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INFORMATION SUPPORT OF OPERATOR ACTIVITY IN ORGANIZING THE TUG SERVICE

ІНФОРМАЦІЙНЕ ЗАБЕЗПЕЧЕННЯ ОПЕРАТОРСЬКОЇ ДІЯЛЬНОСТІ ПРИ ОРГАНІЗАЦІЇ РОБОТИ БУКСИРІВ

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ABSTRACT

Today, the tugs operatingin ports are of a different type and capacity and mostly depend on ship size and port-external conditions of the port (wind, waves, current and shallow water). The main risks at ports, which are pointed out by some authors, can be classified as follows: poor ship and port staff knowledge and training; the human factor in general; poor maintenance of port tugs; poor communication between all parties during a ship's arrival at or departure from the port, as well as mooring operations (in the case that the ship's crew, port pilot and tugs masters communicate in different languages); poor or outdated tug equipment; poor safety culture.

When the vessel navigates in areas with hazardous sections of the waterway, entering and leaving the port, as well as when performing mooring operations to ensure the necessary maneuverability of the vessel and maintain navigational safety at the proper level, line and/or port pilots, escort and harbor tugs are additionally involved. The most dangerous are situations of a ship's power plant failure during maneuvering in confined waters when tugboats become the only means of control that can prevent an accident. During pilotage in international waters, the process of interaction between the ship's crew, pilots and tugs is complicated by the presence of language and cultural barriers, which complicates effective synergy. Therefore, proper training is essential to maintain an adequate level of safety.

In this paper, a plan for maneuvering with the use of the operational effort of tugs in extreme situations has been developed, and a checklist for organizational and administrative preparation of the ship's controls for operation in extreme conditions has been proposed.

Keywords: tugs, emergency situation, maneuvering in port, management system.

АННОТАЦІЯ

На сьогоднішній день буксири, які експлуатуються в портах, мають різний тип і потужність і переважно залежать від розміру судна та зовнішніх умов порту (вітер, хвилі, течія та мілководдя). Основні ризики в портах, на які вказують деякі автори, можна класифікувати так: погані знання та підготовка персоналу судна та порту; людський фактор загалом; неякісне обслуговування портових буксирів; поганий зв'язок між усіма гравцями під час приходу судна в порт або виходу з порту, а також швартовних операцій (у разі спілкування екіпажу судна, лоцмана порту та капітан буксирів різними мовами); погане або застаріле буксирне обладнання; низька культура безпеки.

При русі судна в зонах з небезпечними ділянками водного шляху, заході в порт і виході з нього, а також при виконанні швартових операцій для забезпечення необхідної маневреності судна та підтримки навігаційної безпеки на належному рівні додатково залучаються лінійні та/або портові лоцмани, ескортні та канткові буксири . Найбільш небезпечними є ситуації *відмов суднової енергетичної установки під час маневрування у стиснутій акваторії, коли буксири стають єдиним засобом контролю, який може запобігти аварії. При забезпеченні міжнародного судноплавства процес взаємодії між екіпажем судна, лоцманами та буксирами ускладнюється наявністю мовних та культурних бар'єрів, що ускладнює ефективну синергетичну взаємодію. Тому важливим для підтримки належного рівня безпеки є відповідна попередня підготовка.*

У цій роботі розроблено план маневрування з використанням експлуатаційного зусилля буксирів в екстремальних ситуаціях, запропоновано контрольний перелік організаційно-адміністративної підготовки органів керування судном до роботи в екстремальних умовах.

Ключові слова: буксири, аварійні ситуації, маневрування акваторією порту, система управління.

Defining the general matter and its connection to important scientific or practical objectives

The results of cognition have the property of consistency, which in technical sciences is realized by the construction of meaningful and formalized models that adequately describe the behavior of material objects. At the same time, qualitatively new general scientific approaches to understanding the processes and phenomena of the world around us were formed - systemic, structural, functional, informational, model, probabilistic, deterministic, and a number of others.

The process of maneuvering in extreme conditions includes: course stabilization, control over the geographic coordinates along which the vessel must navigate safely and the use of additional controls in the form of tugs to improve the safety of maritime operations. This requires the implementation of additional procedures for processing information, which significantly complicates navigation and can lead to an excessive delay in making a decision. It is under such conditions that the prerequisites for the occurrence of emergency situations arise.

At the same time, in addition to information about the parameters of the state of the control object and the parameters of external influences, the operator is loaded with a significant amount of other information related to the navigation process. Thus, the navigator’s work is oversaturated with information of various nature and importance. In addition, management of the bridge, tug and engine room operators is required.

In cramped conditions, the number and composition of elementary operations increases, and in extreme conditions it is necessary to use mental actions to find a solution, which leads to a slowdown in the control process. For this reason, the systematization of the structure and content of information that is used in management is very relevant.

Previous researches analysis and definition of new trends in problem solution

Safe operations are very important to the normal functionality of ports. Among the most difficult operations in ports are ships entering ports, mooring and unmooring operations, where the tugs are of the utmost importance. Port tugs assist ships using the port channels, maneuvering of ships turning at basins, shifting to and from quay walls. Today, many ships have thrusters, which replace some of the tug functions, but many ships, especially tankers, bulkers and other big ships, do not possess such thrusters, which is why tugs are very important when it comes to the improvement of navigational safety [1-3].

The article offers a method [4] for quantitative assessment of safe navigation of a vessel with a constrained route using a two-dimensional probability distribution density of positional vectorial error. An alternative method for assessing the probability of safe navigation using a one-dimensional distribution density of the error in the lateral deviation of the vessel is considered. A procedure is obtained for determining the observed coordinates of a vessel using the orthogonal expansion of the distribution density of navigation measurement errors into a Gram-Charlier type A series. The disadvantage of this work is the absence in the calculation of the influence of tugs on the movement of the ship's hull, which must be taken into account for a complete display of the process.

As it can be seen from the analysis above, it is necessary to create a reasonably structured and well-trained tugboat fleet. Under this premise, the auxiliary rationalization of tugs and the coordination of berths can ensure the safety of ships and accurate access to fairways and berths. The port's production efficiency will be improved, the cost of tugboat will also be reduced, and the competitiveness of tugboat enterprises in the market will be improved as shown at work [5]. However, arising a new types of tugs require making the special procedure to operate them.

To study the problem of justifying the optimal number and capacity of tugs that provide access to Ukrainian ports and mooring, the author in this work [6] developed a computer simulation model, which is similar to the distribution of the towing load. At present, the organization of towing work does not provide proper training of the crew for action in an emergency situation. Thus, the development of a plan for operational control of tugs is relevant.

The research objective

To begin the process of manoeuvering it is important to keep in mind a plan how maneuver is intended to the vessel, take into account the wind, tide, state of the ship's trim, draft and freeboard, expert in navigation aids and etc. To tackle these multipurpose factors it is better to use assistant of tugs. Due to this it is highly important to understand operator activity in organizing the work of tug boats, which could been managed in this research article. The research objectives are as follows:

1. Analysis of existing methods of preparation for maneuvering.
2. Improving the ways of organizing the management of the work of tugs.
3. Organization of the work of the bridge crew in case of multi-operator control and ship's engine failure.

Presenting the main material of the research with a full grounding of received scientific results

1. ***Analysis of existing methods of preparation for maneuvering***

Analysis of navigational accidents of vessels shows that many of them are caused by inadequate information support of the navigator.

Improving the work of the management team in emergency situations should be based on the use of the principle of the hierarchy of receiving and processing information. It determines the order of subordination of the composite subordinate information about the state parameters and the sequence of their processing in accordance with the functional necessity to the higher control processes, according to strictly defined steps (hierarchical ladder) and the transition from the lower level to the qualitatively higher hierarchical level.

This type of structural relationship is used in complex multi-level systems, characterized by orderliness, organization of interactions between individual levels along the vertical. Hierarchical relationships are used in control systems that are characterized by both structural and functional differentiation. Moreover, at higher levels, the functions of integration and coordination are carried out.

The need for a hierarchical structure of the information processing system is due to the fact that the management team must process and use large amounts of information, and at the lower levels more detailed and specific declarative information is used, covering only certain aspects of the system's operation. It includes the following questions: selection of the power of tugs and their number; placement scheme relative to the ship's hull; the form of using tugs - escorting or only participating in maneuvering during mooring operations; functional duties of tugs in case of vessel engine failure.

Higher levels receive generalized information characterizing the operating conditions of the entire system, and is presented in the form of knowledge, ready for making a decision adequate to the current emergency situation in the entire system.

The master's decision-making is based on external and internal information supplied to the bridge. Therefore, the distortion of any type leads to the occurrence of errors, which are divided into four types: errors of inaction - a person does not perform the prescribed actions; action errors - they are not performed correctly; sequence errors - the sequence of actions is violated; time errors - actions are untimely.

For normal functioning, the system must have sufficient performance, stability and adaptability. They will allow the connections to be optimally adjusted to perform the proper functions, adequate to the change in external constraints and internal state.

The information hierarchy is based on the efficiency and update of data. At the first level, information for operational management is stored and updated. The upper level stores and processes strategic information for long-term planning. It is characterized by a high level of generalization, unrepeatability, unpredictability and rare use. A hierarchical approach to the management process allows for the automation of data processing at various levels and excludes the use of the thinking abilities of the OR to reduce his load when making a decision.

The amount of information in the probabilistic approach can be calculated using the well-known formula of R. Hartley (1):

$$I(x) = -n\sum_{i=1}^{m} p_i ln\, p_i = -n \cdot m\left(\frac{1}{m} ln \frac{1}{m}\right) = n \cdot \ln m, \quad (1)$$

where $I(x)$ – the amount of information, bytes;
(x) – independent random messages;
n – number of letters in the message (message length);
m – the number of letters in the alphabet of the message;
p_i – equiprobability of symbols (p_i = 1: m).

The characteristic of the average value of the amount of information per symbol – the entropy of information – can be determined by the formula (2):

$$H(X) = -\sum_{i=1}^{m} p(x_i) \cdot \log p(x_i), \quad (2)$$

where $H(X)$ – the informational binary entropy;
(X) – independent random messages;
m – possible states (from 1 to m);
$p(x_i)$ – message probability function.

The amount of information that circulates in the motion control system is 859 bytes. It is difficult for an operator to manage such a large amount of information, so it needs to be structured.

The information that the operator works with when controlling the movement of the vessel and tugs is divided into two types - procedural and declarative. Procedural information is contained in the algorithms of actions that are used in the implementation of the control process and issued commands. Declarative information is embodied in the data which he works with at the same time. The collection of such data forms an information base.

We will describe the parameters in the form of hierarchical structures. Since a large amount of information is simultaneously stored in the databases of information about the vessel, tugs and the effects on them, it is required to organize a special database management system. It allows you to manipulate data and, if necessary, extract them from the database, modify and write back in the required form. The hierarchical structure of information in the ship traffic control system is shown on Fig. 1.

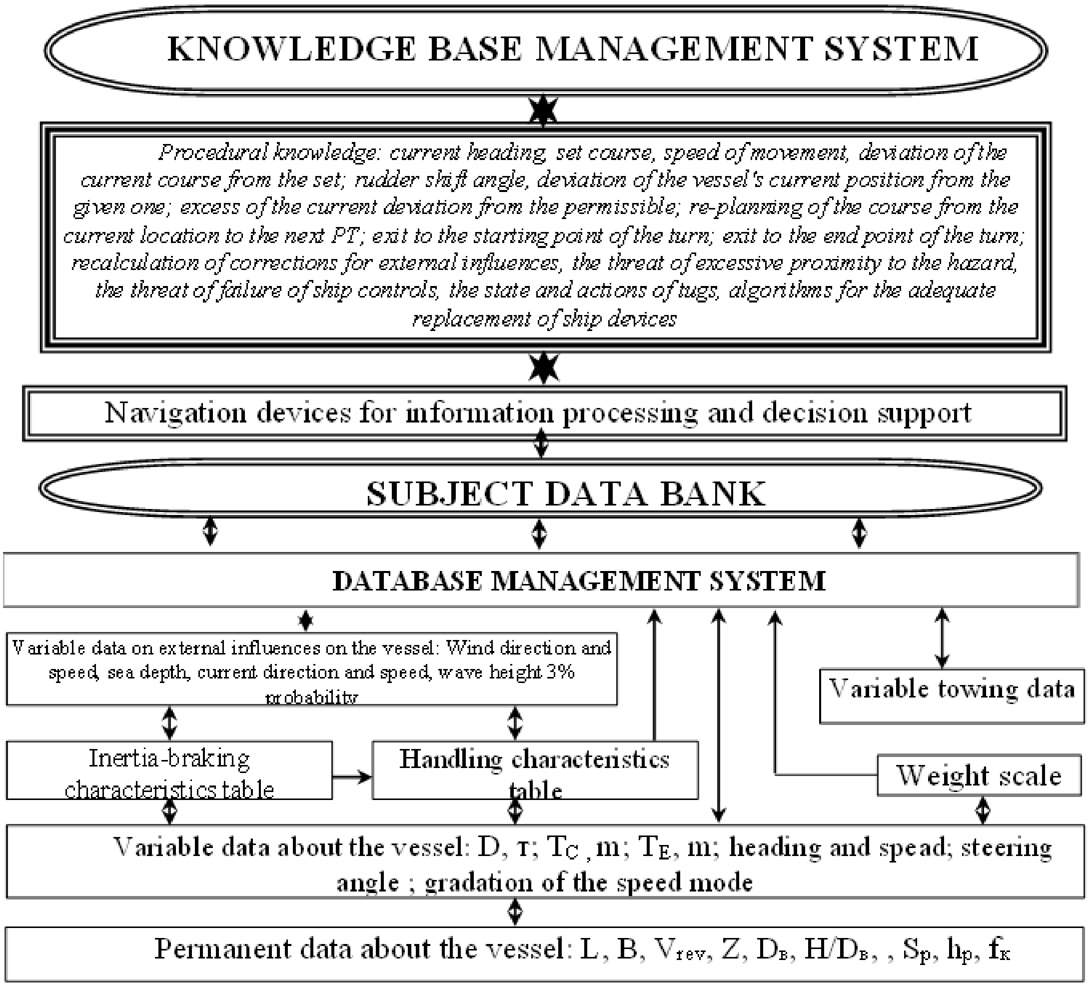

Fig. 1. Diagram of maneuvering control system data flow

When organizing information processing using constant and variable data, you can perform the following elementary actions: choosing the coordinates of the waypoints and calculating the angles of rotation, the true course and distance; compass heading calculation; calculation of circulation parameters; selection of rudder shift angle and calculation of coordinates of trajectory points curvilinear motion; calculation of coordinates of TP straight sections; calculation of the angles of wind drift and drift current; calculation of deviation from a given course and selection of a control action to keep the vessel on TC; calculation of deviations from the specified path and replanning of trajectory points, if necessary, with the choice of a new value of TC; calculation of the number of required tugs; choice of arrangement scheme and method of use.

All data stored in the database about the vessel and tugs are divided into two types - active and passive. Active ones initiate commands that control the movement process in accordance with the given and current state of the system and are practically procedural knowledge. Passive data can be divided into two types - constants, which do not change for a given vessel, and variables, which describe external influences, the current position and state of elements and devices.

Formalization of the traffic information support process allows ensuring the safe navigation of a vessel with tugs in cramped conditions and making adjustments to the structure of the control system.

The use of the proposed models allows: to optimize the information interconnections of the tug control system by choosing the method of their use according to the available data on the parameters of their state; support decision-making in the process of changing traffic conditions, by using procedural knowledge without including the operator's thinking abilities, which significantly speeds up decision-making; to create a theoretical basis for the practical construction of meaningful models and forecasting emergency situations during maneuvering; to investigate the cause-and-effect relationships of the occurrence of accidents, and to analyze the actions of human factor at emergency response when performing elementary actions to prepare the system for operation and operational management; assess the rank of an element in the structure of the control system and determine the hierarchy of information for organizing computing processes, and obtaining it in the form of knowledge; optimize the work of the knowledge base management system.

2. ***Methods for organizing the management of tugboats***

The main parameter that characterizes the tug as a source of control forces is the hook thrust, which is determined by the power of its main engines. Small port tugs have a capacity of up to 150 kW, and large port (sea) tugs up to 10 thousand kW.

There are three methods of towing, differing in the relative position of the tug and towed vessel.

In sea conditions, wake towing is the main method. In this case, the towed vessel follows on a towing rope of a certain length. And both vessels, connected by flexible connection, can make significant relative movements, which is especially valuable in open sea conditions or high seas. The ability to increase the length of the towing line is the important advantage in terms of the drag of the towed vessel. This reduces the effect of the jet propelled by the tug propeller.

The second method of towing is used by a log when vessels are moored and rigidly fixed. The third method is by pushing, when a rigid connection is made between the bow of the pusher and the stern of the vessel being pushed.

The disadvantage of the wake method is poor maneuverability, which makes it necessary to reduce the distance between ships in tight spaces or winding fairways. Therefore, when towing in ports, where the role of maneuverability increases, sometimes it is even necessary to give up wake towing and to switch to the second method - alongside, i.e. side to side. Such towing, in which the towing vessel is moored to the vessel being towed, is possible only in the complete absence of waves, because otherwise it is impossible to reliably fasten the ships and to avoid damage to the side when one ship collides with another.

The third method (push towing) arose as a result of the desire to increase the maneuverability of the tug "with a cart" and at the same time to reduce the negative effect of the jet produced by its propeller. The tug and the vessel, connected rigidly enough, represent a single whole, and the tug can move and control it.

The choice of the way to use the tug when performing mooring operations is determined by the polar diagram of its pulling force. Its type depends on the type of propeller and steering complexes [26], shown on Fig. 2.

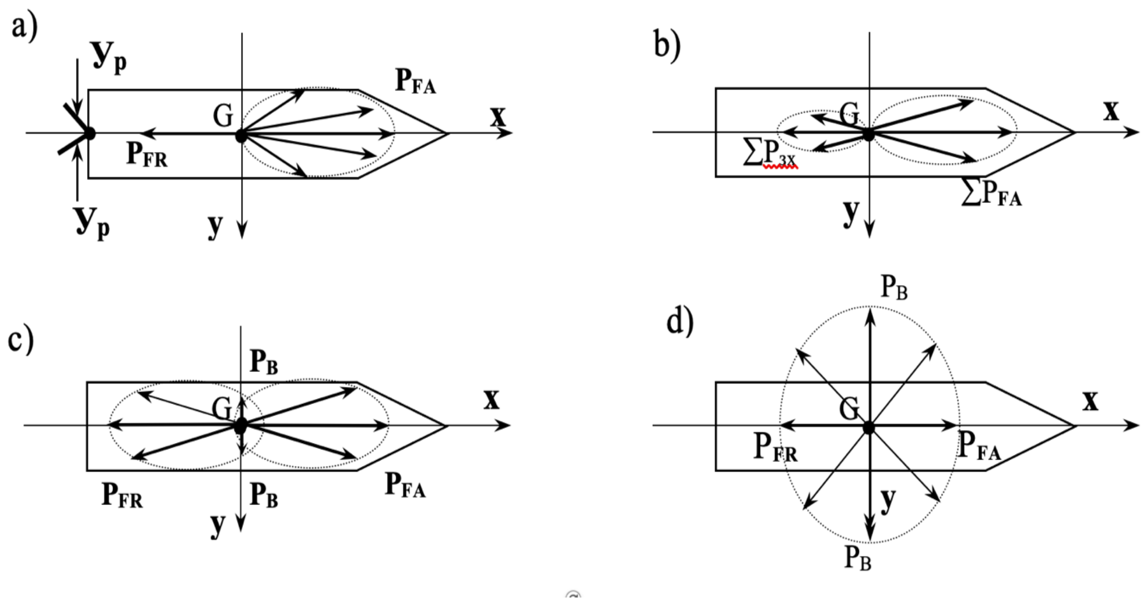

Fig. 2. Polar diagram of the pulling forces of the tug: a) with a fixed pitch propeller and rudder; b) twin-screw; c) twin-screw with on-load tap-changer; d) with a vane propeller

The use of tugs during mooring operations has the peculiarity of the impact of external influences. The work takes place in waters protected from wind and waves, which expands the number of ways to use them. Therefore, operating options limit the types of available tugboats, wind strength and allowable maneuvering speed in port.

However, the method of using tugs is determined by the need to stop the movement of the vessel in the event that the vessel's means of maneuvering fail. This can be achieved when the tugs are ready to provide braking 10 seconds after a failure occurs. This is the time when the command is transmitted to the engine room from the bridge and is executed by the operator who controls the main engine. Another aspect of the problem is the magnitude of the control action, which must be equal to or greater than the engine stop, then the tugs are able to replace the control forces and ensure safe maneuvering.

3. ***Organization of the work of the bridge team in case of multi-operator control and ship's engine failure***

The extreme maneuvering control team consists of operators maintaining the controls, with a single supervisor on the ship's bridge. When performing mooring operations, the crew additionally includes the pilot, the coastal control system and the captains of the tugboats. The peculiarity of the work of such a team is that preparation for work in emergency situations is determined by the main command of the bridge. At the same time, the auxiliary operators on the tugs are the executors of the captain's commands, the pilot gives advice, and the coastal system is not always able to detect the moment of an emergency.

Organizational and administrative training consists of special training for work in extreme conditions of all ship controls, including the organization of the use of backup devices in case of failure of a part of the main ones. For detailed preparation, it is proposed to draw up a checklist, which is shown in Table 1.

Table 1. Checklist of organizational and administrative preparation of the ship's controls for work in extreme conditions

No	Activity content	Ship's time	Response	Comm ents
1.	Main power plant prepared for manual maneuvering	…….	Ch. Eng.	ER
2.	Tested and prepared steering gear for extreme conditions	…….	Fitter Рулевой	Bridge
3.	Bow thruster tested and ready for use	……	Master Ch. Off	Bridge
4.	The anchor gear is prepared for let go with a winch, the anchor is lowered to the water	…….	Bosun	Bow
5.	Mooring gear. Mooring lines spaced apart, throwing lines ready to use	…….	Officers	Bow Aft
6.	Towing gear. The towing lines are sent through through the centre lead on the forecastle and poop deck	…….	Officers	Bow Aft
7.	The tugs approached the ship. The towing lines were sent.out	…….	Officers	Bow Aft
8.	The towing lines were secured, maneuvering for for making fast to the berth began.	……	Ch. Off.	Bridge

The team's work in the event of the risk of an accident will consist of the timely assessment of the probability of an accident and its ability to take adequate measures to prevent it or reduce its consequences by organizing the work of the management team.

Navigational training consists of calculating the safe trajectory for inverse mooring and the ship's navigational plan in extreme conditions using information from the pilot, radar and optimal organization of the work of tugs. The scientific result of solving the first auxiliary problem is the method of organizational and administrative preparation for maneuvering in extreme conditions, including preparation for actions of the bridge team in an accident, by developing a list algorithm for organizing work with multi-operator control.

Conclusion and further research prospects

The research results can be used by sea-going vessels in practical work, in maritime educational institutions to prepare senior cadets for work on ships, in refresher courses and in performing theoretical research.

For effective information management and quick decision-making, including emergency situations, it is necessary to use the type of its presentation in the form of knowledge at the top level of the hierarchy.

REFERENCES

1. Aydin, C.; Karabulut, U.C.; Ünal, U.O.; Sariöz, K. Practical computational procedures for predicting steering and braking forces of escort tugs. Gemive Deniz Teknol. 2017, 21, 21–36. https://doi.org/10.1016/j.oceaneng.2018.08.021
2. Piaggio, B.; Viviani, M.; Martelli, M.; Figari, M. Z-Drive Escort Tug manoeuvrability model and simulation. Ocean Eng. 2019, 191, 106461. https://doi.org/10.1016/j.oceaneng.2019.106461
3. Çakır, E.; Fışkın, R.; Bayazit, O. An Analysis of Accidents Occurred on Tugboats; Dokuz Eylül University, Maritime Faculty: Izmir, Turkey, 2017; pp. 1–13.
4. Vorokhobyn I. I. Otsenka navyhatsyonnoi bezopasnosty pry plavanyy sudov v stesnenyh vodakh / I. I. Vorokhobyn, Yu. V. Kazak, V. V. Severyn – LAP LAMBERT Academic Publishing, – 2018. – 239 s.
5. Wang, W.; Zhao, H.; Li, Q. Research on optimization of port tug scheduling for multi-berth bases. Comput. Eng. Appl. 2013, 49, 8–12.
6. Polivoda M. S. ROZVYTOK BUKSYRNOHO FLOTU V UKRAINSKYKh PORTAKh / M. S. Polivoda. // Internauka. – 2019. – №8. – S. 37–41.
7. J. Esposito, M. Feemster and E. Smith, Cooperative manipulation on the water using a swarm of autonomous tugboats, IEEE International Conference on Robotics and Automation, Pasadena, USA (2008) 1501–1506.
8. Lin, A.; Zeng, J. The formation control method for multiple tugboats assist the lame ship berthing. J. Xiamen Univ. (Nat. Sci.) 2019, 58, 97–103. doi:10.6043/ji.sn.0438-0479.201707018