Structure and the Basic Operating Principles of Test Water Zone for the Testing of Unmanned and Self-Piloted Vessels

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Abstract. Standard procedures for the assessment of vessel maneuverability cannot be used to the full extent for unmanned, self-piloted, and autonomous vessels. This is due to the fact that during field tests of these vessel types, the maneuvers resulting from control commands from the operator or the autonomous control system are hard to record. Therefore, these tests require modern technical solutions that would provide the proper accuracy of control parameter measurement. Field tests of unmanned, self-piloted, and autonomous vessels conducted using modern technical solutions for navigation should include the independent measurement of movements of the vessel's bow and stern. The goal of this article is to develop a structure of a test water zone for safe field testing of unmanned, self-piloted, and autonomous vessels or robotized surface objects.

1. Introduction

Currently, standard field test guidelines, programs, and procedures are used to determine the maneuverability of vessels that are basically reduced to controlling the engines, propellers, rudders, and maneuvering devices at the captain's command. However, this approach cannot always be used for the field tests of unmanned, self-piloted, and autonomous vessels. Such vessels are generally controlled by hardware and software packages combining various technical solutions [1-2]. Thus, these vessels are commonly controlled from a remote control desk or by an autonomous control system located on board.

Various technical solutions can be used to measure the movement parameters of unmanned, self-piloted, and autonomous vessels, based on the navigation signals from global satellite navigation systems (GSNS) [3], hydroacoustic depth and speed measurements, and inertial navigation systems [4-6]. As a rule, these technical solutions are included in the navigation systems of unmanned and autonomous vessels due to their unique properties [7-9]. We must note that the combined use of a set of technical solutions within the navigation system of an unmanned or an autonomous vessel helps mitigate the drawbacks of specific solutions used independently. For instance, the integration of platformless inertial navigation systems (PINS) with the consumer's navigation system (CNS) of GSNS allows for the reception of navigation data from PINS if the reception of GSNS navigation signals is lost for some short time. At the same time, when the CNS of GSNS runs in the standard mode, PINS are adjusted continuously. The experience of using the CNS of GSNS on internal waterways (IWW) shows that errors in positioning are inevitable when boats go under bridge spans. This happens because the receiving antennas of the CNS enter the bridge’s shadow where they cannot pick up navigation signals.
from the GSNS. Thus, the combined use of technical solutions in the navigation systems of unmanned, self-piloted, and autonomous vessels is a good design solution.

However, it can be difficult to understand whether the measured movement parameters are reliable during the field tests on unmanned, self-piloted, and autonomous vessels equipped with combined navigation systems because the control commands for unmanned, self-piloted, and autonomous vessels are based on the data received from the navigation system. Therefore, field tests require an ongoing verification of the decisions produced by the navigation system of the vessel.

This problem can be solved if the field testing of unmanned, self-piloted, and autonomous vessels is carried out in a special water zone with independent high-precision measurement tools located both onshore and onboard. The parameters of the testing water zone are known, and there can be additional navigation/information/communications fields facilitating the use of high-tech solutions for navigations and data communication. The goal of this article is to develop a structure of a test water zone for safe field testing of unmanned, self-piloted, and autonomous vessels or robotized surface objects in real-time. We are expecting to obtain precise data on the route, location, heading, and speed of the vessel, as well as its stability. The collection of data and its transmission to the on-shore observation desk or the operator’s automated workplace shall provide the required navigation safety in the testing zone [10-12].

2. Methods and materials

The establishment of a testing water zone is a pressing issue for water transportation experts involved in the development and deployment of unmanned, self-piloted, and autonomous vessels or robotized surface facilities within the transportation sector of the Russian Federation. We must note that the development of an unmanned or autonomous vessel differs significantly from the development of a conventional vessel, which creates a possibility of brand-new hull types. New hulls, however, must be tested both as models and real vessels [3, 13-15].

The field testing procedures for unmanned, self-piloted, or autonomous vessels are based on the comparison of the parameters set in the control system (task) and the actual vessel movement results recorded, among other things, by an independent system. The testing water zone may include an inertial measuring unit, multi-antenna GSNS receiver units, antenna module, motion control system, control computer, and the metering equipment facilitating the measurement of precise bow and stern movement taking into account the impacts of the current and the wind. The route of the vessel is limited by the navigation buoys equipped with measurement modules comprising the devices converting solar and wind power into DC electricity, a power source with the accumulation function, a Wi-Fi unit (long-range 5.8 MHz with Wi-Fi Positioning System/WPS), a GSNS receiver, a 4G/LTE modem, a weather station in the upper part and the profiling current meter in the bottom part of the buoy, as well as a microcomputer to process the measurement data and send them to the on-shore observation desk or the operator's automated workplace. The navigation buoy can be installed on a fixed base or anchored. If the second option is used, it is necessary to consider the movements of the buoy with respect to the anchor.

Testing consists of determining the precise maneuverability and performance parameters of the unmanned vessel by comparing the measured movement data and the design parameters for the current movement and maneuvering conditions. This is accomplished through the use of measurement units that determine the current position, speed, and heading of the vessel, as well as the impacts of the current and wind on the vessel. During tests, the measured parameters are automatically recorded by the navigation unit microcomputers in the buoys. The recorded parameters are sent to the operator’s automated workplace over the Wi-Fi long-range 5.8 MHz or the 3G/4G LTE connection. Based on the results of the processing of the data received and the set vessel route, vessel movement deviations are calculated. This method helps determine the vessel movement parameters, as well as maneuverability and performance specifics for various hydrometeorological conditions, in practice and transmit the data to the operator's automated workplace over the Wi-Fi, the 4G/LTE modem, or mobile networks for subsequent storage, processing, and analysis.
Testing requires the following sequence of actions. Within the designated testing water zone, it is necessary to form the navigation space by placing 4 navigation buoys. These are activated by commands from the operator's automated workplace transmitted over the Wi-Fi or 3G/4G LTE networks. The data on the mobile testing zone’s readiness is returned to the control desk. The test vessel takes the initial position in a spot with set coordinates, after which the operator commences the test, and the vessel starts moving along the set route. While the test vessel is moving, it uses the Wi-Fi devices to interact with the buoys and register its current position. After this, the data on the position and technical state of the test vessel is sent to the automated workplace and analyzed. The automated workplace displays the trajectories of the vessel bow and stern movement, as well as vessel orientation, the operation parameters of its systems, and the impacts of currents and wind on it with the refresh rate of at least 1 Hz. After the test, the protocol is formed based on the results of the processing of all the telemetric signals.

3. Results and discussion

Figure 1 shows the basic idea of the suggested test procedure with operator's automated workplace 1, the test water zone limited by buoys (A, B, C, D) where test vessel 2 moves, and its data are sent to the operator's automated workplace (over Wi-Fi or 3G/4G LTE networks). During the tests, the operator at the automated workplace (1) commands test vessel (2) to approach the start line (3) within the testing water zone for water transport limited by the buoys (A, B, C, D). After this, test vessel (2) starts moving along the route facilitating the measurement of its maneuverability and performance parameters. The results are obtained by the installation and operation of Wi-Fi units on the bow and the stern of the vessel and their interaction with similar units installed in buoys.

![Figure 1. Testing configuration.](image)

WPS is used to determine distance A1, B1, C1, D1 (to the bow of the vessel) and A2, B2, C2, D2 (to the stern of the vessel) for each of the buoys (A, B, C, D in the chart). The obtained data on distance, wind and current impacts from each of the buoys are transmitted over Wi-Fi or 3G/4G LTE networks to the operator’s automated workplace that displays the set route, water zone limits, and other information required by the operator to determine the technical condition of the vessel and perform maneuverability tests.
4. Conclusions
It is possible to increase the precision of test (unmanned or autonomous) vessel parameter measurement through the improvement of the measurement precision of its current position and movement trajectories for its bow and stern during maneuverability and performance tests. This article solves the problem of obtaining reliable data on the maneuverability of unmanned, self-piloted, or autonomous vessels taking into account the average wind-and-wave parameters and current speeds. The authors believe that the suggested water zone is suitable for the safe testing described in theoretical works [11,13-15]. The analysis of shipbuilding literature performed shows that there have not been any similar technical solutions.

5. References
[1] Ivanova A, Butsanets A, Breskich V, Zhilkina T 2021 Autonomous Shipping Means: the Main Areas of Patenting Research and Development Results Transportation Research Procedia vol 54 pp 793-801 DOI: 10.1016/j.trpro.2021.02.132
[2] Cheng H H, Ouyang K 2020 Development of a strategic policy for unmanned autonomous ships: a study on Taiwan Maritime Policy & Management pp 1-15 doi: 10.1080/03088839.2020.1768315
[3] Karetnikov V, Milyakov D, Prokhorenkov A, Ol'khovik E 2021 Prospects of application of mass-produced GNSS modules for solving high-precision navigation tasks E3S Web of Conferences EDP Sciences vol 244 pp 08006 DOI: 10.1051/e3sconf/202124408006
[4] Karetnikov V, Ol'khovik E, Butsanets A, Ivanova A 2019 Technology Level and Development Trends of Autonomous Shipping Means Energy Management of Municipal Transportation Facilities and Transport (Springer, Cham) pp 421-432 DOI: 10.1007/978-3-030-57450-5_36
[5] Fan C, Fan C, Wróbel K, Montewka J, Gil M, Wan C, Zhang D 2020 A framework to identify factors influencing navigational risk for Maritime Autonomous Surface Ships Ocean Engineering vol 202 pp 107188. doi: 10.1016/j.oceaneng.2020.107188
[6] Wróbel K et al 2021 On the use of leading safety indicators in maritime and their feasibility for Maritime Autonomous Surface Ships Proceedings of the Institution of Mechanical Engineers Part O: Journal of Risk and Reliability pp 1748006X211027689 doi:10.1177/1748006X211027689
[7] Bukhari A C et al 2013 An intelligent real-time multi-vessel collision risk assessment system from VTS view point based on fuzzy inference system Expert systems with applications vol 40 pp 1220-1230 doi: 10.1016/j.eswa.2012.08.016
[8] Zhilenkov A A et al 2020 Intelligent autonomous navigation system for UAV in randomly changing environmental conditions Journal of Intelligent & Fuzzy Systems vol 38 5 pp 6619-6625 DOI: 10.3233/JIFS-179741
[9] Karetnikov V, Chistyakov G, Ol'khovik E 2020 Tasks of developing the aquatory for testing autonomous ships in inland waterways E3S Web of Conferences EDP Sciences vol 157 pp 02010 doi:10.1051/e3sconf/202015702010
[10] Ahn J H, Rhee K P, You Y J 2012 A study on the collision avoidance of a ship using neural networks and fuzzy logic Applied Ocean Research vol 37 pp 162-173 doi: 10.1016/j.apor.2012.05.008
[11] Shipunov I S et al 2021 The Concept of a Partially Unmanned Sea Convoy 2021 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (ElConRus) IEEE pp 661-664 DOI: 10.1109/ElConRus51938.2021.9396302
[12] Karetnikov V et al 2020 Development of Methods for Maneuvering Trials of Autonomous Ships in Test Water Area Proceedings of the XIII International Scientific Conference on Architecture and Construction 2020 (Springer, Singapore) pp 40-46 DOI: 10.1007/978-981-33-6208-6_5
[13] Raber G T, Schill S R 2019 Reef Rover: a low-cost small autonomous unmanned surface vehicle (USV) for mapping and monitoring coral reefs *Drones* vol 3 2 pp 38 doi:10.3390/drones3020038

[14] Karetnikov V, Ol'Khovik E, Butsanets A, Ivanova A 2020 Simulation of Maneuvering Trials of an Unmanned or Autonomous Surface Ship on a Navigation Simulator Proceedings of the XIII International Scientific Conference on Architecture and Construction 2020 (Springer, Singapore) pp 146-156. DOI 10.1007/978-981-33-6208-6_15

[15] Son N S, Kim S Y 2018 On the sea trial test for the validation of an autonomous collision avoidance system of unmanned surface vehicle, ARAGON OCEANS 2018 MTS/IEEE Charleston *IEEE* pp 1-5 DOI: 10.1109/OCEANS.2018.8604803