ROCKET-SPACE DEVICE ENGINEERING AND INFORMATION SYSTEMS
Vol. 6, Iss. 2, 2019, pp. 14–20

The Possibility of Independent Self-Positioning of a Vessel Based on Signals from the AIS System

S.V. Trusov, *Cand. Sci. (Engineering), trusov_sv@spacecorp.ru*
Joint Stock Company "Russian Space Systems", Moscow, Russian Federation
O.I. Baraboshkin, *baraboshkin_oi@spacecorp.ru*
Joint Stock Company "Russian Space Systems", Moscow, Russian Federation
A.M. Kuznetsov, *Cand. Sci. (Engineering), kuznetzov_am@spacecorp.ru*
Joint Stock Company "Russian Space Systems", Moscow, Russian Federation
S.A. Bobrovskiy, *bobrovsky_sa@spacecorp.ru*
Joint Stock Company "Russian Space Systems", Moscow, Russian Federation

Abstract. The work aims to find an alternative method of calculating the position of a vessel in order to detect the deliberate local distortion of the GLONASS and GPS navigation signals (spoofing). A method for determining the coordinates of the vessel based on the combination of measurements of the AIS signal arrival angles from neighboring vessels, as well as the coordinates of the vessels contained in these signals, is proposed. A variant of the receiver circuit for implementing this method based on phase direction finding by a simple two-antenna system is considered. The possibility of determining the direction of arrival of a signal with an average error of 2º is shown with the distance between the two antennas equal to λ (with each antenna λ/4 long). Based on the radio direction finding errors, the accuracy of the methods for determining the coordinates was estimated from two and three signal sources. The maps of the applicability of this method of location for the Sea of Okhotsk region have been constructed. It is shown that within a 2º radio direction finding error, the error in determining the coordinates of the vessel will be no more than 4 km, depending on the number and relative position of the sources of AIS signals. The proposed solution can be used as part of the technical means of control of the fishing fleet.

Keywords: AIS, Fishing Industry Monitoring System, GNSS-spoofing, radio direction finding.

Introduction

Since 1999, in order to prevent the illegal, unreported and unregulated fishing of marine biological resources, the Russian Federation has been operating an industry-based system for monitoring aquatic biological resources, surveillance and control of the activities of fishing vessels (IMS). The system controls 3,500 vessels [1].

Control over the movement of vessels is carried out using technical control means (TCM), mandatory for installation on fishing vessels. The TCM, according to [2], should include a GLONASS /GPS signal receiver, a ship satellite communication terminal (Gonets, Inmarsat), and an AIS system transceiver. TCM should ensure the accuracy of determining the position of the vessel of not worse than 100 m and the transmission of this non-correctable information through the satellite terminal to the regional monitoring center (RMC) of the IMS [2].

The problematic point when using this method of monitoring the position of vessels is a possible distortion of the actual movements of the vessel due to local substitution of the navigation GLONASS/GPS signals (spoofing). Equipment for spoofing attacks is becoming more accessible and can become a common tool for poaching, since its application does not violate the requirements of the law [2]: the integrity of the TCM is not violated; the information is not corrected during the transmission.

The ARGOS system, the transmitters of which were previously used as the TCM, has an alternative possibility of determining the location based on Doppler measurements of the signal characteristics with an accuracy of 150-300 m, but since 2016, ARGOS transmitters cannot be used as the TCM on Russian ships. In this regard, to find an alternative way to determine and automatically register the coordinates of vessels is an urgent problem.

In this paper, we consider an approach to determining the coordinates of a vessel using special receiving equipment for AIS signals, which is proposed to be included in the TCM. The main difference between this equipment and a conventional AIS signal receiver is an antenna system that it can determine the angles of arrival of signals. This information, in combination with data on the location of the sources of these signals, makes it possible to determine the position of the vessel. The problems of accuracy of positioning of the vessel depending on a number of factors are considered.

Fundamental possibility of determining the ship's location using AIS signals

The proposed approach to the determination of coordinates is based on the following provisions:

1. Obtaining the coordinates of the signal sources and the direction of arrival of these signals make it possible to determine the position of the receiver and, accordingly, the vessel.

2. Around a fishing vessel in the radio visibility zone of the AIS receiver (20–40 miles), there is at least one AIS signal source (vessel or coast station) transmitting its coordinates (AIS messages of types 1, 2, 3, 4, 11, 18, 21, 27) and not vulnerable to spoofing.

3. A number of radio direction finding methods are known [3], that make it possible to determine the directions of arrival of signals from each of the vessels.

The source data for choosing the method of determining the location of the target vessel can be: information about the speed, course of the vessel and the number of vessels in the radio visibility zone. Depending on the set of available source data, the following known calculation methods can be used to determine the location of the vessel:

1. If data on the speed and course of a given vessel ~~and~~ registration of angles of arrival of AIS signals from a single source are available~~,~~ it is possible to determine the location of this vessel by the cruise-bearing method, by processing measurements at different times [4];`

2. if data on the course and angles of arrival of AIS signals from two sources are available, the bearing method by two landmarks can be used [4];

3. when registering the angles of arrival of AIS signals from three sources, it is possible determine the location using the single resection method [5];

4. when registering the angles of arrival of AIS signals from four sources or more, the multiple resection method is used [5].

In this paper, we consider the characteristics of the second and third methods, since the first method requires the vessel being positioned to be in motion while the source of the AIS signal remains immobile, which, according to expert estimates, is an unlikely situation, and the fourth method requires a large number of AIS signal sources.

In the general case, the accuracy of the methods is determined by the accuracy of the coordinates of the AIS signal sources and the accuracy of determining the angles

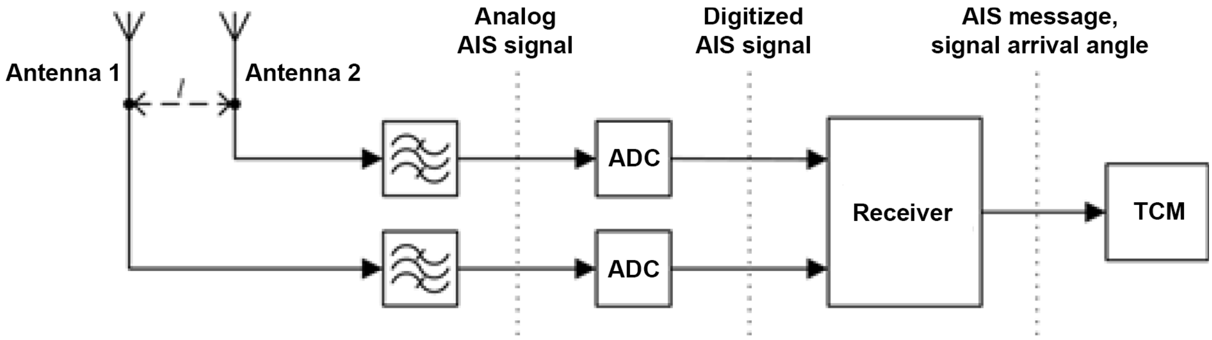


Fig. 1. Diagram of the AIS receiver with the function of determining the angle of arrival of the AIS signal

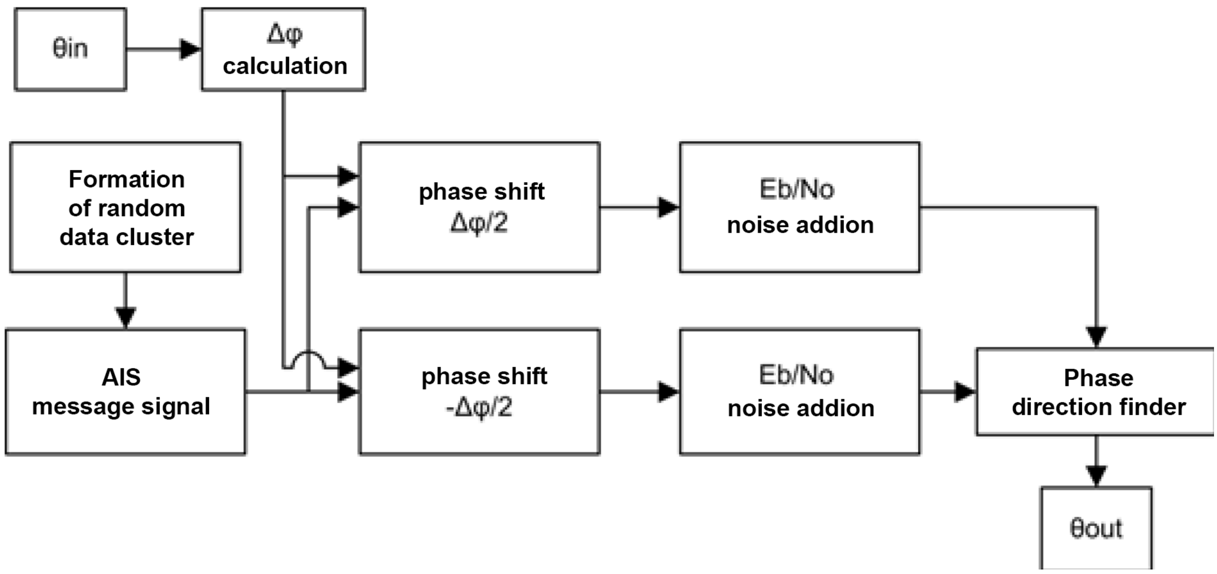


Fig. 2. The block diagram of the model of the AIS signal direction finding system

of arrival of these signals. The accuracy of the coordinates of the sources is 10–100 m and is not considered in this paper.

The accuracy of determining the angles of arrival of AIS signals depends on the signal registration system and the relative location of the sources of AIS signals. These factors are discussed in more detail in the following sections.

System for determining the angles of arrival of AIS signals

According to [3], methods for determining the angles of arrival of an AIS signal are divided into amplitude, phase, and complex methods. For a method using the amplitude characteristics of the signal (the amplitude and complex methods), an antenna system consisting of antennas with a non-circular radiation pattern is required. With a wavelength of $\lambda = 1.85$ m at AIS frequencies, such an antenna system will be very cumbersome, difficult to install on a vessel, and quite expensive. In this connection, it is preferable to use the phase method of direction finding.

In [3], a phase direction finding method using two antennas is presented. Antennas are located at a distance from each other, called the base. Each of the antennas can have a circular radiation pattern and represent a $\lambda/4$ long pin. The accuracy of direction finding and the complexity of placement on a vessel depend on the length of the base. The larger the base, the more accurately it is possible to determine the direction, but the more difficult is the installation. The disadvantage of the method under consideration is the ambiguity in determining the direction — for a base length $l<\lambda/2$ there are two such directions, for $l<\lambda/2<l<\lambda$ there are four directions, etc. To solve the problem of ***monitoring*** the information received from another vessel, ambiguity does not play a significant role, because AIS information from both vessels resolves this ambiguity.

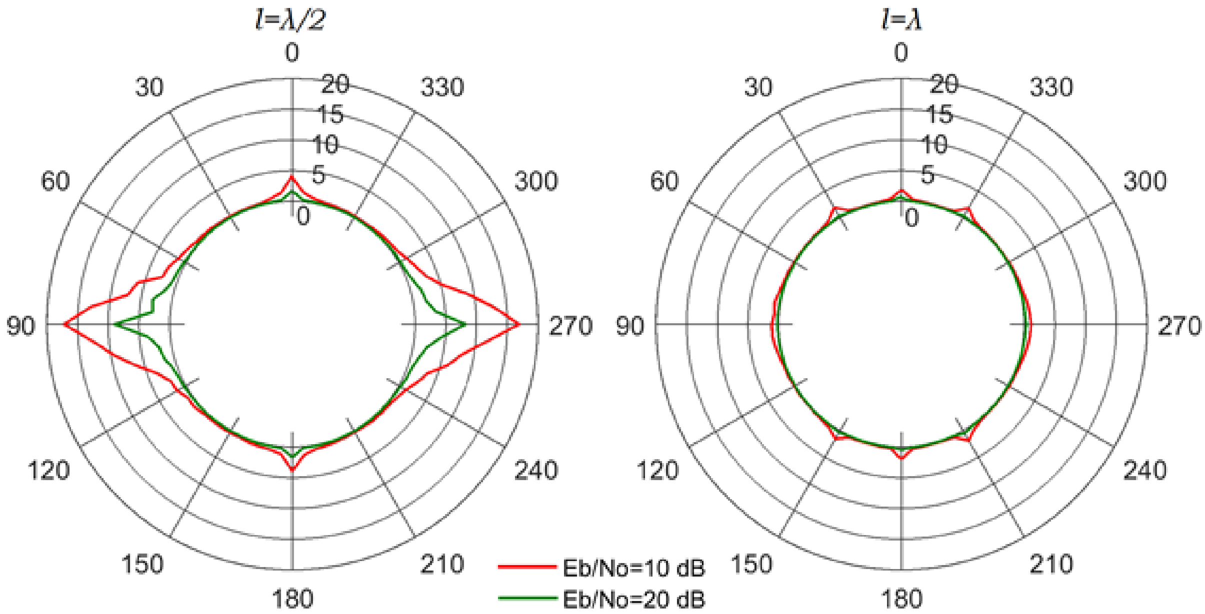


Fig. 3. The average error of the calculated direction of arrival of the signal depending on the actual direction for the AIS signal

Thus, the following scheme of an AIS receiver combined with a radio direction finding system is proposed. The signals from two antennas located at a distance *l* from each other are transmitted to the RF path of the receiver, where they are independently filtered and digitized by two analog-to-digital converters (ADCs) with a common clock generator. One of the signals is processed with the same method as in a conventional AIS receiver, and the beginning and end of each AIS message are determined. This information is transmitted to a receiver module containing a phase direction finder. This module simultaneously processes two signals containing the same AIS message, demodulates the message and finds the angle (Fig. 1).

Calculation of the accuracy of determining the angles of arrival of the AIS signal

The accuracy of determining the angles of arrival of AIS signals when using the proposed AIS receiver circuit is influenced by many factors: the length of the base of the antenna system, noise characteristics of the receiver, the format of the AIS messages, the distance to the transmitter, vessel pitching, errors in the length of the base of the antenna system (temperature fluctuations, installation accuracy), the error in determining the course of the vessel, etc. This section discusses the impact of the first three factors.

To calculate the direction finding accuracy, numerical modeling was used according to the following diagram (Fig. 2). An AIS signal is generated with GMSK modulation, NRZI coding, and a data transfer rate of 9600 bps, containing a random data block [6]. This signal is duplicated, each signal is independently summed with white noise, specified by the ratio of bit energy to power spectral density *Eb/No*. The lower threshold *Eb/No*, at which AIS messages can be received, is defined in [6] and amounts to 10 dB. Next, the first signal is shifted by $\Delta\varphi/2$ and the second is shifted by $-\Delta\varphi/2$. $\Delta\varphi$ is calculated based on a predetermined angle of arrival of the radio signal $\theta_{in}=[-\pi/2..\pi/2]$ according to the formula

$$\Delta\varphi=2\pi l/\lambda\cdot\sin(\theta_{in}).$$

The phase direction finder is constructed according to the design with sum-difference processing [3]. The signal at which the simulation of the angle of arrival of the radio signal θ_{out} is calculated during the modeling, has a length of 224 bits and consists of a training sequence (24 bits), a start indicator (8 bits), a data block (184 bits) and an AIS message end indicator (8 bits).

The simulation results for determining θ_{out} for 75 thousand random messages with a base length $l = \lambda/2$ and $l = \lambda$, *Eb/N0 = 10 dB* and *20 dB* for each θ_{in} with a step of 5° are presented in Fig. 3. The graphs show the average errors ζ_{out} of determining the angle θ_{out} depending on θ_{in}.

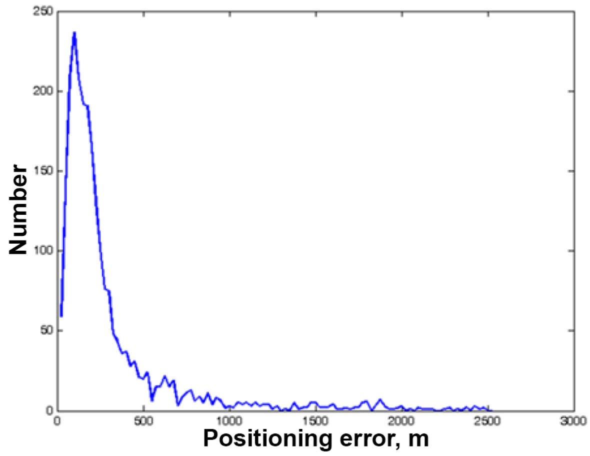


Fig.4. The dependence of the number of measurements on the error in determining the coordinates with a random error of the angle of arrival of the AIS signal within 2 for 10°4 measurements

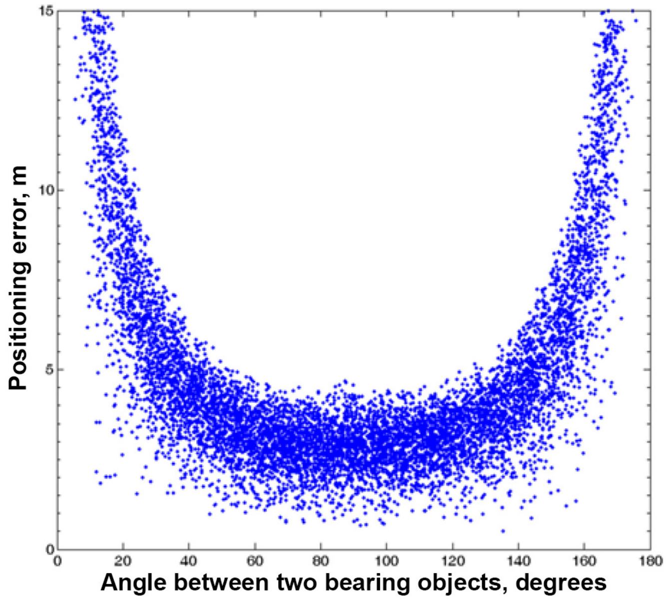


Fig. 5. Dependence of the error in determining the position of the vessel by the bearing of two reference points on the angle between the objects with an error in measuring directions 2°

With the base length $l = \lambda/2$, the direction finding accuracy strongly depends on the direction to the signal source - the errors increase strongly when θ_{in} approaches 90° and 270°. Even with a high signal to noise ratio, errors make it impossible to confidently distinguish between different directions of arrival of AIS signals at $70° < \theta_{in} < 110°$ and $250° < \theta_{in} < 290°$. For other directions with $Eb/N0 = 10$ dB, the average error is less than 5°, and for $Eb/N0 = 20$ dB - less than 2°.

Using the signal base $l = \lambda$ gives a smaller error and more stable characteristics of the direction finding system in the entire range of angles. For $Eb/N0 = 10$ dB, the average error is less than 2°, and for $Eb/N0 = 20$ dB it is less than 1°.

The results obtained show that an antenna system with a base length $l = \lambda$ is more preferable for constructing a vessel position control system.

Modeling errors in determining coordinates depending on the accuracy of determining the angles of arrival of a signal

Locating a ship using three AIS signals. To assess the influence of the accuracy of determining the angles of arrival of signals on the determination of the coordinates of the vessel, a numerical simulation of the determination of coordinates by the method of single resection was performed. The identified vessel was in a circle 36 km (~ 20 miles) in diameter. This, on average, corresponds to the maximum distance for the propagation of AIS signals between ships. Three vessels with known coordinates were randomly placed in this area, arrival angles were determined, a random error of up to 2° was introduced into each of the angles, and a resection problem was solved [5]. After the calculation, the error in determining the coordinates was determined as the distance between the known and calculated points.

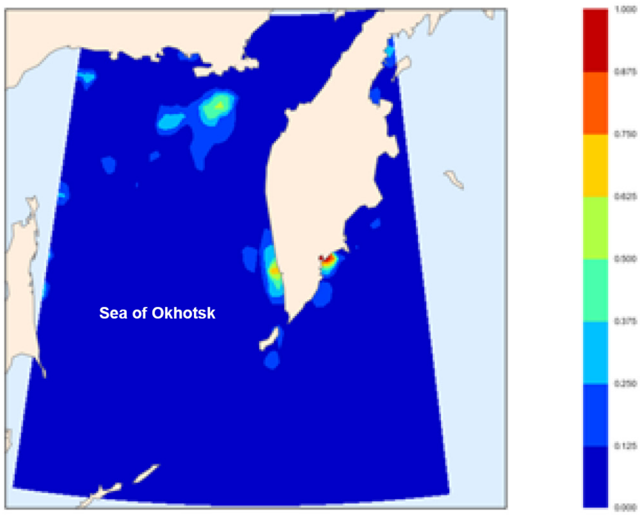
The simulation results of 10^4 cases of ship distribution (Fig. 4) indicate that registration of three AIS signal sources with an error of up to 2° allows in 85 % of cases to get an error in determining the location of the vessel of up to 2 km.

The error in determining the coordinates decreases with increasing accuracy of determining the angles of arrival and a decrease in the average distance between the signal sources and the receiver.

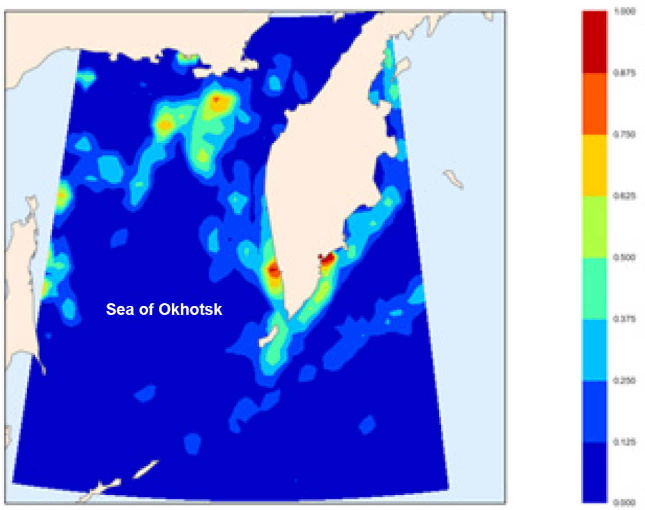
Locating a ship using two AIS signals.
The positioning of the vessel is possible if there are two AIS signals and the known course of the vessel. In this case, the accuracy of determining the location depends on the accuracy of determining the course and the accuracy of determining the angles of arrival of AIS signals. In this method, reference points (AIS signal sources) that are 30–150° apart from each other can be used. The dependence of the error in determining the location on the angle between the reference points (with an accuracy of 2(°), shown in Fig. 5, shows that for the working range of angles, the determination error on average is 4 km.

This method is less accurate than resection, but the conditions for its use are more common than these required for resection (see Fig. 6).

Detection of a false course on one source of AIS signal. If there is one AIS signal, it is possible to check the correctness of the coordinates and course of the vessel, determined by a GLONASS/GPS receiver. To do this, based on the coordinates of the transmitter vessel contained in the AIS message, it is enough to calculate the angle of arrival of the signal and compare it with the measured angle. If the measured angle does not coincide with the calculated angle within the allowed error, then the coordinates of one of the two vessels are incorrect. It is possible to unambiguously identify a vessel with incorrect coordinates when other vessels appear in the vicinity: on a vessel with incorrect coordinates, there will be a mismatch between the calculated and determined signal arrival angles for other vessels.



a



b

Fig. 6. The distribution map of the probability of the presence of AIS signals from N vessels in the Sea of Okhotsk: *a*) *N*=3, *b*) *N*=2:

Estimation of the probability of the presence of other vessels in the vicinity of an arbitrary vessel

To assess the likelihood of the presence of two or more vessels in the vicinity of an arbitrary vessel, which are necessary for applying the proposed method, data were processed on the location of vessels in the waters of the Okhotsk and Bering Seas within latitude limitations of 45 ÷ 60°n. and in longitude 144 ÷ 164°e. The data for May – July 2016 were used [7]. The calculation was made for the grid in increments of 0.33°. For each grid point, the ratio of days on which at least N vessels were registered within a radius of 20 miles from this point to the total number of observation days was calculated; N = [2,3]. The calculation did not use signals from coastal AIS stations with a range of about 40 miles.

The calculation results (Fig. 6) show that the 100% probability of recording AIS signals from three vessels at the same time in the region under consideration exists only in the Petropavlovsk-Kamchatsky region. High probability (> 50%) is seen in the main fishing areas of the North Okhotsk and West Kamchatka subzones of the Sea of Okhotsk (Fig. 6, a). In the remaining water areas, the probability of the presence of three AIS signals from different vessels is less than 12%.

A similar calculation for the probability of receiving AIS signals from two vessels (Fig. 6, *b*) shows that the area of regions with a corresponding probability increases by an average of 4.5 times. Areas with a probability of more than 0.33 correspond to the main fishing areas of the Okhotsk Sea basin [8].

Conclusion

The results of the studies confirmed the authors' assumption that the use of AIS signals from other vessels and a special receiving system make it possible to determine the location of the vessel under a number of conditions.

Numerical simulation of the receiving device showed that a system with two antennas spaced by l allows the phase-direction finding method to determine the angle of arrival of the AIS signal with an accuracy of 1–2°. The directions of arrival of AIS signals, measured with such errors, make it possible, in the presence of two signals, to determine the position of the vessel with an accuracy of 2–4 km, and within 1–2 km in the presence of three signals. In areas of intensive fishing, the probability of determining the position of the vessel by the signals of two vessels is more than 33 %.

In cases where there is only one AIS signal, the false course detection method can be used. All methods should be implemented in a single device, be applied depending on the situation and give to the TCM data on the position of the vessel within appropriate accuracy.

The proposed method for determining the coordinates of the vessel can be used in the design of an improved TCM for use in fiscal systems for monitoring the location of vessels, in particular, for detecting local substitution of the GNSS navigation field, as well as for determining the location of a vessel when the AIS ship transponder is turned off.

References

1. Pyrkov V.N., Solodilov A.V., Degay A.Yu. Otraslevaya sistema monitoringa vodnykh biologicheskikh resursov, nablyudeniya i kontrolya za deyatel'nost'yu sudov rybopromyslovogo flota (OSM) [Sectoral system for monitoring aquatic biological resources, monitoring and controlling the activities of vessels of the fishing fleet (OSM)]. Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa [Modern problems of remote sensing of the Earth from space]. 2015, Vol. 12, No. 5. pp. 251–262. (in Russian)
2. Order of the Ministry of Agriculture of the Russian Federation of July 13, 2016 No. 294 On approval of the Procedure for equipping vessels with technical means of control and their types. (not in effect). Available at: http://www.garant.ru/products/ipo/prime/doc/71439614/ (Last accessed: 14/05/2019). (in Russian)
3. Timofeev V.A. Amplitudnye i fazovye metody opredeleniya uglovogo polozheniya istochnika elektromagnitnykh voln: metod. ukazaniya po vypolneniyu laboratornoy raboty [Amplitude and phase methods for determining the angular position of a source of electromagnetic waves: method, instructions for performing laboratory work]. Yaroslavl State University, 2006, 56 p. (in Russian)
4. Rul'kov D.I. Navigatsiya i lotsiya [Navigation and pilot charts]. Moscow, Transport, 1973, 232 p. (in Russian)
5. Kusov V.S. Geodeziya i osnovy aerometodov [Geodesy and fundamentals of airborne methods]. Moscow, Publishing House of Moscow University, 1995, 160 p. (in Russian)
6. MSE-R M.1371-5 (02/2014) Technical characteristics of an automatic identification system using time-division multiple access in the VHF maritime mobile service band. Available at: https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.1371-5-201402-I!!PDF-R.pdf (Last accessed: 05/14/2019). (in Russian)
7. Kuznetsov A.M., Trusov S.V., Baraboshkin O.I., Bobrovskiy S.A., Romanov A.A., Romanov A.A. Analiz rezul'tatov, poluchennykh za tri goda raboty apparatury monitoringa sudov BRK AIS, razmeshchennoy na KA «Resurs-P» № 2 [Analysis of the Results Obtained over Three Years of Operation of AIS Vessel Monitoring Equipment Based on the Resurs-P No. 2 Spacecraft]. Raketno-kosmicheskoe priborostroenie i informatsionnye sistemy [Rocket-Space Device Engineering and Information Systems]. 2018. Vol. 5, No. 4. pp. 80–87. (in Russian)
8. Obzor snyurrevodnogo promysla v period s 5 po 11 marta 2012 goda. [Review of the snurrevaad fishing in the period from 5 to 11 March 2012]. Available at: http://www.kamniro.ru/presscenter/obzory_promysla/promysel/obzory_promysla3 (Last acessed: 05/14/2019). (in Russian)