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OPTIONS FOR CONNECTING RADAR SENSORS IN MSA SYSTEM

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ABSTRACT

This study presents the results of analyses performed to determine the possibility of remote acquisition of radar sensor data to improve Maritime Situational Awareness. The impact of fading and of delays in the radio data link (Starlink satellite internet) on the quality and completeness of remotely acquired data was investigated.

Keywords— radar-sensor, maritime situational awareness (MSA), Starlink, radio data link.

1. INDRUCTION

The analysis of recent studies and publications [1-5], as well as the experience of building and organizing systems for monitoring the surface situation of the leading countries of the world, shows that today these systems are the basis for building the overall maritime security system of these countries. This includes, as a rule, the entire range of sources of Maritime Security Information to ensure full awareness of the maritime situation (Maritime Situational Awareness - MSA) [6]. This allows states to acquire the ability to be fully aware in the maritime domain of the state (Maritime Domain Awareness).

Additionally, small boats can and have been used as platforms for attacks on ships in port. Reported attempts at ship piracy are on the rise. As a result, the Centre for Maritime Research and Experimentation (CMRE) is developing the Maritime Surveillance System--a tool that NATO nations can use to select the correct suite of sensors to monitor areas of interest [7].

The ship is the point that performs the sensor and information processing (NATO ISTAR process) of the MSA system. Data on the surface condition, which is actually data on the movement of watercraft in a particular area of a water body, can be obtained by various sensors of the ship:

- from the regular navigation radar installed on the ship;
- from video and infrared cameras by visual monitoring of the surface situation;
- from the ship's Automatic Identification System (AIS) receiver.

Radar surveillance of the surface environment is one of the most important technical components of the surveillance system. Compared to other technical sensors in the system (in particular, optical, optoelectronic, AIS transponders, etc.), remote radar sensors have the following advantages:

- allows continuous monitoring of the surface (24/7/365);

- is an active independent surveillance system (i.e., is not dependent upon on/off toggling of special responders at the object of surveillance);
- has a relatively long range;
- is not dependent on weather conditions, etc.

Thus, in order to increase awareness of the maritime situation, the issue of involving ship's and vessel's navigation radar sensors in this system is becoming increasingly relevant.

The transmission of radar surveillance data from the ship's navigation radar to the MSA system renders it a de facto sensor for collective use. Shipboard navigation radar is not initially a regular sensor of the MSA system. Therefore, the issue of the effectiveness of various options for the organizational and technical implementation of connecting a ship's navigation radar in a standard configuration, without special modernization, as a source of data on targets to the MSA system requires analysis and additional study.

The purpose of the present article is to analyze the options for connecting ship's and vessel's navigational radar sensors to the MSA system to increase awareness of the maritime situation.

2. INFORMATION INTERACTION BETWEEN THE SHIP AND MSA SYSTEM

There are two main variants of information interaction between MSA system and ship's navigation radar:

- transmission of target kinematic parameters;
- transmission of radar-video describing the radar environment.

In the first case, kinematic data (course, speed, and distance to the target) describing the target from the ship's navigation radar are transmitted to the MSA system in automatic mode.

To make the second option work requires the presence of an operator on shore. The shore operator must physically acquire targets of interest to take on auto- tracking and calculate their kinematic data, and only then will the operator be able to transmit the data to the MSA system.

The use of radar allows one to receive information about all objects in its line of sight, regardless of the type of ship in question and the equipment operating on it. The accuracy of the data obtained depends only on the characteristics of the radar used, and the data cannot be distorted by the vessel being observed. The area observed by the radar is determined by its location, as the radars used for maritime navigation operate only within line of sight.

A radar-processor must be used to transmit radar-video of the radar environment. The task of the radar-processor is to convert the radar signal of the ambient picture into a stream of digital data. It is the exceptional, rare model of navigation radars that have digital output of radar signals, because the issue of digital output of radar signals is not regulated in international operational standards.

Given that Furuno navigation radars are quite common on ships, then Furuno DRS**-NXT, which has a built-in radar processor, was chosen as a test prototype and for research on the ship in order to transfer the digital data to the MSA system. Tactical and technical specifications of the Furuno DRS**-NXT are given in [8].

During combat operations against an aggressor, the use of Starlink satellite internet mobile terminals has been widely used. In this paper we proposed use of Satellite Internet Starlink (Maritime type, model - High Performance Kit for Boats), as a radio channel for transfer data for information ship-shore interaction.

Thus, the Starlink terminal installed on the ship makes it possible to conduct studies of ship-to-shore information interaction during fading and delays in the radio channel [9].

2.1 ANALYSIS OF TARGET KINEMATIC DATA ACQUISITION FROM THE RADAR

Shipborne navigation radars that are planned to be integrated into an MSA system as radar sensors should provide the following built-in basic functions:

- target acquisition for auto-tracking;
- auto-tracking of targets;
- issuance of information messages with target movement parameters to external devices.

The absence of support for any of the above functions in the subject radar makes its inclusion it in the MSA system, as a full-fledged sensor, inappropriate.

The implementation of support for the above functions allows us to determine in advance the presence or absence of an integrated Automatic Radar Plotting Aids (ARPA) in the radar.

Requirements for ARPA are set out in the standards of the International Maritime Organization (IMO) for the development of ship/shipborne radar, in particular, IMO Resolution A.823(19) [10], IMO Resolution MSC.192(79) [11], IEC 62388:2013 [12], which defines the minimum operational and maintenance requirements.

The ARPA system should provide conditions for quick determination of bearing and distance to any object in the viewing area [13, 14]. It is necessary that the auto-tracking mode provide, within a period of time not exceeding one minute after target acquisition, data on the direction of movement of the object. Within three minutes from the start of tracking, it must display a prediction of target motion in accordance with the situational environment. The "auto-tracking" should continue to track an acquired target that is clearly distinguishable on the display for 5 out of 10 consecutive scans. Also, the operator should be able to select any of the acquired targets for additional information.

The identification of tracked targets is usually performed by the ARPA by automatically assigning a unique number in the range from 1 to N (the maximum number of tracked targets).

The output of ARPA information about the tracked targets to external devices is performed in accordance with the generally accepted requirements of the IEC 61162-1:2024 standard [15]. Information about targets (kinematic data) tracked by the ARPA is carried by the following standard data messages: TLB, TLL, TTM, TTD. The purpose of these data sets is described in more detail in [16].

As seen in [16], the standard ARPA Tracked Target Message (TTM) contains target data that is necessary to solve the task of safe divergence from an oncoming vessel. Therefore, the TTM includes such parameters as speed, heading and distance to the target. However, the MSA system must have another data and parameters.

The MSA system needs to know the location of the target in absolute values - "Target Position". The RMC (Recommended Minimum Specific GPS/Transit Data) message contains the ship's coordinates, and the TTM contains data on the target's displacement relative to the ship, so these data are sufficient to calculate the "Target Position".

Given the geographical position of the carrier platform, recalculating the target position from relative "Target Distance" and "Bearing from own ship" to absolute values is not a difficult computational problem, but it requires the involvement of third-party computing resources. Based on the approach to prevent introduction of any modifications to the ship's radar, the recalculation must be performed on the shore side.

Thus, the analysis shows that the transmission of data from the output of the ship's ARPA module regarding targets that have been taken on auto-tracking to the MSA system in the form of TTM, TTD and RMC messages does not require the modernization of the radar.

2.2 ORGANIZATION OF INTERACTION BETWEEN THE SHIP'S RADAR AND MSA

Schematic diagram of connectivity between the ship's radar, sensors of the ship's kinematic parameters, and Starlink channel on the ship is shown in Figure 1.

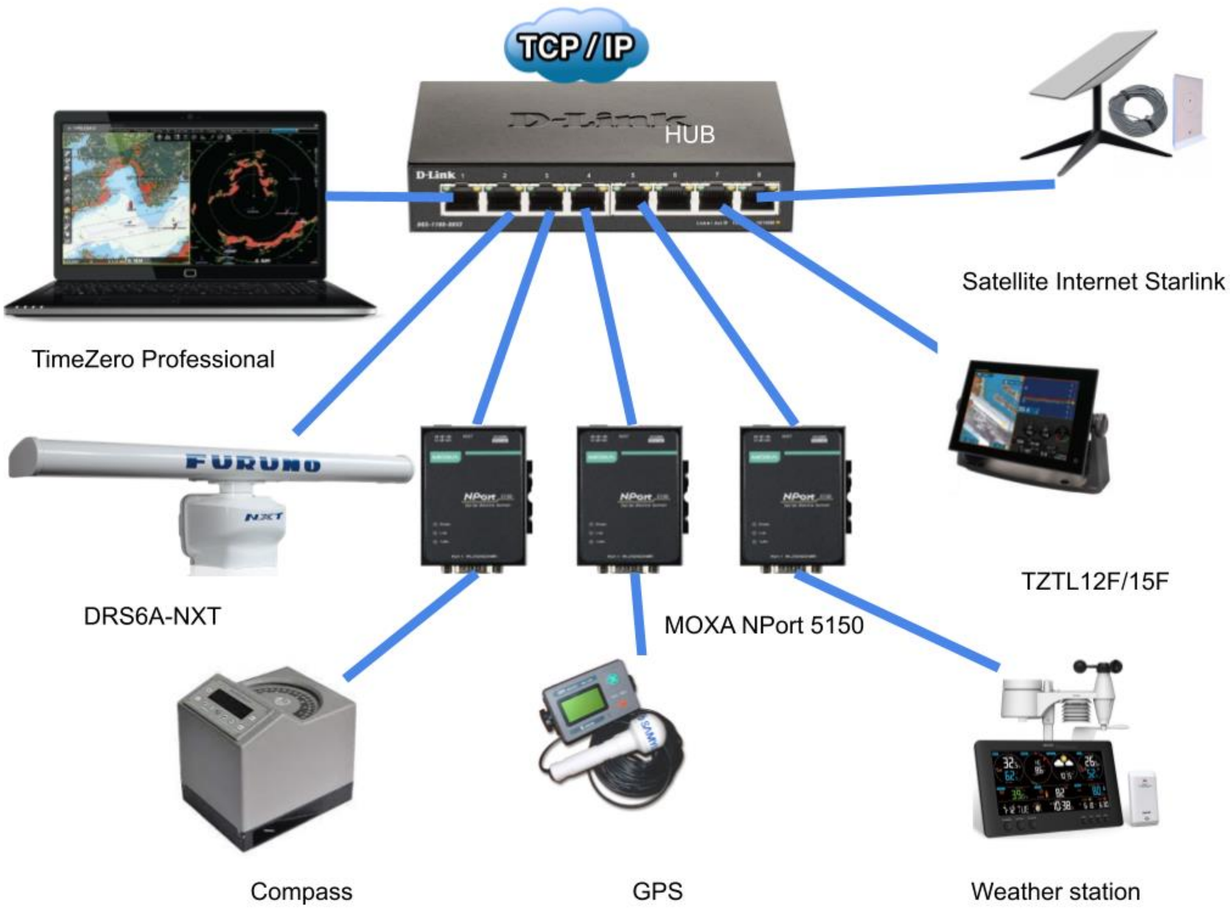

*Fig. 1 Structural scheme of the organization of the information interaction between the FURUNO DRS**-NXT shipborne radar with MSA (made by the authors)*

Given that the DRS**-NXT series radars allow output radar-video in the form of digital data stream, an opportunity to investigate two above mentioned variants of ship navigation radar connection to MSA is provided.

To visualize the radar environment and control the DRS**-NXT radar, the ship is equipped with a Multi-Function Display (MFD) TZTL12F/15F [17].

In order to conduct research on the optimal organization of information interaction, the standard navigation sensors providing operation of Furuno DRS**-NXT were reconnected via NavNet network.

Two MFDs were also added on the basis of personal computer (PC) and software "Nobeltec TimeZero Professional" - software application for universal PC [18]. Software “TimeZero Professional” allows you to effectively increase the number of workstations on the ship with radar visualization by installing universal PCs or industrial single-module PCs in addition to the standard MFDs.

The specialized NavNet MFDs will include the ARPA module, which allows one to manually and automatically capture radar targets, and then track their movements. The ARPA module in the TZTL12F/15F MFD models can automatically track a maximum of 30 targets.

In order for the ARPA module to perform the necessary calculations of the kinematic parameters of the targets acquired for auto-tracking, one must enter the dynamic parameters of one’s vessel's movement: position, course, speed taken from the ship's navigation sensors into the MFD. Without obtaining the necessary data through the relevant IEC 61162-⅓ information messages, the built-in ARPA module in the MFD does not function. For any radar function to work properly, the data refresh rate must be 100 ms [15].

2.3. DATA INPUT/OUTPUT WHEN INTERACTING WITH MSA

In the MFD TZTL12F/15F and "Nobeltec TimeZero Professional", the input of relevant information messages is possible in a variety of ways. In the present study, we used the option of input via the LAN port NavNet using a "Serial-to-Ethernet" converter to the proprietary NavNet network.

This approach to data input/output has a number of advantages. First, it allows the user to integrate devices with a serial interface into modern network infrastructures. Secondly, it facilitates system scaling and modernization, as one can add or replace devices connected to the Serial-to-Ethernet converter without having to change the network infrastructure. In addition, this approach allows the user to remotely control and monitor devices over an Ethernet network.

The navigation data output parameters from the TimeZero Professional terminal are configured manually for the UDP (User Datagram Protocol) connection in TimeZero Professional, allowing it to act as a data source.

TimeZero Professional allows transmitting UDP data packets only to NavNet consumers. Therefore, we configure the UDP connection to send the TTM message with the parameters of the requested targets to the gateway address: 172.31.3.151. Local IP Port:10022.

To issue the RMC message we specify the address - 172.31.255.255. Local IP Port:10021, which means the address "NAVNET NMEA".

From this address other devices in the NAVNET network (TimeZero in particular) can receive data from NMEA sources. Recipients of data from this address must have different addresses on the 172.31.x.x subnet.

The following freely available software - “NMEA Router” was used as a gateway. Software reads broadcast messages at the data output ports - 10021/10022 and forwards them to devices in the external network (server MSA) as UDP.

3. INVESTIGATING THE IMPACT OF STARLINK SATELLITE RADIO CHANNEL ON CONNECTIONS TO THE MSA SYSTEM

When connecting a remote user (server MSA) to the local NavNet network via Starlink satellite radio channel, with high probability the parameters will change, namely: fades and delays will appear, packet losses will increase and the channel bandwidth in general will decrease, which can degrade the performance of remotely connected equipment (Fig. 2).

In this section, it was investigated how much the above parameters deteriorate for a radio channel compared to a wired channel. When studying this problem, the entire cycle involving the flow of information in the MSA system was first evaluated visually: target acquisition by the operator, transmission of target kinetic parameters to the MSA system server, and then target visualization in the MSA system. Finally, the impact of random failures in the channel on this process was quantitatively assessed over a long interval of time.

In our research, the operator performed the acquisition of a test target for auto-tracking. Target acquisition for radar auto-tracking is one of the typical functions of a watch officer (operator) on the bridge. A mark indicating target acquisition for auto-tracking appeared on the NavNet TZtouch2 MFD screen. Target acquisition for tracking was accompanied by the generation of a TTM information message with the parameters of the acquired target.

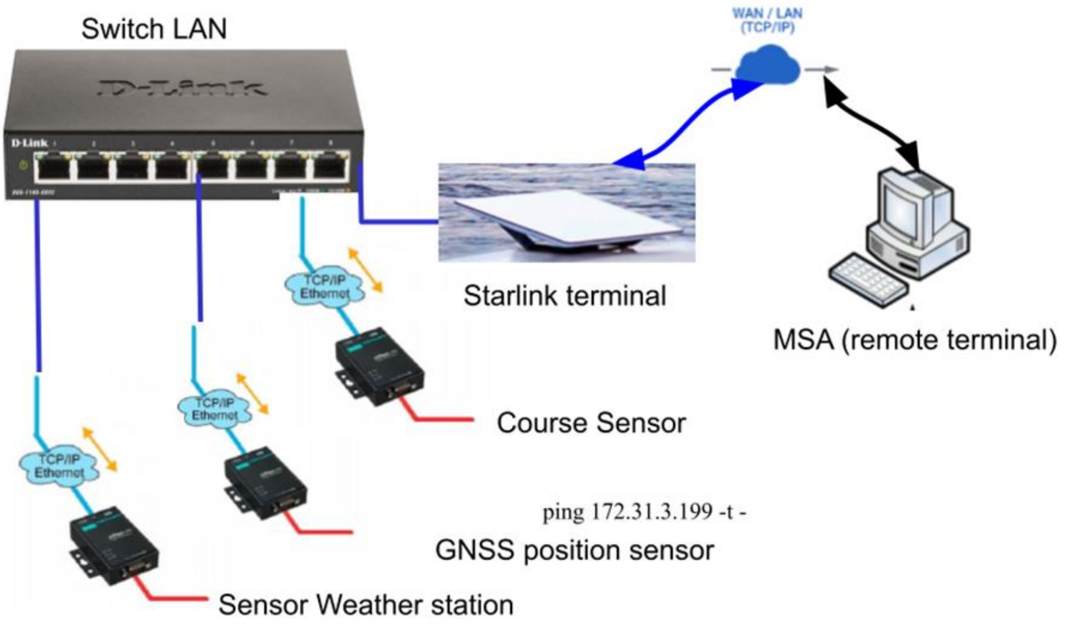

Fig. 2 Schematic diagram of remotely connected equipment (made by the authors)

The TTM message, packed in a UDP-packet, was transmitted to the address of the MSA system server. At the same time, an RMC message was also sent with the parameters of the absolute location of the surface ship, i.e. the point of installation of the test ship's navigation radar. On the MSA system server, the data on the target and the position of the ship's navigation radar were converted into absolute coordinates of the targets, which were visualized in the MSA system interface.

There were no distortions introduced by the Starlink radio channel in the parameters of auto-tracked targets when visualized in the MSA system (Fig. 3).

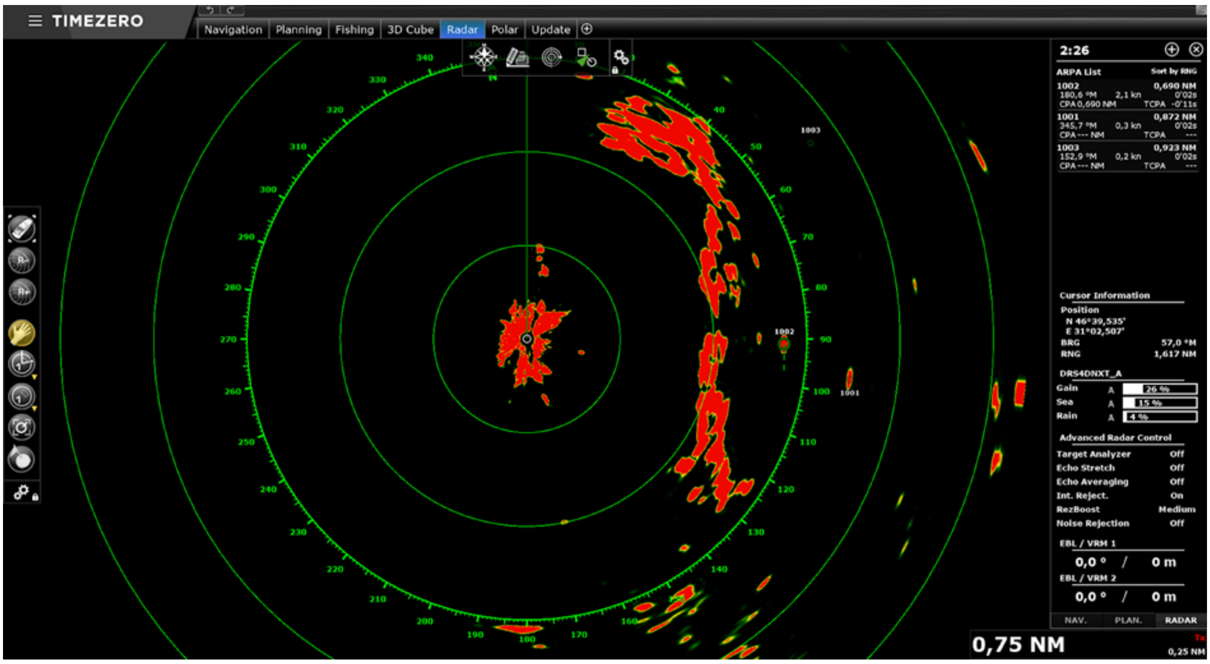

Fig. 3 MFD TimeZero screen view with targets 1001, 1002, 1003 acquired for auto-tracking (made by the authors)

The actions of the watch officer on the bridge to work with the ship's navigation radar were routine and did not require him to perform any additional operations that distracted his attention.

The only difference was in the rules of target selection for auto-tracking: they were expanded. Not only targets that posed a threat to navigation, but also distant, newly appeared targets of interest to the MSA system had to be acquired and put on auto-tracking.

3.1. EVALUATION OF THE IMPACT OF THE SATELLITE CHANNEL ON THE INFORMATION INTERACTION BETWEEN SHIP SENSORS AND THE MSA SERVER

All equipment is designed on the information interaction over a local wired Ethernet network with preliminarily known network bandwidth characteristics - 10 Mbit. Using the PING utility, the characteristics of both wired and wireless networks were evaluated for several hours.

The following statistical estimates of the wired channel quality were obtained during the session of its testing in the network.

The protocol of PING utility operation in the local wired network:

Pinging 172.31.3.20 with 32 bytes of data: *[Pinging packets of 32 bytes. The request is executed at 1 second intervals].*

Reply from 172.31.3.20: bytes=32 time<1ms TTL=255 *[delay time ~ 1 ms]*

Reply from 172.31.3.20: bytes=32 time<1ms TTL=255

Reply from 172.31.3.20: bytes=32 time<1ms TTL=255

Ping statistics for 172.31.3.20:

Packets: Sent = 15, Received = 15, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 0ms, Maximum = 1ms, Average = 0ms

Thus, for a wired network, the level of packet loss is no more than a few percent, and packet delays are very low.

To assess the quality of wireless network operation, the PING command in the Windows command line was given by the MFD of the MSA system operator (operator of the coastal Command Center).

For testing in PING one can specify the address of any device in the NavNet network on the ship. For example, ping 172.31.3.199 -t- is the address of the "Serial-to-Ethernet" converter device, which transmits GNSS position data to the address of the "NAVNET NMEA" port in the NavNet network from the NMEA 0183 data source connected to it (Fig. 2).

The following statistical estimates of the quality of the satellite communication channel, formed by the Starlink V2 terminal, during the session of its testing in the wireless network were obtained.

The protocol of PING utility operation in a local wireless network with radio channel participation:

Pinging 172.31.3.199 with 32 bytes of data:

Reply from 172.31.3.199: bytes=32 time=192ms TTL=255 *[Exchange in packets of 32 bytes. The request is executed with an interval of 1 second]*

Reply from 172.31.3.199: bytes=32 time=259ms TTL=255 *[delay time ~ 200 ms]*

Reply from 172.31.3.199: bytes=32 time=255ms TTL=255

Request timed out. [If no response is received within 4 seconds of the request, a message is displayed "Request timed out"]

Reply from 172.31.3.199: bytes=32 time=161ms TTL=255

Reply from 172.31.3.199: bytes=32 time=157ms TTL=255

Reply from 172.31.3.199: bytes=32 time=169ms TTL=255

Reply from 172.31.3.151: Destination host unreachable. *[The Ping utility has changed the error status. Message appearance interval 4 seconds]*

Reply from 172.31.3.199: bytes=32 time=150ms TTL=255

Reply from 172.31.3.199: bytes=32 time=154ms TTL=255

Ping statistics for 172.31.3.199:

Packets: Sent = 8866, Received = 8391, Lost = 475 (5% loss),

Approximate round trip times in milli-seconds:

Minimum = 118ms, Maximum = 2551ms, Average = 191ms

Thus, because TTM messages from the ARPA module as part of the ship's navigation radar are generated from each auto-tracking target once per full rotation of the radar antenna, i.e., approximately once every 3 seconds, the additional delay of ~200 ms inherent in the satellite channel does not affect the information interaction between the ship's navigation radar and the MSA system.

Appearance of "Request timed out" and "Destination host unreachable" messages indicates fading (interference) in the satellite channel. There are various reasons for fading in the satellite channel, but for the Starlink ship terminal the most significant causes are pitching and manoeuvres while the ship is moving. "Request timed out" messages appear much more often in these conditions. The numbers of occurrences of “Request timed out” or “Destination host unreachable” messages indicate the duration of the delay, so if the number of messages is 5, then the delay is 20 ms.

If the next TTM message with the parameters of the auto-tracking target is not received, the processing algorithm in the MSA system should be "approximately" the following: if the message is not received by the MSA system within a period of time equal to 3 antenna rotations (~10 sec) the target must be removed from the screen as a lost target. If no more than 1-2 messages are missed in a row, the target is retained on the screen.

Statistical estimates of the quality of the satellite communication channel formed by the Starlink V3 terminal during the session of its testing:

Ping statistics for 172.31.3.199:

Approximate round trip times in milli-seconds: Average ~ 100 ms

Packet loss did not exceed (3% loss) in different test sessions,

The delay in the satellite channel has been halved compared to the Starlink V2 terminal.

It should be noted that the channel break (fading) for 4 seconds and more was observed, i.e. the channel discontinuity occurred up to units of a minute.

Evaluation of the radio channel influence showed that compared to the characteristics of the wired communication channel between the bridge navigation equipment, the satellite channel shows deterioration in 3 parameters:

- packet loss increased slightly (3-5 % loss);
- delay in satellite channel is approximately ~100-200 ms;
- channel break (fades) from 4 seconds to units of minutes are observed.

For the latest version of the Starlink terminal (terminal Starlink V3) the channel delay has decreased slightly.

3.2 STUDY OF INFORMATION INTERACTION BETWEEN THE MSA SYSTEM AND THE SHIP'S RADAR USING RADAR-VIDEO

The influence of the satellite communication channel on the quality of digitized radar image from the ship's navigation radar DRS4D-NXT, transmitted from the ship to the MSA system was investigated. A personal computer with TimeZero Professional software enabled as an additional remote MFD for the ship's navigation radar DRS4D-NXT was used as an MSA system simulator. The ARPA module was enabled on this additional MFD. In this scheme of interaction with the ship's navigation radar, the shore operator also received control of the target acquisition. This can be attributed to the advantages of this scheme.

However, practical tests have shown shortcomings in the implementation of this scheme. From a remote MFD it is indeed possible to acquire targets for auto-tracking without the ship's crew, but delays (fading) in the satellite channel for 9 seconds or more lead to frequent loss of acquired targets. There is a need to perform frequent reacquisition of targets, their re-identification and linking their tracks with previous movements. This negatively affects the perception of the environment by the watch officer on the ship.

Thus, practical testing of the second variant of information interaction with MSA system (radar-video transmission) is largely limited by the characteristics of the communication channel between the ship and shore, which showed the inexpediency of implementing this option.

4. CONCLUSIONS

Data from navigation sensors such as GNSS receiver, gyrocompass and from ARPA ship's navigation radar are initially generated in NMEA 0183 message format (IEC 61162-1) and are transmitted to the MSA system unchanged. The period for updating information from sensors can be configured. Usually, it is 1 second.

Delays and fading in the Satellite radio channel for several seconds, and even minutes, did not distort the picture, because the data from sensors were not used in the MSA system to navigate the ship, but only positioned the point of observation of the surrounding surface environment. The frequency of observation changes in the surface operation zone at intervals of up to 10 minutes is quite acceptable.

Under conditions of war at sea, navigation in coastal waters is significantly reduced and the task of safe divergence from oncoming vessels is relegated to the background. In such conditions, engaging the watch officer in the task of identifying newly appearing surface targets in the operation zone, which have interest to the MSA system, and putting them on auto-tracking, does not overload his normal ability.

The option of transmitting radar-video and its subsequent processing ashore by the ARPA module for target tracking has proven ineffective due to delays and fading in the Satellite radio channel. Fading that occurs frequently for 10 seconds or more causes disruptions in radar tracking of targets, which does not allow normal visualization of radar targets in the MSA system.

Thus, we conclude that the option of transmitting target kinematic parameters to the MSA system becomes the most optimal.

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