radiation trail of the underwater object. An integral part of the majority of modern search UCFCs is photo and video tools for detecting and identifying underwater objects.

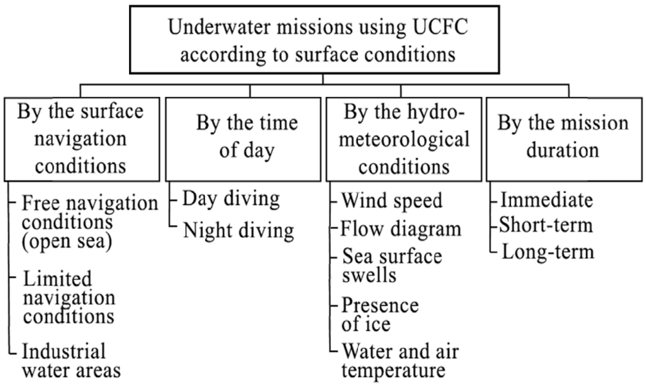


Fig. 2. Classification of underwater missions with the use of UCFC according to their surface conditions

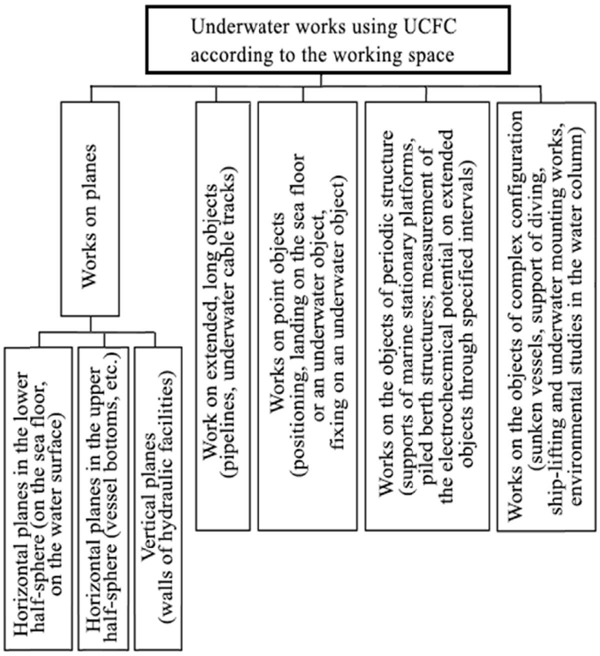


Fig. 3. Classification of underwater works according to the working space

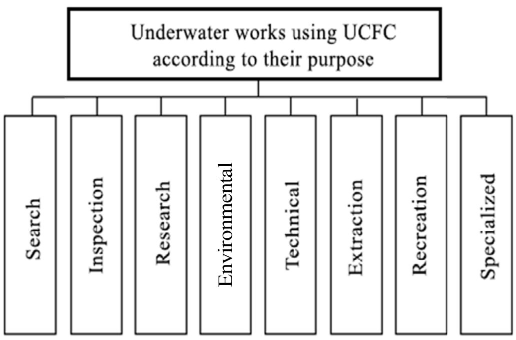


Fig. 4. Classification of underwater works according to their purpose

Thus, hydroacoustic systems (azimuth search sonars and sector-scanning sonars, echo-sounders, etc.) have a wide-band range and are used for detection of large underwater objects and safe movement of the UV under the conditions of low water transparency (Fig. 5).

Within the inspection works, inspection and examination of an underwater object (UO) can be conducted. The former comprises visual identification, analysis of the exterior, determination of the spatial position and the state of individual components of the object. It is performed with the aid of photo and video cameras installed on the UV. Meanwhile, examination involves measurement of the physical fields of the object, visual determination of its technical condition, and establishment of the object's compliance with the technical requirements. In this case, one of the main requirements for the UCFC is its functional flexibility, i. e. simplicity of re-equipment of the UV with various measuring devices when changing the task. A typical example is inspection of underwater pipelines (Fig. 6).

The research works occupy a rather important place among the areas of UCFC application. They suggest oceanographic, hydrophysical, hydrochemical, hydrobiological, ecological, and archaeological research and provide for the use of a wide range of instruments measuring hydrophysical and hydrochemical characteristics of water. These also include working with artifacts.

Typical underwater works of this type include water and soil sampling, capture and selection of marine animals and plants, sea bottom echolocation, seismic sounding, documentation of the detected artifacts and lifting them to the surface, etc. [9]. The peculiarity of designing such UCFCs is the need to ensure their functional flexibility, low noise level, movement along a given trajectory, possibility of positioning, and metrological reliability of the measurement results. These works commonly employ photo and video systems with high optical characteristics and specialized spot and general lighting fixtures that provide for the required quality of color transfer.

The UCFCs of the scientific research purpose and the results of their underwater missions are presented in Fig. 7.

By their very essence and requirements they pose for the UCFC, the environmental works are close to inspection and research; however, they require specific designs for preservation of water and soil samples. Besides, additional requirements for such systems deal with metrological control of the navigation and measurement devices.

The technical missions include underwater works performed by the UCFC with floating or bottom working-class UVs equipped with tools for underwater cutting, welding, weld and surface dressing, underwater object sealing, application of underwater clamps and manipulators (see Fig. 8).

Moreover, the soil works performed by the UCFC with bottom working-class UVs like earthmoving trenchers and cable layers also belong to this type of missions.

The underwater extraction works are intended for extraction of the World Ocean's litho- and hydrosphere resources on an industrial scale. They cover the following main directions (both existing and developing):

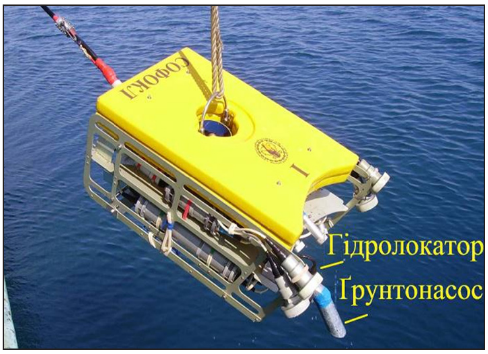
– mining of solid minerals: ore sands, diamond-bearing bottom sediments, sulfur, gold and platinum, deposits of titanium and zirconium minerals on the continental shelf (at depths of 90-200 m); iron-manganese nodules and deep-water sulfide ores (at depths of 2000-6000 m);

– mining of building materials: pebbles, construction sand, and shell deposits (at depths up to 50 m);

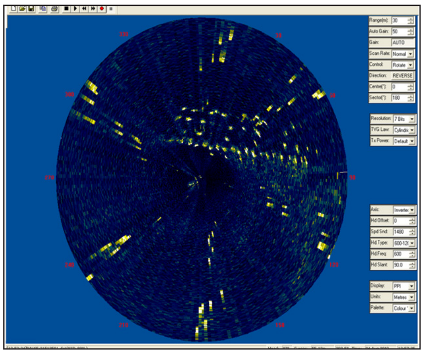
– extraction of fresh water (from underwater sources), salts and brines for the food and chemical industries;

– extraction of organo-mineral deposits of the biogenic origin (sea sapropel) for the use in agriculture;

– marine energy engineering: extraction of gas hydrates, use of the energy of underwater currents and waves;

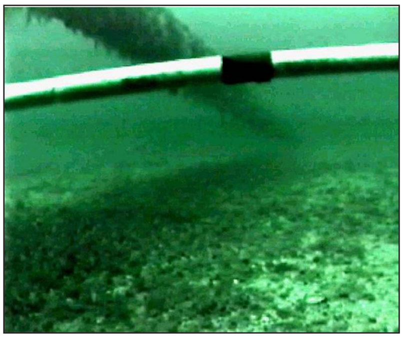


a)



b)

Fig. 5. Search UCFC: *a* — search sonar and ground pump installed on the multipurpose UV of the "Sopfokl" project (manufactured by the Admiral Makarov National University of Shipbuilding); *b* — sonogram of the search for sunken objects in the water area of the Southern Bug River (Mykolaiv)

a) *b)*

Fig. 6. Search and inspection UCFC of the "Poshukovets" project and the results of an underwater pipeline inspection: *a* — ROV (manufactured by the Admiral Makarov National University of Shipbuilding); *b* — sagging defect of the underwater main pipeline that was revealed


a) *b)*


c) *d)*

Fig. 7. Research UCFC and the results of appropriate underwater missions: *a* — UV of the "Inspector" and "Sophokl" projects (manufactured by the Admiral Makarov National University of Shipbuilding); *b* — artifact lifting; *c*, *d* — examination of a sunken Byzantine galley


a) *b)*

Fig. 8. Underwater vehicle of the Admiral Makarov National University of Shipbuilding used for underwater technical works: *a* — modernized working-class UV (project "MTK-200"); *b* — testing of the UV with a manipulator in the experimental tank

– production of seafood: fish (using specialized underwater equipment, for example, in order to monitor the state of fishing gear), algae (such as phyllophora) for the food, medical, and beauty industries.

The recreational underwater works include entertainment, educational and sporting activities performed with the use of underwater devices. At present, these works are more vigorously conducted with the use of inhabited autonomous vehicles. However, the role of UCFC in technical support of the recreation industry is increasing.

The specialized underwater works include emergency and rescue operations and operations in hazardous environments. The emergency and rescue works may suggest delivering rescue divers to the emergency object, providing life support, power supply and communication systems to the crews of sunken submarines, delivering tools and personal safety devices, performing underwater works with the use of appropriate tools, supporting the evacuation of crew members from an emergency submarine.

The works under hazardous conditions involve search, inspection and technical operations in chemically, biologically, thermally or radioactively aggressive waters, in the areas with sunken hazardous objects.

An analysis of the entire spectrum of underwater works allows formulating the following special features.

The UV operation range is limited due to the finite length of the FC; thus, fthe work of both the surface and underwater parts of the UCFC has to be organized in a special way.

The quality of the results of underwater works is substantially affected by the ship motions and disturbances that arise on the FC. Particularly sensitive to such disturbances are the UVs that perform positioning, video shooting, and the like.

The task of synchronous movement of the underwater and surface parts of the UCFC at the examination of large objects is rather complicated. It is further impeded by the UV operation in the current or under the conditions of an intense wind wave effect on the support vessel.

When working under limited navigation conditions, it is important to predict and control the spatial configuration of the FC. Otherwise, the FC might get either entangled and caught up in underwater obstacles or sucked into the propulsion and stern units of the support vessel. In this case, the FC will be damaged and the UV will be lost.

CONCLUSIONS. 1. The article provides a definition of the underwater complex with flexible connections as an important type of marine robotic equipment. It considers the modern underwater technologies realized with the help of underwater vehicles and complexes with flexible connections and establishes the key characteristics of their operation.

2. It is proposed to supplement the existing systems of classification of underwater complexes with flexible connections by classification features related to basic underwater technologies implemented by such complexes, surface conditions of underwater works, underwater space characteristics, and intended use.

3. The system of classifications of underwater complexes with flexible connections has been refined. It provides the methodological basis for designing and marine robotic vehicles determining the areas of their preferential use.

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