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ОПТИМИЗАЦИЯ ПРОЦЕССА ЗАЖИГАНИЯ ДУГИ НА СТАНКАХ РАЗМЕРНОЙ ОБРАБОТКИ ДУГОЙ

Исследованы процессы в электроэрозионной камере типа АМН-1 в момент зажигания электрической дуги на станке размерной обработки дугой. Приведен характер изменения давления рабочей жидкости в электроэрозионной камере. Предложено значение величины давления, при котором системой автоматической подачи при подводке электрода-инструмента к заготовке обеспечивается автоматическое изменение скорости с максимальной до рабочей.

Ключевые слова: автоматическая система, размерная обработка дугой, давление рабочей жидкости, скорость подачи, электрод-инструмент, зажигание дуги.

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IMPROVEMENT OF THE MANAGEMENT OF MATERIAL AND TECHNICAL RESOURCES OF WATER CLEANING PROJECTS FROM EXPLOSIVE OBJECTS

Запропоновано процесну модель управління проектами роботизації завдань очищення акваторій від вибухонебезпечних об'єктів. Дана модель знаходиться в складі подмоделі управління базовими роботізованими підводними завданнями, які реалізують безпечні технології очищення акваторій, а також подмоделі управління базовими завданнями щодо ефективного застосування спеціальних засобів морської робототехніки, що утворює теоретичну основу для підвищення ефективності управління проектами захисту акваторій від надзвичайних ситуацій техногенного та природного характеру.

Ключові слова: *морська акваторія, вибухонебезпечний предмет, підводний робот, управління матеріально-технічними ресурсами проектів.*

1. Introduction

Cleaning of the territories and waters from explosive objects is one of the priorities of «State Program of population and territory protection from emergency situations of technogenic and natural character for 2013–2017 years» approved by the Law of Ukraine on June 7, 2012 № 4909-VI. For the territorial waters of Ukraine urgency of this task is due to the need to do in safe areas of the Black and Azov seas, waters of marine transport routes and waters of inland transport routes (navigable rivers) containing explosive objects of WWII and fighting in the postwar period.

Material and technical support of water cleaning objects from explosive objects (EO), unlike similar land-based works, involves the use of divers and is characterized by increased risk to their lives. This is due to poor visibility under water, EOs mud accumulation, complexity of their classification and evaluation of technical condition. In addition, the complex process is a primary search, detection

and identification of EOs because existing diving technology is a low-productive and unreliable.

The task of improving management of water clean projects from EOs by managing the development of new robotic marine technology, creation and implementation of specialized marine robotics tools (MRT) in marine practice for their implementation and equipping the departments of the State Emergency Service of Ukraine (SES) at this time is relevant and related to the tasks of national importance.

2. The object of research and its technological audit

The object of research is robotics project management of water cleaning tasks from explosive objects.

Practical experience of the authors [1] shows that the main road for realization of water cleaning projects from EOs is the use of modern specialized marine robotics by SES units. However, modernization of the technical equipment of these units by new marine technics requires solving a number of applied scientific tasks for improving the management of logistical resources for such projects.

In particular, it is necessary to explore the process management features of creation of robotic cleaning technologies and acquisition processes of SES units by new robotic resources, explore features of the formation of the project team for water cleaning from EOs considering the implementation of underwater robotic technologies.

The authors [2] see it appropriate to pursue a policy of robotics in this area according to the philosophy of the process approach to management (in English literature — Business Process Management, BPM), which provides for the submission of the organization activity as a set of interdependent business processes that focus on getting the most valuable result. As MRT for their role in the projects of water cleaning is an effective tool that complements the currently existing tools of specialized SES units (diving equipment, boats, etc.), we proposed a stepwise approach [3] in the process management of their implementation in practice within the existing organizational management structures.

3. The aim and objectives of research

The aim of research is to improve the management of material and technical resources for state water cleaning projects from explosive objects by robotics of the basic tasks of such projects.

To achieve this aim it is necessary to perform the following tasks:

1. To analyze the problem of national importance to clean water areas from explosive objects.
2. To develop a process model for implementation of new marine robotic technologies and modern means of marine robotics for their implementation.

4. Literature review

The tasks of process management for creation of new robotic tools and robotic technologies are long in the field of academics and producers [4–6].

In recent years, a number of remotely operated underwater and overland wheeled and tracked robots were developed that allow to do a search, classification and neutralization of Eos [7, 8].

Some studies are devoted to project management for humanitarian demining on land and fight fires using specialized remote-controlled land robots [9–11].

As project management of water cleaning from drifting, muddy and ground-located EOs, the information in the literature is very limited [12, 13].

The improvement of project management of water cleaning from EOs by applying robotic underwater technologies in scientific and technical literature is not covered.

5. Materials and methods of research

Data from publications [7, 14–16] was used. These publications are devoted to the current state of development of tethered and autonomous underwater vehicles, robots, methods of their application in solving problems of civil and military nature (oceanography and combating sea mines) and publications [4, 17, 18] are devoted to standard methods and processes of project management and project management mechanisms of regional and sectoral development.

In the study we used the following research methods: a method of process approach in management, system analysis method and mathematical modeling method.

6. Research results

Implementation of robotic technology in practice of SES units envisages acquisition of territorial units by towed, self-propelled autonomous and remote-controlled underwater vehicles-robots (UVR) and unmanned surface vessels (USV) and aircrafts (UA), which technical and operational characteristics correspond to natural specific conditions of the waters and able to implement specific underwater tasks for water cleaning from EOs [19–21]. Basic components for such tasks M that it is advisable and possible to do using MRT can be represented as follows underwater tasks:

$$M = \{M_I;\ M_D;\ M_O;\ M_N;\ M_V\}, \quad (1)$$

where M_I — basic task of water exploration to identify EOs and their prior identification and surveying; M_D — basic task of documentation of detected EOs, which includes determining the technical condition, expert and instrumental threat assessment, calculation of geographic coordinates, entry into the state register of potentially dangerous underwater objects; M_O — basic task of monitoring (inspection) of detected EOs after their detection and before neutralization; M_N — basic task of neutralization of detected and documented EOs by their disposal in place (undermining or concreting) or lifting and transportation for retrieval or disposal in special landfill; M_V — basic task of documentation of water cleaning results from EOs, the results are designed for processing accounting documentation and closing of the project.

From the standpoint of project management, robotics of SES underwater activities for water cleaning from EOs can be represented by a process model that is shown in Fig. 1.

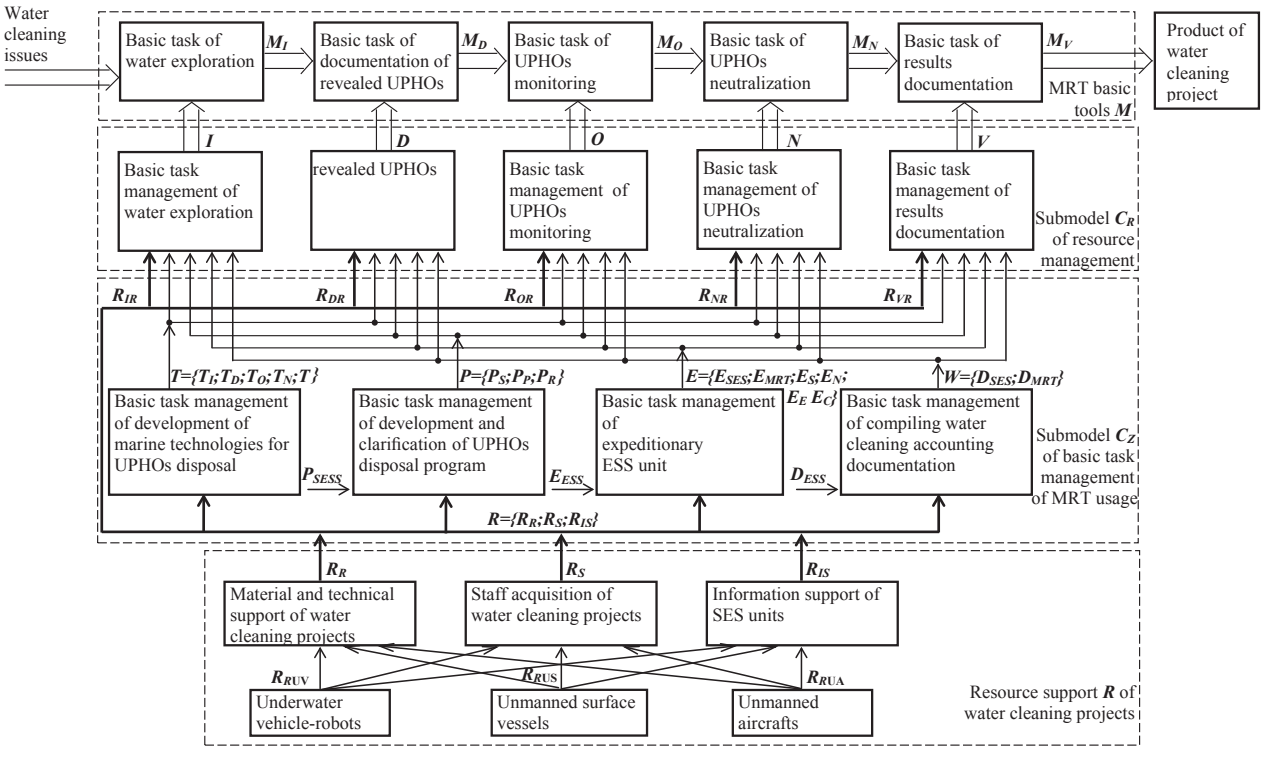

Fig. 1. Project management process model of robotics of SES underwater activities for water cleaning from EOs

Project management process model of robotics of SES underwater activity C_{PM} is offered as two submodels:

$$C_{PM} = \{C_R;\ C_Z\}, \quad (2)$$

where C_R — submodel of resource management of basic tasks for water cleaning from EOs, which is implemented based on safe robotic technologies; C_Z — submodel of basic management tasks to ensure the effective use of special MRT.

There are following structures for these submodels:

$$C_R = \{I;\ D;\ O;\ N;\ V\}, \quad (3)$$

$$C_Z = \{T;\ P;\ E;\ W\}, \quad (4)$$

where I — basic task management M_I of water exploration, which is performed using MRT; D — basic task management M_D of documentation of detected EOs, which is performed using MRT; O — basic task management M_O of robotic monitoring (inspection) of detected EOs after their detection and before neutralization; N — basic task management M_N of neutralization of detected and documented EOs, which is performed on the basis of pre-emptive MRT use; V — basic task management M_V of documentation of water cleaning results from EOs for drafting the final project report; T — basic task management of justification and development of marine technology for EOs disposal (neutralization) using special robotics; P — basic task management of development and clarification of EOs disposal program, which includes organizational, technical, robotic, legal and other necessary measures; E — basic task management of expeditionary SES units with appropriate means of marine robotics and its deployment in marine waters and/or coastal areas for water cleaning works from EOs; W — basic task management of compiling water cleaning accounting documentation and its transferring to use by local governments.

Management of indicated basic underwater tasks (1) using MRT provides for three types of resource support R:

$$R = \{R_R;\ R_S;\ R_{IS}\}, \quad (5)$$

where $R_R = \{R_{RUVR};\ R_{RUSV};\ R_{RUA}\}$ — material and technical support of water cleaning projects — underwater vehicles-robots R_{RUVR}, unmanned surface vessels R_{RUSV} and unmanned aircrafts R_{RUA} with appropriate equipment for the implementation of the basic tasks M — exploration, inspection and measurement, instrumental and manipulation, etc; $R_S = \{R_{SUVR};\ R_{SUSV};\ R_{SUA}\}$ — Staff acquisition of SES units by qualified professionals for the effective MRT use, which are planned in the project — operators and technicians of underwater R_{SUVR}, surface R_{SUSV} and aircraft R_{SUA} unmanned equipment; $R_{IS} = \{R_{ISDB};\ R_{ISN};\ R_{ISI}\}$ — information support of SES units (database R_{ISDB} of detected and documented UPHOs, navigation support of marine works R_{ISN} and instrumental support R_{ISI} for rapid communication, documentation and transmission of information on the progress and results of the marine works.

Let's consider the possibility and feasibility of specialized MRT R_R to perform basic tasks M (1) and robotics project management features of underwater SES activity C_{PM} (2).

The basic task of the water exploration $M_I \in M$ to identify EOs is usually performed by towed UVRs R_{TUVR}, providing maximum performance of the search. In difficult hydroclimatic conditions, when the use of towed UVRs is not possible (storm, ice on the water, etc.), effective technical measures for EOs exploration is self-propelled UVRs R_{SPUVR} [20].

EOs exploration on small bottom areas can be carried out with the assistance of tethered UVRs R_{THUVR}.

Recently, with the appearance of unmanned surface vessels (boats, catamarans, motor yachts) and the development of sonar search tools it is promising to their use for the exploration of shallow waters R_{USV}.

Thus, component I of the process management submodel C_R of formation of the necessary technical resources R_{IR} for robotics of the basic task $M_I \in M$ includes three main MRT types:

$$R_{IR} = \{R_{TUVR};\ R_{THUVR};\ R_{USV};\ R_{SPUVR}\}. \quad (6)$$

The basic task of exploration and documentation of detected EOs $M_D \in M$, based on the authors' experience, it is advisable to perform using tethered remote-controlled UWRs R_{THUVR} because this type of underwater robotics gives a most comprehensive and reliable information about underwater objects [1]. The use of self-propelled UVRs R_{SPUVR} is appropriate only in circumstances where the use of tethered remote-controlled UVRs is impossible or impractical (great depth, storm conditions, the presence of ice cover at a given water area, etc.).

Thus, the D component of process management submodel C_R of formation of the necessary technical resources R_{DR} for basic problem $M_D \in M$ includes use of two main MRT types:

$$R_{DR} = \{R_{THUVR};\ R_{SPUVR}\}. \quad (7)$$

The basic task of detected EOs monitoring $M_O \in M$ is performed, usually within realization of water cleaning $\{T; P; E\}$, when detected EOs may be the subjects of unlawful malicious actions (such as larceny for the purpose of unlawful EOs use). In cases of forced long-term detention of detected EOs in their natural environment, while their operational neutralization is impossible or impractical, EOs monitoring is performed to monitor the technical state of the objects and identify dangerous trends of its change.

Technical implementation of the basic monitoring task $M_O \in M$ can be realized in two directions — examination of the technical state of properly EOs and control of unlawful access of unauthorized persons or technical means to their places.

Resource support of such basic task is proposed to implement by the following technical means of marine robotics:

— Self-propelled remote-controlled autonomous UVRs R_{THUVR} and R_{SPUVR} — for visual and instrumental inspection of the current EOs state.

— Unmanned surface vessels R_{USV} and unmanned aircrafts R_{UA} — to control access to water areas, which store detected EOs.

Thus, component O of process management submodel C_R of formation of the necessary technical resources R_{OR} of the basic tasks $M_O \in M$ is provided to use four main EOs types:

$$R_{OR} = \{R_{THUVR};\ R_{SPUVR};\ R_{USV};\ R_{UA}\}. \quad (8)$$

The basic task of neutralization $M_N \in M$ *of* detected and documented EOs provides for the following MRT:

— To neutralize detected and documented EOs by their undermining in place — using tethered remote-controlled UVRs R_{THUVR} to transportation of explosive charges and their installation on the EO, and to exploration and documentation of the bottom surface after EO neutralization.

— To neutralize detected and documented EOs by their concreting in place — using tethered remote-controlled UVRs R_{THUVR} for remote process control of underwater concreting and documentation of the results.

— To neutralize detected and documented EOs through their lifting and transportation for retrieval or disposal in special landfill — the use of tethered remote-controlled UVRs R_{THUVR} to lift on board of USV, USV use R_{USV} for EOs transportation to the surface or underwater retrieval and the use of tethered remote-controlled UVRs R_{THUVR} to unload EO from USV in the place of underwater disposal.

Thus, component N of process management submodel C_R of formation of the necessary technical resources R_{NR} of the basic task $M_N \in M$ requires the use of two main MRT types:

$$R_{NR} = \{R_{THUVR};\ R_{USV}\}. \quad (9)$$

The basic task of documentation of the water cleaning results from EOs $M_V \in M$, the results of which are designed for processing accounting documentation of the project, is done to fix the fact of threat elimination from EOs on the water and a decision on its transfer for use by appointment.

Establishment of the EOs elimination facts is advisable to carry out using the technology of re-exploration of the bottom surface or the water, which held underwater works and by exploration of bottom surface of the sea polygons in order to establish the facts of EOs neutralization.

Such works are appropriate to perform using UVRs, the particular type of which is determined by the peculiarities of the task. For example, point objects on the sea bottom or small area of sea bottom is encouraged to examine using tethered UVRs, large areas of the bottom surface — using towed UVRs, and in cases where there are restrictions on the use of these UVRs types (ice cover of the waters, etc.), the only UVRs type for such problems is autonomous unmanned underwater vehicles.

Thus, component N of process management submodel C_R of formation of the necessary technical resources R_{VR} for robotics of basic task $M_V \in M$ is provided three main MRT types:

$$R_{VR} = \{R_{TUVR};\ R_{USV};\ R_{SPUVR}\}. \quad (10)$$

The basic task management $T \in C_Z$ of substantiation and development of robotic technologies for EOs neutralization consists of organization of works on creation of specialized marine technologies of MRT for SES benefits:

$$T = \{T_I;\ T_D;\ T_O;\ T_N;\ T_V\}, \quad (11)$$

where T_I — robotic technology of water exploration to identify EOs, which should include automated or automatic EOs search modes, their identification and exploration by visual instruments and tools; T_D — robotic documentation technology of detected EOs, which should include metrological operation to determine the spatial position

and technical condition of EOs, expert and instrument evaluations of threat to the population and navigation from finding detected EO in this water area, calculation of EOs geographical coordinates and entering data about it to the state register of underwater potentially dangerous objects; T_O — robotic technology of current monitoring of detected EOs, which is performed until their neutralize with defined intervals (continuous, periodic, special, crisis monitoring); T_N — robotic technology of EOs neutralization, which should include a disposal scenario in place by undermining or isolation of EOs from human impact or influence of external marine environment (concreting, retrieval in place, etc.) or scenario of lifting and transportation of EOs with the purpose of retrieval or disposal in the designated and equipped marine or terrestrial landfills; T_V — robotic documentation technology of water cleaning results from EOs for future inclusion of its products to the accounting documentation of the project; technology should provide geographical reference of documentation results serve as a basis for the decision to water cleaning from EOs.

Management of the development and justification of these technologies is integral part of water cleaning projects from EOs and should be based on the performance of existing MRT and/or to assign tasks to create new types of submarines, surface or aircraft MRT with the required characteristics.

Basic task $P \in C_Z$ of management of development and coordination of EOs disposal programs provides planning work to improve existing P_{SSES} or create a new organizational structure P_S of SES unit that provides high-performance MRT use and planning of legal P_P and resource P_R support of these units for all components of the water cleaning project:

$$P = \{P_{SSES};\ P_S;\ P_P;\ P_R\}. \quad (12)$$

P_S component management aims at inclusion of teams of specialists in the organizational structure of such SES units that are operated with MRT (UVR, USV, UA), that is a dependency $P_S = f_S(R)$.

Due to extensive MRT use in water cleaning projects, the particular relevance will process management of developing legal support of their use P_P. As a result of the development it should be created basic documents on the responsibility of road users in the water area, which would regulate the joint venture of manned and unmanned (robotic) marine moving objects. In this case there is a $P_P = f_S(R)$, which takes into account the MRT properties as road users in the water area.

Resource support management P_R of the task P involves obtaining of a reasonable MRT list for a particular water cleaning project, based on the planned technologies T presented in (11).

In general, robotic software of these works (5) is the basis for planning the project key performance indicators (staff security, performance, documentation reliability, etc.) and therefore should be based on the actually existing MRT types or be a source of tasks of the creation of their new species.

The basic management task $E \in C_Z$ of SES expeditionary unit organization, equipped with appropriate means of marine robotics and organization management of its deployment in the area of work to for water cleaning from EOs provides, in addition to SES-regulated measures E_{SES} [21], also development of additional procedures for process management of staffing SES expeditionary unit necessary MRT $E_{MRT} = f_{MRT}(R)$ and process management of preparation of their staff E_s, navigation E_N, energetic E_E and communication E_c support:

$$E = \{E_{SES};\ E_{MRT};\ E_S;\ E_N;\ E_E;\ E_C\}. \quad (13)$$

Practical implementation of these four components of this task must be based on MRT list that are involved in expeditionary unit, as well as training management of their operators and staff, legal preparation of processes of complex and dangerous underwater operations in water areas that are usually widely used for navigation , fishing and others.

The basic task management $W \in C_Z$ of providing accounting documentation of water cleaning and their preparation for transfer to use by local government is the final phase of the works and is, in fact, the main product of the project. Management of the development of accounting documents is defined by the normative SES documents D_{SES} [22], but photos, video and mapping information about initial state of the water area, process and outcomes of cleaning D_{MRT} are provided almost entirely from MRT apparatus, which has been involved in the project.

Therefore, process model of compiling documentation management at the completion of the project is:

$$W = \{D_{SES};\ D_{MRT}\}. \quad (14)$$

Thus, all components of the project management process model of SES underwater robotics (2)–(4) contain information about MRT and characteristics of the latter are the basis for effective project management of water cleaning.

Dependencies (2)–(4) in conjunction with (5)–(14) form a project management process model of SES marine robotics that could serve as a theoretical basis for improving the efficiency of the tasks of national importance for water cleaning from EOs in Ukraine.

7. SWOT analysis of research results

Implementation of advanced marine robotic technology and modern means of marine robotics for water cleaning from EOs will help to improve productivity and quality of marine operations as problems of national importance, and reduce risks to life and health of people involved in such operations.

Created process model of implementation of new marine robotic technologies and modern means of marine robotics forms the theoretical basis for the effective management of material and technical resources of water cleaning projects from EOs.

Equipment of SES units by the modern means of marine robotics will require additional financial costs associated with the creation or procurement of such equipment and training of MRT operators for its effective use.

The next tasks of management of material and technical resources of water cleaning projects from EOs are development and scientific justification of organizational structure in SES for technical and staff support of robotics of its activities. The priority measures in this direction include development of the models of organizational structures as

a part of units of the development of underwater robotic technologies for water cleaning, SES acquisition by marine robotics and educational and training activities.

There is no alternative for processes of SES marine robotics. However, the implementation of these processes depends on two factors:

— Legislative support of robotics concept for operations of the disposal of explosive objects in the water areas, such as the adoption of the relevant state program.

— Providing guaranteed financing of costs associated with the development and creation of appropriate marine robotics and staff training for its effective use.

8. Conclusions

1. Based on the analysis of national importance task to water cleaning from explosive objects, which is carried by SES of Ukraine, the necessity for full implementation of modern marine robotics is shown. This implementation is seen as a project-oriented activities aimed at reducing threats to human life and health and to improve productivity and quality of marine works.

2. Project management process model for robotics of the tasks of water cleaning from explosive is proposed for the first time in the management submodel of basic robotic underwater tasks and management submodel of the basic tasks on the effective use of special means of marine robotics. The obtained process model forms the theoretical basis for improving the management of material and technical resources of water cleaning projects through the use of safe and highly efficient robotic technologies for water cleaning.

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СОВЕРШЕНСТВОВАНИЕ УПРАВЛЕНИЯ МАТЕРИАЛЬНО-ТЕХНИЧЕСКИМИ РЕСУРСАМИ ПРОЕКТОВ ОЧИСТКИ АКВАТОРИЙ ОТ ВЗРЫВООПАСНЫХ ОБЪЕКТОВ

Предложена процессная модель управления проектами роботизации задач очистки акваторий от взрывоопасных объектов. Данная модель находится в составе подмодели управления базовыми роботизованными подводными задачами, которые реализуют безопасные технологии очистки акваторий, а также подмодели управления базовыми задачами по эффективному применению специальных средств морской робототехники, что образует теоретическую основу для повышения эффективности управления проектами защиты акваторий от чрезвычайных ситуаций техногенного и природного характера.

Ключевые слова: морская акватория, взрывоопасный предмет, подводный робот, управление материально-техническими ресурсами проектов.

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