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Application of unmanned USV surface and AUV underwater maritime platforms for the monitoring of offshore structures at sea

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JEL Classification: C40, C62, C63

Abstract

The operation of offshore structures at sea requires the implementation of advanced systems for their permanent monitoring. There is a set of novel technologies that could be implemented to deliver a higher level of effective and safe operation of these systems. A possible novel solution may be the application of a new maritime unmanned (USV) surface and underwater vehicles/platforms (AUV). Application of such vehicles/platforms may increase the level of operability and safety of the offshore structures and installations. Practical use of these platforms requires the application of advanced forms of different technologies to platform structures, materials, strength of structures, applied propulsion systems, energy supply sources, dynamics of platforms, control, and communication systems. The new control and communication systems may require an application of AI (artificial intelligence) technology to obtain more advanced offshore monitoring systems. The application of the USV/AUV platforms for monitoring offshore structures may provide an increase in the functionality, performance, and safety levels of those structures in operation. This paper presents a concept for an offshore monitoring system based on the application of the USV/AUV platforms. The complexity of the research is shown by presenting the performance-oriented risk-based method. The basic information on the platforms is given. The main drivers that determine the functionality, performance, and safety of the USV/AUV platforms are introduced. A brief description of the primary operational characteristics of the platforms is presented. An example of a simple operational procedure (scenario) during the monitoring of an offshore structure is described. In the final part of this paper, conclusions are given.

Introduction

New opportunities for monitoring offshore structures. The implementations of USV/AUV platforms at sea may concern navy patrol and reconnaissance tasks and monitoring of the offshore installations. Such applications require advanced hardware and software solutions to be used onboard the USV/AUV platforms and by the entire offshore monitoring system. The compatibility between all the platforms and offshore monitoring systems may be provided by the higher level of control and autonomy of the USV/AUV platforms. The general requirements to obtain such platforms and particular solutions are associated with autonomy from the energy supply, self-control, and a self-navigation point of view. It may concern no communication between the platforms and the mission operating center. Even a basic level of autonomy (a "first-level") requires innovative solutions concerning the sensors, effectors, and control to be implemented. The greatest challenge associated with these platforms is to determine and apply a kind of artificially intelligent platform. To obtain such a platform, it is important to acquire precise data, using its sensors, from the surrounding environment on the water surface and within the underwater space to process such data and use it to perform tasks during the mission in a real-time domain. A good solution to solve some of the problems with the USV/AUV platform control seems to involve using a mini-brain for the control process to compare the "onboard virtual reality" (a virtual model) following from the database with the reality outside the platform (a real model). It is possible to achieve this with the help of the sensors, mini-brain control system, and effectors that the platform is equipped with. Such that the online comparison may enable an obtaining of the expected functionality, performance, and safety of a platform for the benefit of the mission.

Unmanned maritime vehicles. The last decade has been devoted to further development and implementation of unmanned maritime vehicles. One area of promise is the USV and AUV (unmanned) platforms. There is a growing interest in determining and implementing fully developed unmanned maritime platforms for applications. The main drivers towards the development of such platforms are technologies involving the concepts of autonomous systems (platforms), hull form geometries, innovative construction materials including nanomaterials and intelligent materials, innovative energy supply sources, propulsion systems combining efficient and silent engines and propellers, sensors, effectors, and innovative IT technologies including the systems of navigation, communication, and control. Within these technologies is a role to play by artificial intelligence (AI) technology used by advanced control systems. An additional set of features that the USV/AUV platforms may possess are stealth-based and bio-technology-based solutions.

Implementation of unmanned vehicles as an element of the offshore monitoring system

The operation of offshore structures and installations at sea requires the application of novel systems for the permanent monitoring of the workings of such systems. The need to implement new solutions originates from the challenges following from normal operational conditions and abnormal operational conditions via the hazards that originate from terrorism and military conflicts. A fast development of new technologies enables the implementation of deck robots and unmanned maritime vehicles as the USV/AUV platforms for the permanent monitoring of offshore structures and installations at sea. The operational and safety systems supported by the deck robots and unmanned maritime USV/AUV platforms may provide an increase in the level of functionality, performance, and safety of offshore structures and installations of pipes and cables, for example. The main elements of the monitoring system for the offshore structures and installations are presented in Figure 1.

Combining the unmanned USV/AUV platforms with the novel systems of sensors and effectors

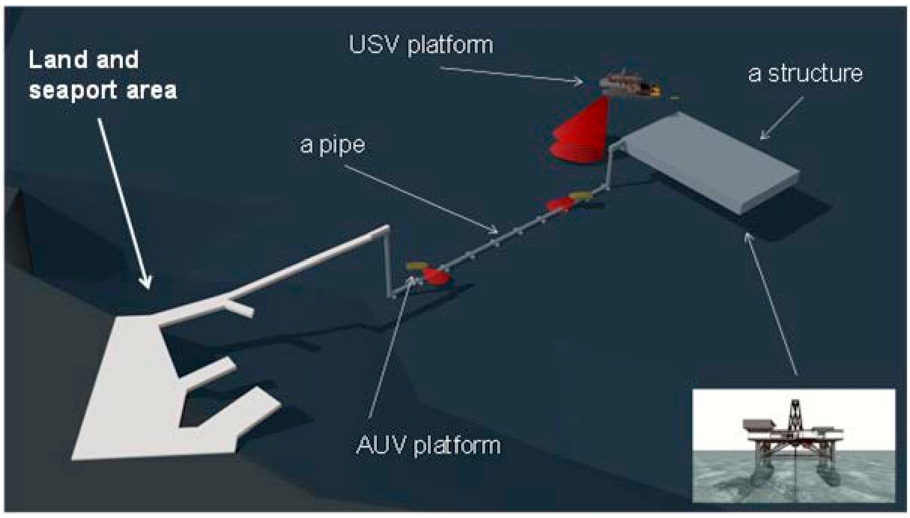

Figure 1. Major elements of a novel system for the monitoring of offshore structures and installations

and then linking them with the existing operational offshore systems may help to build a new generation of monitoring offshore systems. Development of the USV/AUV platforms ready for the monitoring activities at sea is a difficult task. The development method of such platforms equipped with modern sensors and effectors requires the support and collaboration of several partners. Before some information on designs of the USV/AUV platforms is introduced, it should be underlined that a precise prediction of the performance characteristics of the platforms is a key factor in the estimation of platform dynamics including the resistance, demanded power of propulsion system, capacity of source of energy, and seakeeping of each platform under consideration. Platform dynamics and their characteristics are the basis for the design of the sensors, effectors, and control system, which are the main components for the prediction of the range and autonomy of each platform. Then, it is relatively easy to evaluate the potential of each platform to apply them for the monitoring activities. A precise estimation of the capacity of the source of energy necessary for the propulsion and work of sensors and effectors may enable the preparation of the USV/AUV platforms for the 2, 4, 8, 12, and 24-h monitoring activities in real operational conditions. The implementation of the approach presented above may certainly increase the levels of functionality, performance, and safety of the entire offshore monitoring system.

USV/AUV platforms

A successful final solution concerning the USV/AUV platforms can be obtained using a procedure consisting of the following research steps: (1) definition of the USV/AUV platform, (2) definition of the mission, (3) definition of the requirements relating to the platform and mission, (4) identification of options of the USV/AUV platform solutions, (5) examination of tradeoffs and development of the USV/AUV platform in terms of technologies, approaches, methods, materials, structure, propulsion, source of energy, statics, dynamics, and specifications (such as parameters and characteristics), (6) cost analysis for the project work plan, time schedule, and expenditure, and (7) selection of the USV/AUV platform solution and design (Lamb, 2003; Faltinsen, 2005; Furey et al., 2007; Gerigk & Wójtowicz, 2014). It follows from experience that it is necessary to define the key design and operational drivers depending on the requirements, which are very important when obtaining a USV/AUV platform that satisfies the standards and criteria of functionality, performance, and safety.

The last decade has brought fast developments in the research, design, and implementation of unmanned maritime vehicles and platforms. In general, unmanned maritime platforms may be of different types: unmanned surface vehicles (USV), unmanned underwater vehicles (UUV), autonomous underwater vehicles (AUV), and remote (underwater) operated vehicles (ROV). Generally, different solutions regarding the source of energy supply and control may be applied in the case of unmanned maritime vehicles/platforms, depending on the application. If the platforms have a physical connection with the mother ship or mission operating center (a console) concerning the energy supply or/and control, they may be considered typical ROV platforms. The USV platforms have no direct (via a cable) energy supply and control in general. However, they have wireless communication connections with the operators and a gasoline-based propulsion system. The UUV platforms very often have no direct (via a cable) energy supply connections (having batteries onboard), but they still keep a direct (via a cable) connection for control purposes. The AUV platforms should have no direct (via a cable) energy supply and control connections. They may have a set of batteries that guarantee a platform to be autonomous from the energy supply point of view for two, four, or even more hours. If they worked in silent mode, they could have spent a week or two under the surface of the water. They may still be controlled from the mother ship or mission operating center using underwater communication subsystems or kids. Then, they may be called AUV platforms.

In general, unmanned maritime USV, UUV, and AUV platforms may be treated as semi-autonomous if there is no direct energy supply and control connection with the operator. If such platforms are pre-programmed, from the mission point of view, they may reach the first, second, or even third level of autonomy. In the future, the pre-programmed AUV platform vehicles, which may perform the locomotion and have a full set of sensors and effectors onboard, including the manipulators, could be treated as fully autonomous platforms if they may have a high precision positioning system onboard to ensure self-stabilization of the position and the correct self-orientation of the platform. These should be combined with the mission objectives, including all the particular tasks to be performed. The domains of the application of the USV, UUV, and AUV platforms depend mainly on the objectives of the missions in operation.

They may be a typical patrol, monitoring, reconnaissance, or even combat. The USV, UUV, and AUV platforms may be double-mode platforms concerning civil and military applications. From the applications of the offshore monitoring systems, depending on the mission, the USV/AUV platforms should be equipped with either sophisticated reconnaissance electromagnetic, hydro-acoustic, or other IT-based subsystems.

The research presented in the paper concerns our own design of both the USV and AUV platforms. Such an approach follows from the operational requirements of the contractors and potential customers. However, preliminary work on our own design required a knowledge of the advances in the domain of unmanned maritime vehicles previously achieved by academia, research institutes, and producers. Therefore, it was very important to have basic knowledge of the best-known USV and AUV designs currently in operation. The scope of this paper does not enable a full presentation of the majority of the most important parameters and characteristics of the designs presented in Tables 1 and 2 (Web: ihsjanes360.com, 2022), but it is relatively easy to obtain them from general information published in leaflets, from the internet and the publications of the producers. The designs presented in Tables 1 and 2 should be treated as the potential elements of the system for monitoring the offshore structures and installations presented in Figure 1.

Table 1. Autonomous surface systems – USV (Web: ihsjanes360.com, 2022)

No.	Name	Manufacturer	Role
1	Silver Marlin	Elbit Systems	ISR, SAR, EW
2	Protector	Rafael	ISR, ASuW, MCM/MW, SAR, EW
3	Inspector MK2	ECA	MCM, ISR, ASW
4	Venus	ST Electronics	MCM, ISR, ASW, EW
5	Fleet Class CUSV	AAI Corp	ISR, MCM, ASuW, ASW
6	Sentry	ECA	MCM, ISR, ASW
7	Interceptor	ECA	MCM, ISR, ASW
8	Stingray	ECA	MCM, ISR, ASW
9	U-ranger	ECA	MCM, ISR, ASW

ASW – anti-submarine warfare, AsuW – anti-surface warfare, EOD – explosive ordnance disposal, EW – electronic warfare, I – identification, ISR – intelligence, surveillance, and reconnaissance, ISTAR – intelligence, surveillance, target acquisition, and reconnaissance, MCM – mine countermeasures, MPAU – mission planning and analysis unit, MW – mine warfare, REA – rapid environmental assessment, RECCE – reconnaissance, and SAR – search and rescue.

Table 2. Autonomous underwater systems – AUV (Web: ihsjanes360.com, 2022)

No.	Name	Manufacturer	Role
1	Bluefin 9	Bluefin Robotics	EOD, MCM
2	Seaglider	Kongsberg UT	REA
3	Alister 100	ECA	MCM, REA, RECCE, ISTAR
4	AUV 62	SAAB	MPAU, MCM
5	Hugin 1000	Kongsberg	MCM, REA, ASW
6	Bluefin 21	Bluefin Robotics	MCM
7	Remus 600	Hydroid	MCM, RECCE
8	Gavia	Teldyne Gavia	MCM, ASW, REA, RECCE
9	Remus 100	Hydroid	MCM
10	Seafox C	ATLAS Elektronik	MCM, EOD
11	Archerfish	BAE Systems	MCM, EOD
12	LBV 300-5	Seabotix	EOD, SAR, MCM
13	Seaeye Tiger	SAAB Seaeye	SAR, I
14	Double Eagle MkIII	SAAB Bofors Dynamics	MCM
15	Slocum	Teledyne Webb Res.	REA, MCM, ASW
16	Barbaros	Gate Elektronik	MCM, EOD

Key: see Table 1.

Some particulars of the vehicles are presented in the final columns of Tables 1 and 2, and some explanations are presented below the Tables.

From our more-than-a-decade experience in this area, it can be stated that it is difficult to find research-based information on the results and solutions concerning any unmanned maritime platform hull geometries, materials, structures, propulsion systems, sources of energy, sensors and effectors, and deck control systems for any designs obtained by different researchers, institutions, and laboratories, even if they seem to be similar to own USV/AUV platforms. These designs should be treated as multifunctional manned and unmanned platforms and the key elements of the proposed offshore monitoring system.

Multifunctional USV logistic platform. The proposed solution of the USV platform is highly appreciated and useful during the monitoring activities. The main aim of the application of this platform is to perform different tasks, including the delivery of unmanned aerial vehicles (UAV), smaller USVs, and AUV platforms. Next, to complete the reconnaissance activities, there is a monitor of the offshore structures on the water surface and immersed parts of offshore structures, which include the underwater installations (including pipes and cables). The platform should be equipped with passive and active

Table. 3. Selected particulars of the USV platform

Specification	Description
Implementation scope	USV platform for deployment of unmanned aerial, surface, and underwater vehicles. The platform is intended for logistics, reconnaissance, and monitoring operations.
Main parameters	Platform versions. Length: 8 or 12 m, breadth: 2.1 or 4.2 m, power of main drives: up to 1000 kW, maximum speed: 35 kn, and operational range: above 100 NM.
Innovativeness of solution	Determined by hull form geometry, wave piercing (hull form), main drive (dual-fuel), and electric auxiliary drive and propulsion systems: jet-water drive with a Z-type “afterburner”.
Technologies used	Innovative materials. Innovative solutions in the field of hull form, source of energy supply, propulsion system, and onboard subsystems: sensors, effectors, control, navigation, and communication. Novel solutions concerning unmanned vehicles and launching and landing systems.

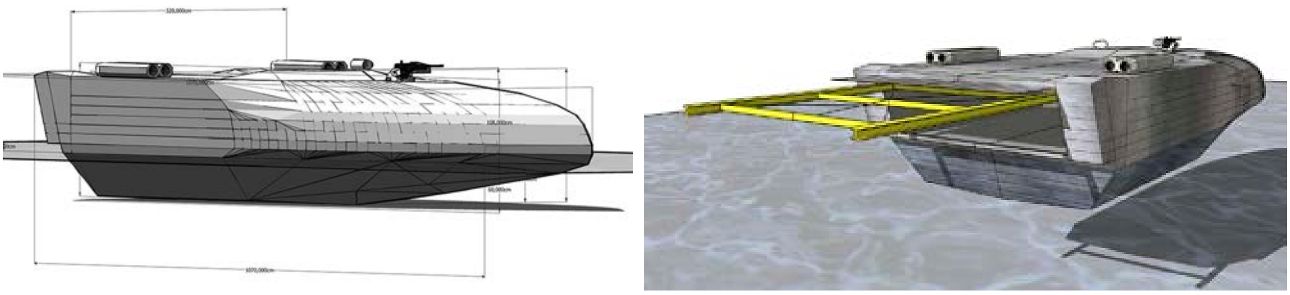

Figure 2. A visualisation of the USV platform

sonar, echo sound, and a special head of sensors. These systems will be published in a separate paper. The selected data of the USV platform are given in Table 3. A visualization of the USV platform is presented in Figure 2 (Gerigk, 2017).

Multifunctional AUV platform. The solution of the AUV platform can be considered as a priority and a possibility for implementation in a relatively short period of time from the application point of view. It depends on the technology level demanded and the scale of integration with the rest of the offshore monitoring system. The main aim of the application of this platform is to perform different tasks, including reconnaissance activities, monitoring the offshore structures under the water surface, and monitoring the immersed parts of offshore structures, including the underwater installations (including pipes and cables). The platform can be of different sizes: small with 1–2 m length and medium with 4 m length. A large-sized AUV platform is also considered. The platform may be of low speed (for covert actions) and medium speed (for similar combat actions). The platform can be equipped with passive and active sonar, echo sound, conventional onboard sensors and effectors, and a special head of sensors. These systems will be published in a separate paper. The selected data of the AUV platform are presented in Table 4. A visualization of the AUV platform is presented in Figure 3 (Gerigk, 2017).

The concept of the USV platform, including unique solutions, was determined by the authors. The concept of the AUV platform, including

Table. 4. Selected data of the USV platform

Specification	Description
Implementation scope	The platform is intended for underwater logistics, reconnaissance, and monitoring operations.
Main parameters	Platform versions. Length: 1–2 or 4 m, breadth: 0.5–1.0 or 2 m, weight: up to 360 kg, operating speed: up to 2.5 m/s, mission time: form minimum 2 h (it depends on destination, speed, and changes of positioning), and range (depends on missions and tasks).
Innovativeness of solution	Determined by hull form geometry, electric main and auxiliary drives, power supply source, silent propulsion system equipped with a jet water drive enabling relatively low and medium speeds, skin coatings, soundproofing of onboard subsystems, and control system.
Technologies used	Innovative materials, including coatings and soundproofing coverings. Innovative solutions in the field of hull form, source of energy supply, propulsion, and onboard subsystems: control, sensors and effectors, navigation, and communication. Innovative approach to the application of stealth technologies.

Figure 3. A visualisation of the AUV platform during a prototyping process

the unique solutions, was also found by the authors. Later, this concept was developed for the research project No. PBS3/A6/27/2015 conducted at the Gdańsk University of Technology between 2015 and 2018. The partners in the project were the Warsaw University of Technology and KFB Acoustics Sp. z o.o in Wrocław. The particular research and design problems have been solved by a team of cooperating specialists and partners from the Polish research sector and industry under the supervision of Mirosław K. Gerigk (Kardaś, Tiutiurski & Gerigk, 2016; Gerigk, 2016; Barański & Gerigk, 2018; Ciba, Dymarski & Gerigk, 2018; Gerigk, 2018; Research project, 2018).

A method of research based on the performance-oriented, risk-based approach

The major features of the USV/AUV platforms based on their parameters and characteristics are functionality, performance, and safety. The functionality is connected with the application area the vehicle is operated for. The functionality may be described as an example by the mass and payload of the USV/AUV platforms. A good example of the USV/AUV platform performance may be the speed, resistance, demanded power of the propulsion system, capacity of source of energy supply, and range of the platforms. The functionality, performance, and safety of the USV/AUV platforms are the features that require a definition of the mission and all tasks of the mission within the operation. It is connected with predicting all the USV/AUV platform activities (one by one) during the mission. Accounting for the monitoring of the data offshore structure, it is relatively easy to prepare a scenario of events during the mission that will control and check operations. Such an approach enables an estimation of all the objective functions, which enables the estimation of the risk of performing or not performing the data tasks. The best method to define the missions and tasks to be performed in operation is the techniques of event trees (fault tree analysis (FTA) and event tree analysis (ETA) are called the tree of consequences). The event trees may be determined by the operational officers for each mission and each task performed during the mission. Each event tree may be treated as a scenario of events, and each event should be treated as a task to be performed. The event trees are the base for predicting the USV/AUV platforms performance for each event (each task) separately.

The key issue when assessing the USV/AUV platform performance for each task is the necessity of estimating the platform parameters and characteristics for each event. These parameters and characteristics are estimated at the design stage, enabling the creation of a USV/AUV performance database necessary to control the platforms in a real operational environment. Such an approach enables an evaluation of (even at the design stage) if the platforms can perform the data task during operations. This approach leads to an increase in the probability at the planning stage that a mission would be successful. At the same time, this approach seems to be a good method and tool for training the operators and controlling the tasks during the data mission. Accounting for the event trees and assessment of performance, it is possible to assess the risk of not performing or performing the mission using the quantitative risk assessment approach (QRA). The structure of the procedure of assessment of the USV/AUV performance and risk assessment of a mission under consideration is presented in Figure 4 (Faltinsen, 1990; Dudziak, 2008; Gerigk, 2010; Gerigk, 2017).

The following steps should be conducted to perform a full operational procedure combining the performance-oriented approach with the risk-based approach:

1. Define the USV/AUV functionality: mission, tasks, and mission event tree (sequence of tasks).
2. Assess the USV/AUV performance: estimation of the USV/AUV parameters and characteristics.
3. Quantitative risk assessment (QRA) of the USV/AUV platforms mission: based on the values of USV/AUV parameters and characteristics (performance data), which is estimated for each event of the event tree definition of event tree (mission), the risk of performing or not performing each event, and the entire estimated mission.

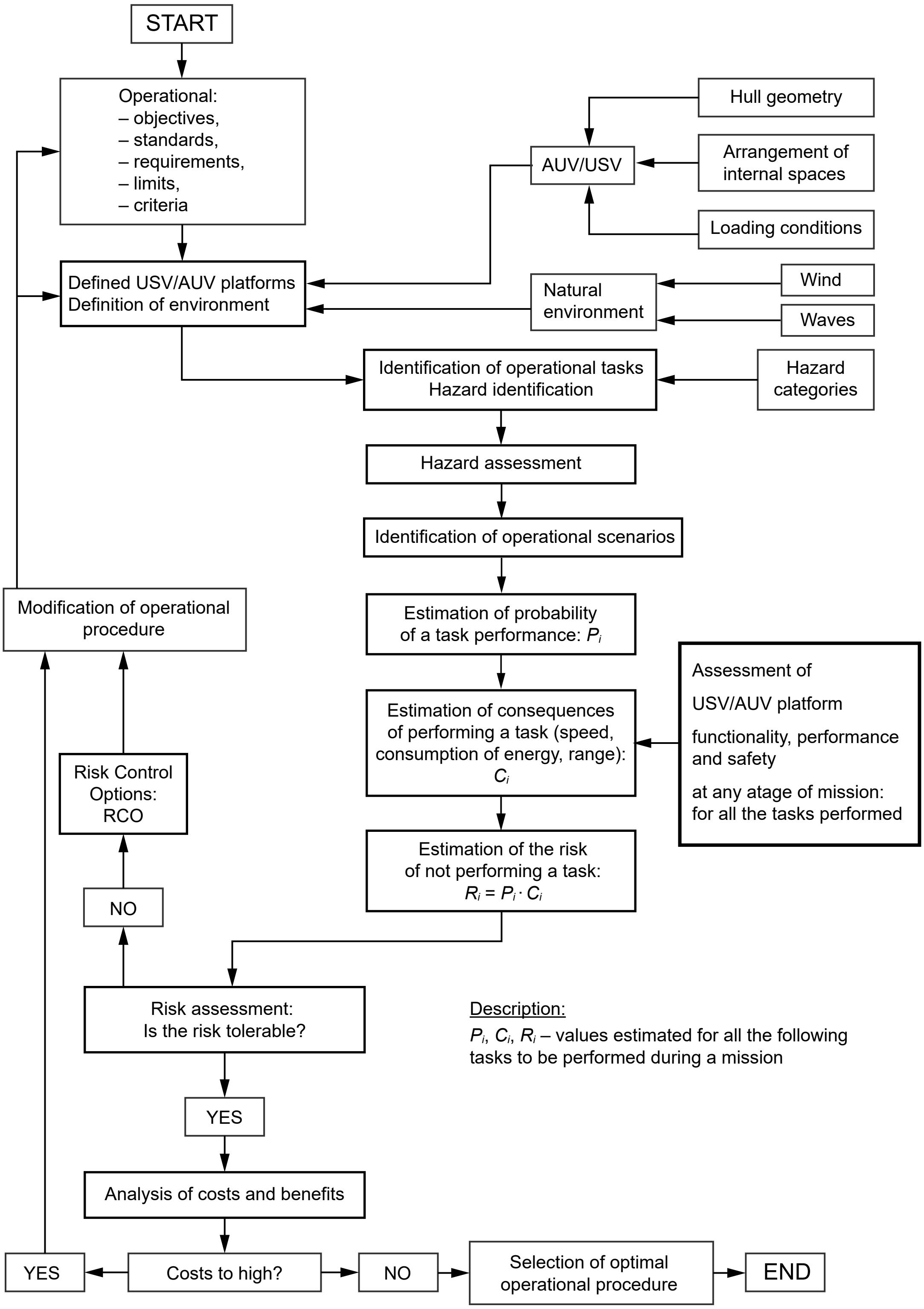

Figure 4. Structure of the procedure of assessment of the USV/AUV performance and risk assessment of a mission under consideration

The presented approach enables an optimization of the operational procedure by controlling the values of the objective functions in the time domain: USV/AUV speed and resistance, demanded power, consumption of energy, and range.

Key operational drivers of USV/AUV platforms

The USV/AUV parameters and characteristics in operation depend on many factors, which should be obtained during the research and design stages.

Table 5. Basic set of USV/AUV dynamics-based operational characteristics

Steps	USV/AUV features	USV/AUV operational parameters and characteristics
1	Main requirements and operational features	Speed, demanded power, source of energy, range, etc.
2	Definition of vehicle Environment definition	Hull form geometry, length, breadth, etc. Sea state, wind, depth, etc.
3	Arrangement of internal spaces	Number of bulkheads, etc.
4	Materials	Features of materials, mass of structure, etc.
5	Equipment and onboard systems	Distribution and weights of components, etc.
6	Mass of the light vehicle	Mass of the light vehicle, the position of the center of gravity, etc.
7	Mass of the vehicle for operational loading conditions	Mass of vehicle for operational loading conditions, center of vehicle's gravity for each loading condition, etc.
8	Platform performance – statics	Draft, trim, angle of heel, buoyancy, displacement, floatability, stability, survivability, criteria, etc.
9	Platform performance – dynamics	Resistance, propulsion, maneuverability, degrees of freedom, equations of motion, dynamics, seakeeping, criteria, etc.

Table 6. Basic set of USV/AUV energy-based operational characteristics

Steps	USV/AUV features	USV/AUV operational parameters and characteristics
10	Demanded power to run the propulsion and auxiliary systems	Demanded power of propulsion and auxiliary systems
11	Demanded power to run the sensors	Demanded power of each sensor, etc.
12	Demanded power to run the control, navigation, and communication systems	Demanded power of control, navigation, communication systems, etc.
13	Demanded power to run the effectors	Demanded power of each effector, etc.
14	Demanded power to run the AI-based mini-brain control system if applied	Demanded power of the AI-based mini-brain control system, etc.
15	Demanded capacity of the main- and hotel-based source of energy supply	Demanded capacity of main and hotel-based source of energy supply

The procedure to achieve the values of these characteristics is based on the performance-oriented and risk-based approach, as presented in section above. The application version of this procedure may be called the approach for effective and safe operation. A basic set of the USV/AUV dynamics-based and energy-based operational characteristics assessed at the research and design stages are presented in Tables 5 and 6.

The characteristics introduced in Table 5 are the key operational drivers for predicting the energy-based characteristics of the USV/AUV platforms. They are necessary to predict the power necessary for the propulsion and capacity of the energy source.

Key operational characteristics of the USV/AUV platforms

Based on the prediction of the sets of USV/AUV dynamics-based and energy-based operational characteristics, it is possible to show how to predict the data level of the USV/AUV autonomy for the data operational conditions. The level of autonomy from null up to two may be treated as USV/AUV working conditions similar to those of automated robots not performing the programmed mission and tasks. The levels of autonomy (from three up to five) for the USV/AUV platforms may have a higher level of solutions concerning the advanced sensors, effectors, and control system. The most advanced solution, i.e., level five of autonomy, should concern the case when the USV/AUV platform has an AI-based mini-brain onboard, which is able to evaluate the situation and compare the online situation outside the platform (reality) with the virtual reality stored onboard within the USV/AUV platform's AI-based mini-brain by using the advanced sensors.

To show how all the characteristics presented in Tables 5 and 6 are interrelated, let us now concentrate on the AUV platform. The battery packs of underwater vehicles are power-limited. This means that the available onboard power has a limited value available over a finite time. The problem of predicting the demanded capacity of the main- and hotel-based source of energy supply, introduced in Table 6, can be explained in the following way. The below presented algorithm is substantially improved and developed version in comparison with an energy estimation procedure presented in the work of AUVSI/ONR (Furey et al., 2007). The main advantage of the method developed by the authors is a possibility of precise estimation of the platform energy consumption in time domain which enables to predict the platform real range in operation.

The amount of power required for the AUV platform can be estimated by the range and speed defined by the mission. The power in the time domain is defined as the force multiplied by velocity, i.e.:

$$P(t) = F(t)\cdot v(t) \tag{1}$$

where P is the power, F is the force, v is the velocity of the AUV platform, and t is the time domain. The required propulsive power can be estimated from the drag of the vehicle, D, and the speed at which the AUV platform travels. From the hydrodynamics of the platform point of view, the drag is proportional to the velocity of the platform squared. Thus, the required power may be expressed as follows:

$$P(t) = D(t)\cdot v(t) = 0.5\cdot c_D\cdot \varrho\cdot A\cdot v(t)^2\cdot v(t) \tag{2}$$

where c_D is the drag coefficient of the AUV platform previously defined according to the hydrodynamics fundamentals. The amount of energy used by the AUV platform is defined as the force acting on the platform multiplied by the distance (range) over which the platform has moved. The amount of energy that must be stored (installed) onboard the platform can be assessed according to the following expression:

$$E(t) = F(t)\cdot d(t) = D(t)\cdot d(t) = \\ = 0.5\cdot c_D\cdot \varrho\cdot A\cdot v^2\cdot \text{Range} \tag{3}$$

where E is the energy available. The term distance, d, can be equated to Range, which is the range of the AUV platform. To estimate the Range achievable by an AUV platform with a data battery pack, the above relationship is rearranged to obtain the Range in data form, i.e.:

$$R = \text{Range} = E / (0.5\cdot c_D\cdot \varrho\cdot A\cdot v^2) \tag{4}$$

The sensors onboard also use the power from the battery pack. Therefore, a good solution is to divide the power for propulsion and sensor purposes. To show the impact of the power used by the onboard equipment (systems) on the Range possible to achieve by the AUV platform, the Range equation can be augmented to include the “hotel power”, understood as the power necessary to maintain the onboard functions of the vehicle. Accounting for the definition of power above, an equivalent force (generated by the onboard functional elements) acting on the system can be estimated from the required “hotel power” as follows:

$$P_{AP} = v\cdot F_{AP} \quad \text{or} \quad F_{AP} = P_{AP} / v \tag{5}$$

By using the energy equation, the total energy required to pass a distance R = Range is given as follows:

$$E = (R + F_{AP})\cdot \text{Range} \tag{6}$$

The range may be achieved from equation (6) as follows:

$$\text{Range} = E / (R + F_{AP}) = \\ = E / (0.5\cdot c_D\cdot \varrho\cdot A\cdot v^2 + P_{AP} / v) \tag{7}$$

The above algorithm shows that, when selecting the battery packs for the AUV platform, the mission and all the tasks to be performed during the mission should be defined in order to select and size the required power pack. This algorithm has been used to investigate the values of the operational “time of monitoring” in the application of the AUV platform for monitoring the data offshore structures under consideration, as presented in Figure 5.

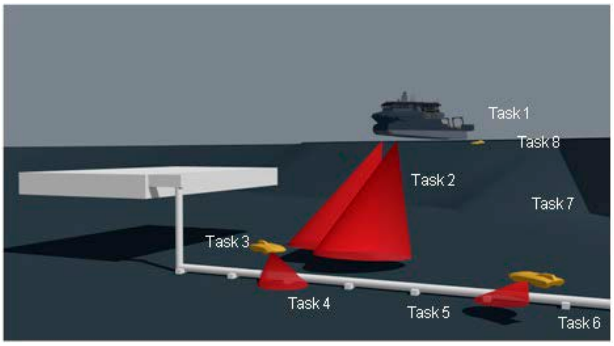

Figure 5. A visualization of application of the AUV platform for monitoring the data offshore structures under consideration

The example results of the prediction of the “minimum time of monitoring” in the case of the AUV platform application for monitoring the data offshore structures (Figure 5) are introduced in Table 7.

For the computer simulation of the minimum time of monitoring of the selected area presented in Figure 5, including the disturbances, the entire time of the monitoring procedure with no onboard sensors is 60.9 min. About 50% of the energy supply source has been used to conduct this monitoring procedure using the AUV platform.

Table 7. Prediction of the "time of monitoring" in the case of the AUV platform application when monitoring the data offshore structures presented in Figure 5

Tasks – events	Description of tasks	Distance passed [m]	Initial speed [m/s]	Disturbances	Minimum time of monitoring (time increased by disturbances) [min]
1	Launching of AUV – starting position 1	null	null	large	null
2	AUV is diving from position 1 to position 2	400	2.0	medium	3.33 (4.93)
3	AUV is diving from position 2 to position 3	800	1.5	small	8.88 (15.1)
4	AUV is moving from position 3 to position 4	200	1.0	negligible	3.33 (4.16)
5	AUV is moving from position 4 to position 5	100	1.0	negligible	1.67 (2.51)
6	AUV is moving from position 5 to position 6	200	0.5	small	6.67 (9.99)
7	AUV is moving from position 6 to position 7	500	1.0	small	8.33 (12.49)
8	Surfacing of AUV – to final position 8	600	1.5	medium	6.67 (11.66)
	Entire slow passing time of monitoring (no deck sensors used)				60.9

A concept of offshore monitoring system by using the AUV platform AI-based mini-brain control system

It should be underlined that calculations on the AUV platform equipped with (in the future) an AI-based mini-brain control system do not mean that the platform could be equipped with a steering system consisting of sophisticated hardware and AI-based software. Obtaining the AI-based AUV platform requires the implementation of many elements onboard this platform, including an innovative hull form geometry. It simply means that the platform should be very efficient when diving and performing the mission. It also requires that, if the platform performance is good, the sensors and control system driven by the AI mini-brain may guarantee higher levels of functionality, performance, and safety. There is a high level of probability that all the mission tasks and the mission itself would be performed according to the set of requirements and objectives.

A mini-brain-based control system should be treated as a kind of governor that coordinates the distribution of energy, acquisition of data using the sensors, processing and analyzing of the obtained data, outcome information for setting all the onboard systems, AI-based mini-brain itself, and controlling of the AUV platform (Chabris, 1987; Sejnowski, 2018). The concept for a novel design of the AUV platform is based on the assumption that, working on the AUV AI-based platform, it is necessary to replace two- or three-dimensional workspaces with the idea of an information workspace. Within such a working space, humans will be supported and sometimes replaced by AI technology. The information will be exchanged online between all the linked systems having access to one another. Within the information workspace, the exchange of data in the real-time domain should be permanent.

Complex air-based systems require a data transfer speed at a level of 500 Mb/s or more. This means that the AUV and USV platforms are systems that should be a kind of systems of systems. It is necessary to apply such an approach if the future of the USV/AUV platforms is functional, has good performance, and has a safe information workspace. The sensor and AI-based mini-brain control system determine the USV/AUV AI-based platform senses. The visual, pressure, electromagnetic, and hydro-acoustic signals may be processed by the AI-based mini-brain control system. This system works as a forward and backward chaining inference engine. Such an approach enables a comparison of the AI-based control mask (virtual reality) onboard the USV/AUV platform with the reality being described onboard by the sensor systems.

The preliminary results of the research have shown that the future USV/AUV AI-based platforms could be a kind of intelligent platforms if the functionality, performance, and safety during the operation (mission and tasks) are under the control of the AI-based mini-brain control system performing the following tasks associated with the physical fields changing in the time domain. (i) The acquisition, analysis, and use of electromagnetic signals; (ii) the acquisition, analysis, and use of noise and vibration-based signals; (iii) the acquisition, analysis, and use of hydro-acoustic signals; (iv) the acquisition, analysis, and use of thermal signals; (v) the acquisition, analysis, and use of pressure signals; (vi) the acquisition, analysis, and use of visual-based

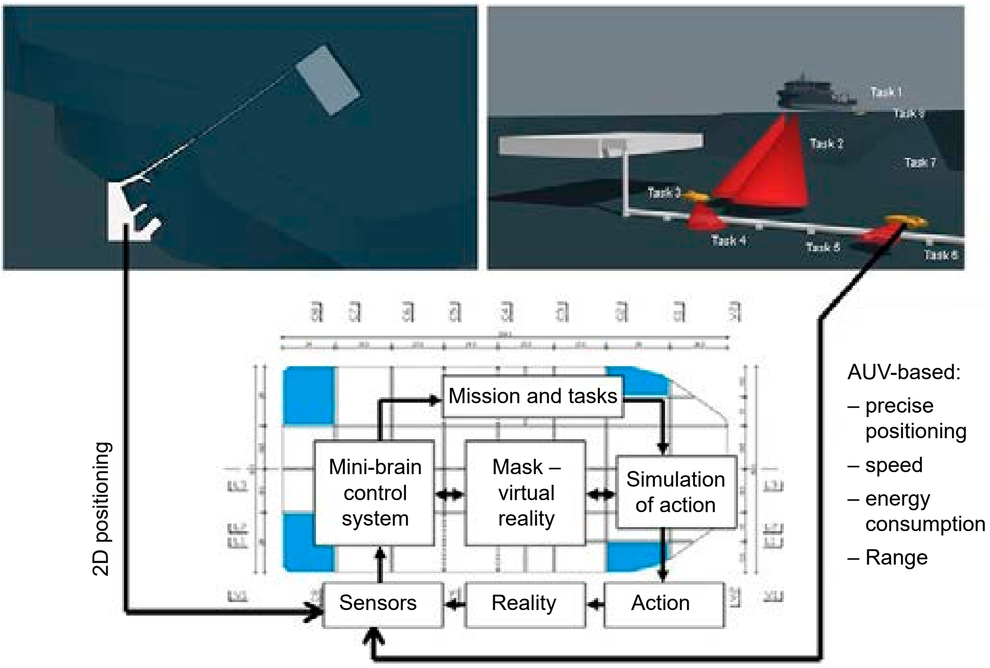

Figure 6. Visualization of the simplified structure of the AUV AI-based mini-brain control system

signals, and (vii) accepting and emitting the false signals. A simplified structure of the AUV AI-based mini-brain control system is presented in Figure 6.

Conclusions

The last decade has been devoted to the further development of different unmanned maritime platforms. There is a growing interest in applying USV/AUV platforms in the navy and ocean engineering sectors. The problems discussed in the paper concern the application of unmanned USV/AUV platforms for the monitoring of offshore structures at sea.

The main drivers for further development of the USV/AUV platforms are the technologies of autonomous systems, technologies of sensors and effectors, materials technologies, innovative solutions concerning the energy supply sources, advanced solutions connected with the propulsion systems, and IT (i.e., for control, navigation, and communication) and stealth technologies. There is a growing interest in the development of both the vision and reality of the fully autonomous USV/AUV platforms equipped with an AI-based mini-brain control system. Such an onboard solution for the USV/AUV platforms could substantially increase their functionality, performance, and safety. This means that the platforms may be very useful for monitoring offshore structures and installations at sea.

New concepts for USV/AUV platforms equipped with the AI-based mini-brain control system have been described in this paper. By using such a control system, it could be possible to compare the USV/AUV outside the reality of the platforms with the onboard computer-generated virtual reality to improve the platform operations. This could be a straightforward way to obtain fully autonomous USV/AUV platforms.

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