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Y. Tymoshyn, M. Shevchenko

INTELLIGENT CONTROL OF A GROUP OF TRANSPORT UNDERWATER ROBOTS USING A COORDINATOR ROBOT

Abstract: The article addresses the problem of utilizing a group of underwater transport robots in an uncertain environment by implementing a robot-coordinator. It includes the analysis of situations, a management model, and the internal and external environment of the robot group.

Keywords: underwater robot, situational management, robot-coordinator.

Introduction

The possibility of using a robot-coordinator in a group of mobile robots stems from the need to optimize work and ensure effective interaction between members of the group of transport robots. The robot-coordinator allows managing the group of robots, distributing tasks, and controlling their progress, as well as adapting to changes in external environmental conditions. It is responsible for analysing the situation, assessing the external environment, and determining the most effective strategies and adjusting behaviour based on the obtained data [1]. This enables the group of mobile robots to work in harmony, ensuring high productivity and reducing the risks of errors or accidents. Implementing a robot-coordinator contributes to increasing the autonomy of the group of robots, its flexibility, and adaptability, which are key factors in successfully performing complex tasks in uncertain environmental conditions.

Assessing the external environment of a group of transport robots is an important aspect for further processing and situational analysis by the robot-coordinator. Taking into account various parameters, such as obstacles, dynamic changes in conditions, and other factors, allows the robot-coordinator to more accurately analyse the situation and make optimal decisions regarding the group's work strategies. Analysing the external environment helps the coordinator adapt to new situations, anticipate possible problems, and respond quickly to changes in circumstances. This improves the overall efficiency and productivity of the group of transport robots, ensuring their safety and reducing the risks of problematic situations. Conducting such an assessment also contributes to the intelligent allocation of resources, such as energy and time, and optimization of the group's work based on current data on the external environment. In this context, the robot-coordinator plays a key role in ensuring successful interaction between group members and adapting to rapidly changing conditions in the surrounding world.

Problem formulation

The issue addressed in this article concerns the development and implementation of an effective coordination system for a group of underwater mobile robots, with a focus on the robot-coordinator. This issue is relevant since ensuring reliable coordination and interaction of robots in complex and dynamic environments becomes a key factor for the successful performance of various tasks. The consideration of the problem is useful for robotics as a science, as it contributes to understanding and developing new approaches to coordinating groups of robots [2, 3]. This helps to increase the efficiency of robots in performing joint tasks, ensuring quick and flexible adaptation to changes in the external environment, and reducing the need for active human-operator intervention. Studying this issue may lead to the development of new methods and technologies that significantly improve the work of robot groups, particularly underwater mobile robots, and can be applied in various fields such as oceanographic research, search and rescue operations, and environmental monitoring.

External environment of the group of transport robots

The investigation of the external environment of the robot group is an essential aspect of successful task performance and adaptation to various situations. Collecting detailed information about the external environment helps robots to more accurately determine the parameters of dynamic obstacles and conditions they encounter during task execution [4]. This also allows the coordinator to consider the entire range of possible deviations from the characteristics of the external environment and the robots in the group, and to respond to them in a timely manner, ensuring optimal movement of the group and accident-free situational management. Analysing the external environment of the robot group enables the robots to be flexible and adaptable to changing conditions and to respond appropriately to unforeseen circumstances [5]. This contributes to the successful execution of tasks and minimization of risks, as they can work more efficiently and more coordinated, even in the case of unplanned situations or environmental changes.

Fig. 1 shows the components of the external environment model for a swarm robot, including the robots and coordinator of this swarm, as well as tools and materials for task execution, and sensors for external monitoring.

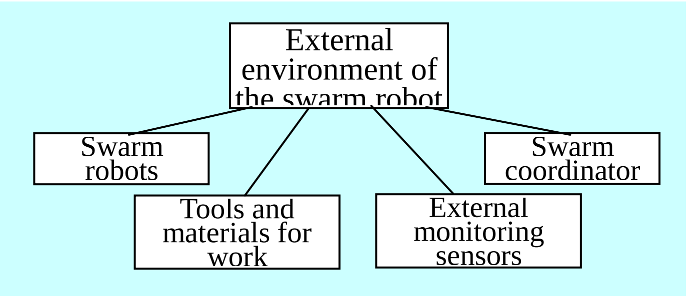

Figure 1. Components of the external environment model of a swarm robot

The external environment of the group consists of the surrounding environment of the group, the natural environment, and the infrastructure above the swarm, namely the Ground Control Center.

Table 1.

External environment characteristics of the group of transport robots

Characteristic name	Measurement unit	Min. value	Max. Value	Step
Group movement speed	km/h	0 km/h	20 km/h	1 km/h
Immersion depth	m	0 m	20 m	0.5 m
Group acceleration	m/min	0 m/min	30 m/min	5 m/min
Distance to obstacle	m	0 m	100 m	5 m
Distance to end point of the route	km	0 km	2 km	0.1 km
Distance to base	km	0 km	2 km	0.1 km

Table 2 provides approximate characteristics of the external environment for a swarm robot according to the components of Fig. 1.

For a better understanding of the processes occurring in the external environment of the group of transport robots, the term "situation" is introduced. A situation represents the state of the group of robots constructed as a result of interaction with the surrounding environment based on the list of parameters from Table 1. Situations that arise in the external environment of the group of transport robots can be divided into two types: working and problematic. Working situations are characterized by the fact that the values of characteristics do not exceed permissible limits and there is enough information for analysis and processing of the situation. Working situations provide optimal conditions for task execution by the group of robots.

Problematic situations differ from working situations in that they have a low probability of occurrence or contain contradictions and require adaptation of intelligent control. To understand and analyse such situations, it is necessary to consider additional information, which leads to the need for more complex information processing algorithms involving intellectual components, such as neural networks. Problematic situations also require an expansion of computational resources in a short period to ensure effective group robot response to unforeseen circumstances.

To improve the efficiency of processing working and problematic situations, they should be considered at the level of subtypes aimed at creating a hierarchy of priority situations that are subject to processing. Working situations can be classified as normal, acceptable, and pre-accident. Normal situations are characterized by being within the minimum and maximum values of the characteristics presented in Table 1. In turn, acceptable and pre-accident situations are defined as situations where the characteristics exceed the norm by 5% and 10%, respectively. As for problematic situations, they can be divided into accident and loss of control situations. Accident situations are those where the values of the characteristics and criteria exceed the limits by more than 10%. Loss of control situations cover situations where the criteria are significantly exaggerated or impossible to measure due to the failure of critically important modules and subsystems of the group's robots. Developing such a hierarchy of priority situations allows for more efficient management of coordinator robots, ensuring optimal resource allocation and rapid adaptation to changes in the environment.

Table 2.

External environment characteristics of the swarm robot

Characteristic name	**Measurement unit**	**Min. value**	**Max. Value**	**Step**
Configuration/position number in the group	number/number of robots	1/1+3	5/1+10	1/1
Tool catalog code/weight	number/kg	- /0,1	- /2,0	- /0,1
Material catalog code/quantity	number/kg number/(m*m)	-/0,5	-/3,0	-/0,5
Total weight of materials and tools	kg	0	5,0	0,5
Movement time	min	0 min	180 min	10 min
«Hanging» time	min	0 min	30 min	5 min
Distance to end point of the route	km	0 km	2 km	0.1 km
Distance to base	km	0 km	2 km	0.05 km
Distance to the front robot	m	0 m	3 m	0.5 m
Distance to neighboring robot (top, bottom, left, or right)	m	0 m	2 m	0.2 m

Fig. 2 shows the structure of components that define the monitoring objects for the swarm coordinator, swarm robots, and their relationships at the level of different environments, the interaction with which forms the basis of intelligent swarm robot control. In the case of the "Superstructure above the swarm", for example, the Ground Control Center can act, which usually operates with the Swarm Coordinator and, in extraordinary situations, with the swarm robots directly.

Therefore, the analysis of the external environment is the basis for ensuring effective interaction of robots with the external environment. Taking into account different types of situations, conflicts, and disturbances allows developing optimal management strategies and adaptation of the group of robots, ensuring successful completion of transport tasks and responding to unforeseen circumstances.

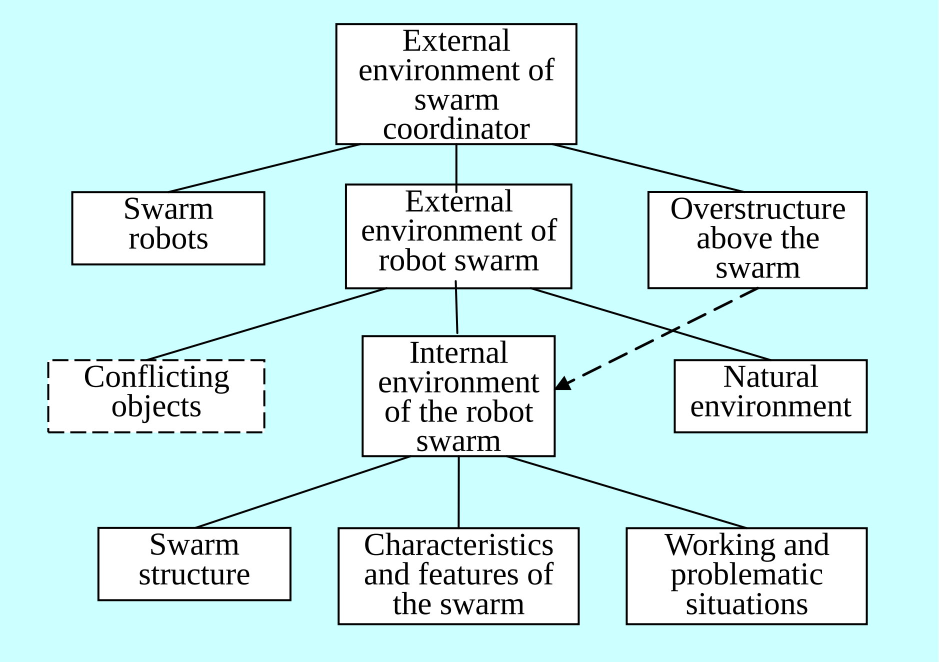

Figure 2. Structure of components for monitoring group robot behavior

Model of analysis and processing of the situation by the coordinator robot

Creating a model of analysis and processing of the situation for the coordinator robot is an important step in ensuring effective interaction between members of the group of underwater mobile robots. With such a model, the coordinator robot will be able to adapt to different situations arising in an uncertain ecological environment, anticipate and react to dynamic obstacles and changes in the environment. By optimizing the movement of the group of transport robots, the model allows for accident-free coordination and task execution [5, 6]. In addition, the model facilitates the training of the coordinator robot for new situations and minimizes the need for human coordinator intervention. Optimization and adaptation criteria are key tools for improving the work of the coordinator robot under various situations and challenges. They help ensure the most efficient and safe movement of the group of underwater mobile robots [7].

The proposed optimization criteria include minimizing response time, resource conservation, and load balancing. Minimizing response time involves quick detection and response to changes in the environment, enabling effective coordination of the group of robots. Resource conservation involves the rational use of energy, time, and other resources, ensuring the long-term and stable operation of the group of robots. Load balancing involves the even distribution of tasks and functions among robots to optimize group performance and reduce the risk of overloading individual robots.

Regarding adaptation criteria, self-learning and algorithm flexibility are of great importance. Self-learning implies the ability of the coordinator robot to learn from its own experience, analysing responses to different situations and optimizing its behaviour accordingly. Algorithm flexibility means the ability of the coordinator robot to adapt to different conditions and requirements, adjusting its problem-solving techniques in response to new situations and challenges. Flexible algorithms allow the coordinator robot to apply various approaches and strategies, considering the characteristics of a specific situation and the properties of the group's robots.

By applying these optimization and adaptation criteria, the coordinator robot can manage the group of underwater mobile robots much more effectively, supporting the reliability and stability of the group's work. As a result, the interaction between the robots in the group improves, tasks are performed faster and more efficiently, and resources are used rationally. Optimization and adaptation increase the autonomy of the coordinator robot, reducing dependence on the human coordinator and ensuring greater stability in the dynamic underwater environment.

Fig. 3 shows a model developed to analyse and process situations by the coordinator robot interacting with a group of transport robots and a human operator. This model is characterized by the presence of a communicator, which serves as the entry point for exchanging messages with the group of robots and the human operator. Message variability may include data from the robot's sensory systems, information on malfunctions of the robot's subsystems, task execution status, and new instructions from the operator.

Using the communicator, messages received from the group's robots or the human coordinator are transmitted to the message processing subsystem, where they are converted to data formats suitable for processing by the coordinator robot. After that, the information goes through the stage of situation analysis, at which the coordinator robot refers to the knowledge base of the states of the group of transport robots. This contains general information about the patterns of the states of the group of transport robots, the characteristics of the group, and the history of the states of the group of robots since the beginning of the mission. This information allows assessing the urgency level of situation processing based on the basic information and history of the group's states and determining the priority of situation processing according to the hierarchy of situation priorities and the history of the group's states. The result of the situation analysis is the determination of the priority of its processing, as well as supplementing the received information with the information stored in the database of the group's states.

After the situation analysis stage, the situation enters the situation queue, where it awaits processing in the situation handling subsystem. This subsystem has access to the knowledge base of the group's characteristics and parameters, which contains detailed information about each robot in the group and the group as a whole. Based on this information, the situation handling subsystem can investigate problematic situations in detail, providing additional information for further analysis. After this, problematic situations are passed to the problematic situation handling subsystem, which employs a neural network. The neural network is a crucial step in dealing with problematic situations, as it can process and learn from them, adapting to new situations and improving its decision-making strategies. Moreover, the neural network can detect and consider complex patterns and dependencies, which may not be evident for traditional algorithms [8, 9]. The problematic situation handling subsystem also has access to the knowledge base of problematic situation handling algorithms, which contains the necessary algorithms for dealing with various types of situations [10]. It collaborates with the neural network to solve complex problematic situations, combining existing algorithms and the network's deep learning capabilities. Thanks to this collaboration, the robot coordinator can more effectively analyse and solve problematic situations, improving its skills in the learning process and gaining new knowledge from its database.

The result of processing a problematic situation is instructions that describe the sequence of actions for the group of robots to resolve a similar situation. Generated instructions are stored in the knowledge base of typical situations, thereby transforming the problematic situation into a typical one and simplifying the further processing of similar situations by providing instructions without the need for repeated processing.

After determining the optimal solution, the instructions are sent to the group monitoring subsystem, which tracks the mission execution by the group of mobile robots and updates the knowledge base of the states of the group of transport robots. The next step is sending the instructions to the message generation subsystem, which converts the instructions into comprehensible message formats for mobile robots and the human coordinator. The final stage is sending the messages to the group of robots and the human coordinator via the communicator.

In case it is impossible to determine the instructions for resolving the corresponding situation, it is classified as requiring support from the Control Center operator, for which the swarm coordinator generates the appropriate message, as well as a simultaneous message about the temporary suspension of the mission execution by the swarm for all robots. After the operator's intervention and receiving the relevant instructions by the swarm coordinator, the mission can be resumed or canceled.

Thus, a model is presented that allows the robot-coordinator to effectively analyse and handle various situations that arise during cooperation with a group of transport robots and a human operator. The model includes a series of subsystems and knowledge bases that contribute to optimal decision-making, ensure adaptability to new situations, and facilitate the learning of the robot-coordinator. As a result, this model helps increase the efficiency and safety of task execution by a group of transport robots, and reduces the need for human-coordinator intervention.

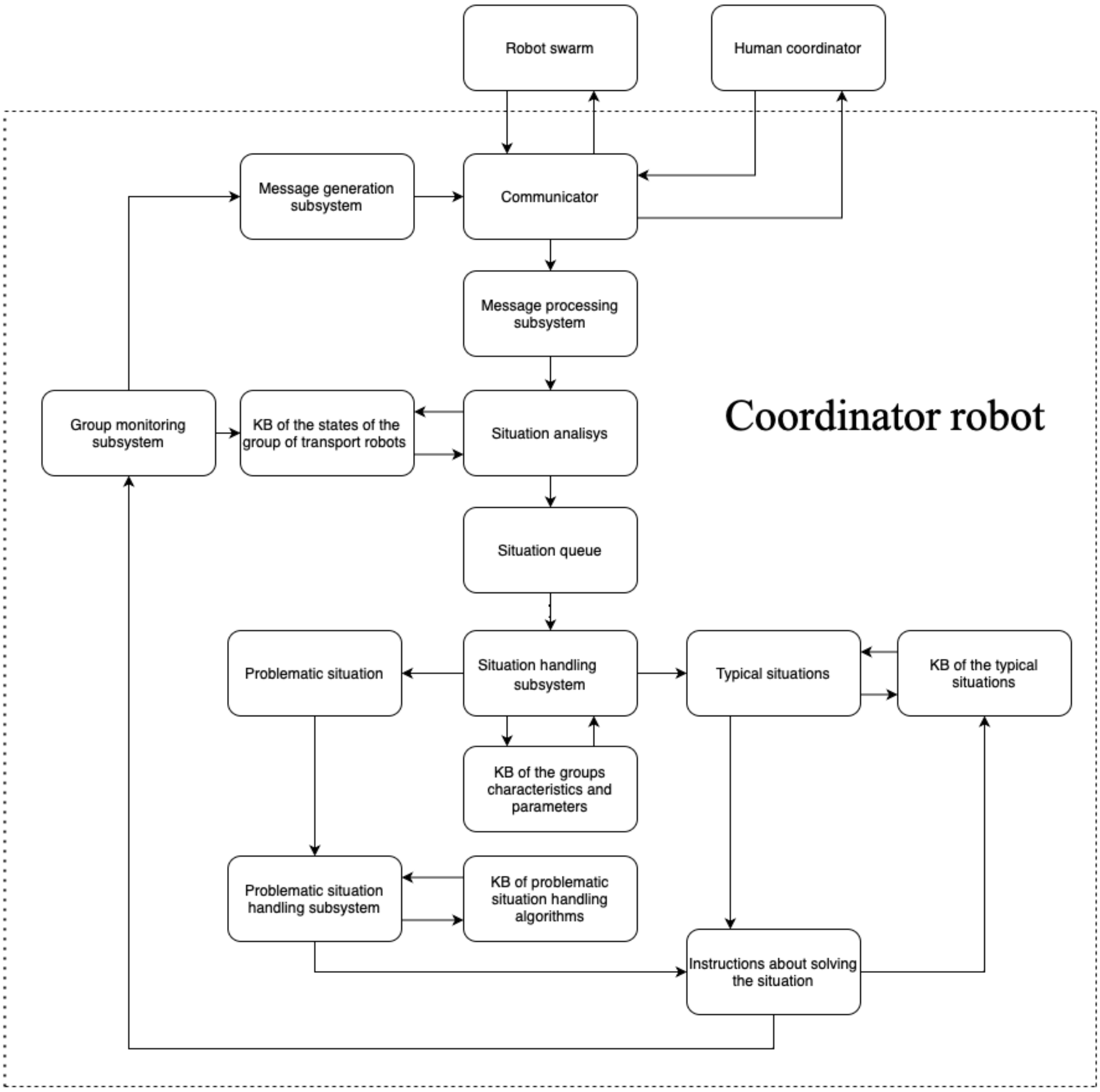

Figure 3. Model of analysis and processing of the situation by the coordinator robot

Conclusion

In this article, a model of situation analysis and processing for the robot-coordinator has been presented, which plays an important role in interacting with a group of underwater mobile robots. The model uses an intellectual component, namely a neural network in the subsystem for handling problem situations, which helps the robot-coordinator adapt to different situations, anticipate, and respond to dynamic obstacles and changes in the surrounding environment. As a result, the robot-coordinator can optimize the movement of the group of transport robots and ensure accident-free coordination and task execution.

The model is also based on several knowledge bases that provide detailed information on the states of the group of transport robots, group characteristics, problem situation processing algorithms, and typical situations.

One of the key features of the model is the ability to analyse the external environment of the group of robots using the sensory systems of the group's robots, which includes various environmental parameters, as well as static and dynamic obstacles. The model helps the robot-coordinator better understand and adapt to these changes, ensuring more efficient interaction between group members and more accurate route planning.

Thus, the proposed model allows for easier learning of the robot-coordinator to new situations and minimizes the need for human-coordinator intervention. As a result, this model can contribute to increasing the efficiency of the work of a group of underwater mobile robots and ensuring the uninterrupted execution of various tasks.

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