Alternative of Infrastructure GIS Marine Vessel Under the Purpose of Swimming*

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Abstract. Designing a geographic information control system for a marine vessel is a complex systematic process, characterized by a combined application stage of automatic generation the structure of geographic information system and expert solutions. The purpose of the research is to develop methodological support for the formation of a geographic information system by successively approximating its structural-functional model to a given set of properties. It has been proposed a structural-functional model of a geographic information system for controlling a marine vessel. Quantitative and qualitative description of the model allows performing structural optimization of the geographic information system for different purposes. It has been developed a methodology for forming the structure of a geographic information system for controlling a marine vessel. It has been developed as an expert system, which automates this methodology. The expert system allows in the interactive mode to form a list of the necessary equipment and functional modules of the geographic information system. The practical significance of the results presented in the article lies in the fact that the expert system can be useful in the design of integrated control systems for marine dynamic objects.

Keywords: dynamic object, geographic information system, decision making, management of a dynamic object, structural-functional model, method of forming the infrastructure of a dynamic object, sea vessel, local network.

1 Introduction

The use of geographic information systems (GIS) in the management of dynamic objects is a complex task that requires the use of special mathematical models, methodologies and software and hardware tools for the implementation of GIS [1]. Especially this task becomes actual to the management of marine vessels. It is necessary to obtain real-time information about their location, environment, meteorological conditions calculate the route load, time of arrival and, based on this data, make decisions about laying and adjusting the route [2].

Analysis of publications and regulatory documents of the last 5-7 years in the technical implementation of the tasks of managing marine vessels has shown that this field is developing in the direction of integrating existing complexes, stations, systems, and functional elements into a geographic information system of a marine vessel, which built on the technology of local switching networks.

On the other hand, the implementation of a GIS for the control of a sea vessel is associated with a number of problems.

These problems include:

- the need to operate with large volumes of heterogeneous geographic data coming from different sources and often in incompatible formats [3];
- limited area of the vessel for the implementation of infrastructure GIS on it [4];
- lack of an integrated approach for designing such GIS with regard to the existing limitations on its performance and reliability [5].

2 Structural and functional model of GIS marine vessel

The structural-functional model of the GIS of control a marine vessel can be rep-re-sented as a three-layer structure. The inner layer corresponds to the information support, medium – software and external – hardware [3, 4].

GIS information support is the cartographic data and data necessary for controlling the vessel. Together, these data form an electronic cartographic navigation in-formation system.

The software implements the functionality of GIS and consists of basic software and application software. The basic software consists of operating systems, database management systems, data visualization systems, and others. Application software designed to solve specialized problems of navigation, signal processing, data processing, and transmission and others.

The GIS hardware layer is represented by six functional modules (FM), consist of devices and means that implement the corresponding function (Fig. 1):

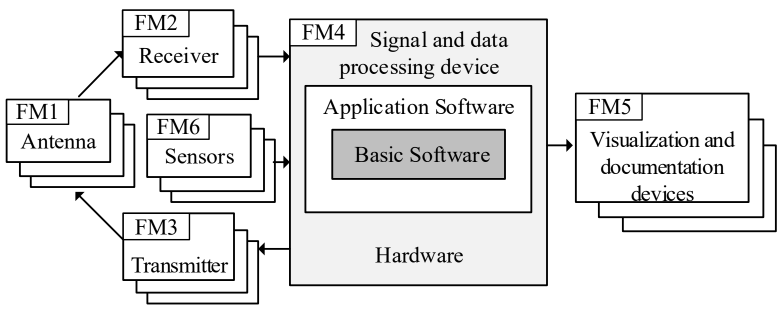

Fig. 1. Hardware GIS marine vessel

FM1: devices that convert electromagnetic (acoustic) energy, as in the case of radiation, and as receiving signals, or in other words, antennas.

FM2: devices that receive, amplify, demodulate and decode signals, or in other words, receivers.

FM3: devices performing reception, amplification, modulation and transmission of signals, or in other words, transmitters.

FM4: means of processing received signals and data.

FM5: visualization tools that provide a dynamic display of marine vessels and their trajectories; documentation of data on the card and paper carrier; document viewing and statistical display of the most important data.

FM6: devices that transform the effects of the environment into electromagnetic signals, or in other words, sensors.

A local computer network with segment switching is the transport of GIS marine vessels. This technology allows us to simultaneously transferring data between all interacting pairs of "Client-Server" (Fig. 2) [6].

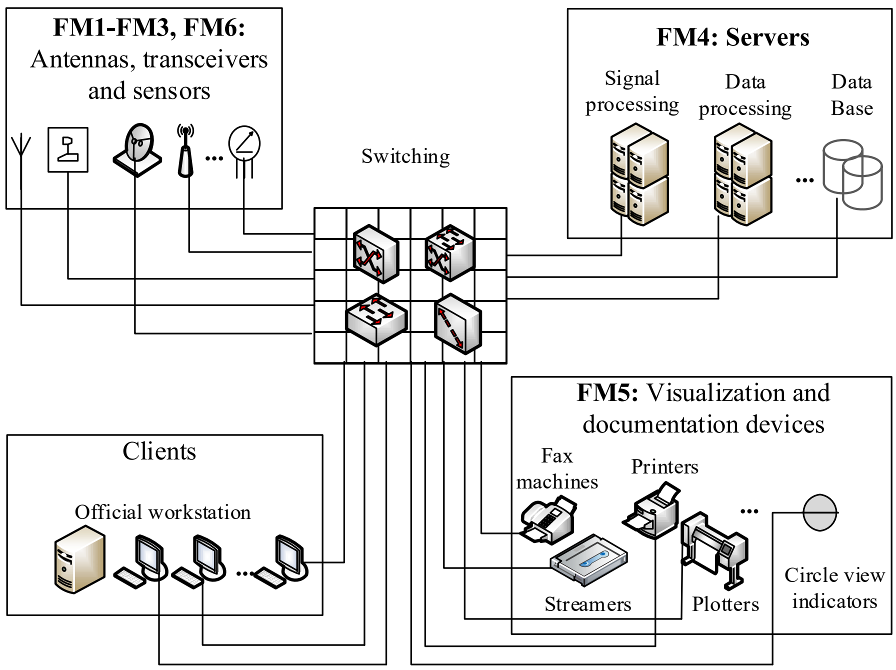

Fig. 2. Local network GIS for control marine vessel

3 Formulation of the problem

The structural-functional model G of the geo-information system of a marine vessel is present as a set

$$G=f\left(\mathrm{FM}_i,\ P_i,\ C_i,\ i=\overline{1,4}\right), \quad (1)$$

where P – the set of performance characteristics of functional modules GIS;
C – the set of cost characteristics of functional modules GIS.

The research task is formulated as an integer multiparameter problem of optimizing the GIS infrastructure of a marine vessel for navigation purposes with restrictions on the performance characteristics of GIS when working with spatial data:

$$C(G) \to \min_{P}, \quad (2)$$

$$\overline{t}_{\mathrm{d}}(G) \le T_{\mathrm{lim}}, \quad (3)$$

where $\overline{t}_{\mathrm{d}}(G)$ – the average delivery time of spatial data to the official person making the control decisions;
T_{lim} – delivery time limits recommended by spatial data distribution standards.

It is proposed the methodology to approximate the structural-functional GIS model to given properties set (1) – (3).

The sequence steps of the methodology are given below.

4 The methodology of forming the structural-functional model GIS

The methodology of forming a structural-functional GIS model includes, firstly, a solution algorithm that ensures the formation of a GIS infrastructure; secondly, the approaching of a GIS architecture to a given set of properties.

The algorithm for forming a GIS infrastructure consists of the following steps:

1. Determination of the source data for the forming of GIS.

The input data is the destination of the vessel, its category and sea navigation area.

1.1. Determination of the minimum number of workstations N_{ws} based on the purpose and category of the vessel.
1.2. Determination of the minimum composition of N_{eq} equipment depending on the sea navigation area.
1.3. Determination of the total number of network nodes $N_{nod} = N_{ws} + N_{eq}$ depending on the sea navigation area.

2. Evaluation of time characteristics.

The requirements for information processing time are determined at the time of receiving geographic data from the functional modules FM_1, FM_2 and FM_3 of GIS model. The allowable data transfer time T_{lim} will be directly proportional to the distance of the signal source [7]. Real $\overline{t_d}$ is estimated as the sum of the following components [8]:

2.1. The estimate $\overline{t}_{\mathrm{pr}}$ – the average processing time of spatial data.

2.2. The estimate $\overline{t}_{\mathrm{e.c}}$ – the average time to establish a connection with a source of spatial data [10].

2.3. The estimate $\overline{t}_{\mathrm{tr}}$ – the average time of transmission of spatial data over the established connection.

2.4. Condition verification (3).

3. Determination of GIS infrastructure satisfying the requirements (1) – (3).

3.1 Determination of the number FM_i, $i=\overline{1,4}$ of the local computer network.

3.2 Determining the type of cable.

3.3 Definition of a list of models of processors, RAM, storage systems.

3.4 Optimization of the list of equipment for processing the information on the workstations according to cost characteristics.

4. Definition of the "bottleneck" in the GIS structure.

4.1. Determining the FM that introduces the greatest delay.

4.2. Recommendations for replacing the "bottleneck" with another node with better performance characteristics.

5 Determination of the source data to build the structure of GIS for control marine vessel

Input data are:

A is the sea navigation area, and NP is the purpose of the sea vessel.

$A=\{A_1, A_2, A_3, A_4\}$ (Fig. 3):

- Sea area A_1 – an area within the coverage area of at least one coastal ultrashort-wave (VHF) radio station providing a permanent possibility of distress alert using digital selective calling (DSC) on channel 70 (20-30 miles);
- Sea area A_2 – an area with the exception of sea area A1, within the coverage area of at least one coastal radio station of intermediate/short waves (MF/HF radio station) providing a constant possibility of distress alert using DSC (about 100 miles);
- The sea area A_3 – an area, with the exception of sea areas A_1 and A_2, within the coverage area of the INMARSAT geostationary satellites (approximately between 70° north latitudes and 70° south latitudes;
- Sea area A_4 – an area outside the sea areas A_1, A_2, and A_3.

$NP_s, s=\overline{1,3}$:

- NP_1 – transport vessel;
- NP_2 – fishing vessel;
- NP_3 – research vessel. Determining the category of the vessel allows determining

the number of workstations N_{ws} and the estimated amount of spatial data with the corresponding equipment – N_{eq}.

The minimum composition of the equipment Neq on the ship gives the sea area, which in the Russian Federation is determined by the Global Maritime Distress Communication System (GMDSS).

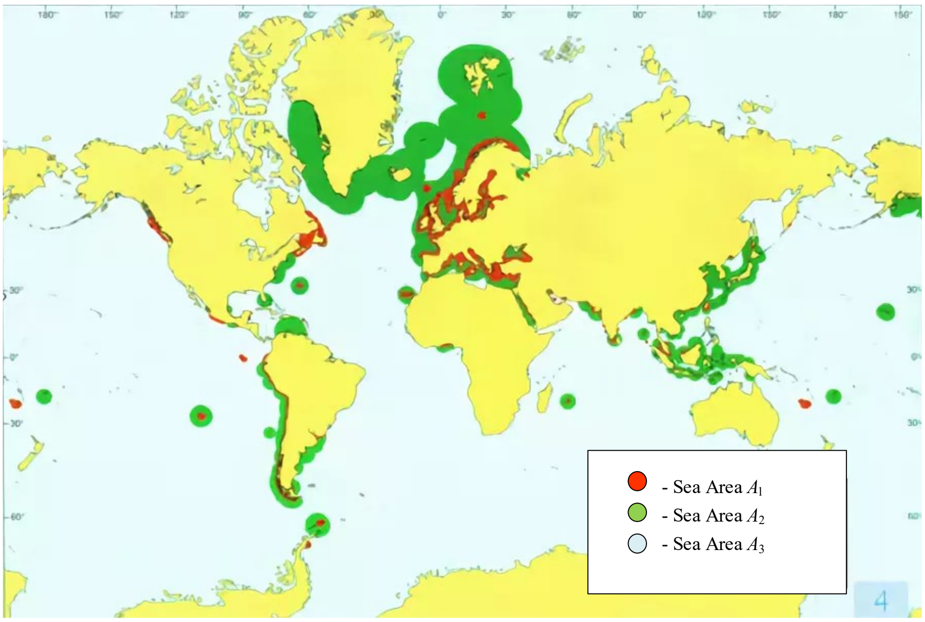

Fig. 3. Sea Areas

The minimum composition of radio equipment depending on the navigation area is shown in Fig. 4.

Time is estimated as the sum of the components: the time of establishing a connection with FM1 – FM3, FM6, the processing time of spatial data in the modules FM4 and FM5, the transfer of spatial data to the official workstations. All components are determined using the queuing theory [7, 8].

The value of T_{lim} depends on the time spent on receiving spatial information from FM1–FM3.

For radio navigation at sea, only one type is used and improved - active pulsed two-coordinate radar.

Marine navigation radars measure two parameters in the polar coordinate system: the distance to the object and the direction to the object (heading angle or bearing).

Distances are measured in an amplitude (pulsed) way. The distance to the object is determined by measuring the time T_{lim} from the moment of radiation of the “probe” pulse to the reception of the corresponding reflected pulse. The time T_{lim} is defined as the time of passage of the pulse to the object and back:

$$T_{\lim} = \frac{2D}{c}, \qquad (4)$$

where D – the distance to the object;
c – the propagation velocity of radio waves.

Sea Area				Equipment
A_1	A_2	A_3	A_4	VHF radio station Automatic identification system DSC receiver NAVTEX receiver Emergency beacon
	A_2	A_3	A_4	Wearable VHF MF / HF radio installation with cordless telephone Inmarsat-S ship earth station with extended group call receiver
		A_3	A_4	MF / HF radio installation with radio telephone, DSC and narrow-band direct printing (radio telex) MF / HF radio installation for general purpose radio communications
			A_4	500 kHz radio transmitter 500 kHz radio receiver

Fig. 4. Minimum composition of radio equipment depending on the navigation area

The farther the object is moving away from the source of the signal, the more time it takes for the signal to be received over the radio channel, therefore the speed of information processing at the workstation should increase. Increasing the speed of information processing at the workstation will compensate for the time spent on receiving, and thereby increase the speed of decision-making by the person controlling the ship. From this, we can conclude that the permissible data transfer time will be directly proportional to the distance of the distribution source.

Knowing the maximum distance from the source of distribution in the maritime areas of navigation, we determine $T_{\lim}$ for each:

In the sea area of A_1, the maximum distance from the coast source is 30 miles or approximately 48,28 km. Knowing the speed of propagation of radio waves $T_{\lim} = 32{,}1 \cdot 10\text{-}5$ s.

In the A_2 sea area, the maximum distance from the coastal source is 100 miles or approximately 160 km, therefore $T_{\lim} = 106 \cdot 10\text{-}5$ s.

In the sea area A_3 and A_4, satellite systems are used for navigation, in which case the maximum distance from the source is 20 000 km, hence $T_{\lim} = 0{,}65 \cdot 10\text{-}1$ s.

The proposed technique is brought to the prototype of the expert system. The block diagram of the general algorithm of the expert system is shown in Fig. 5.

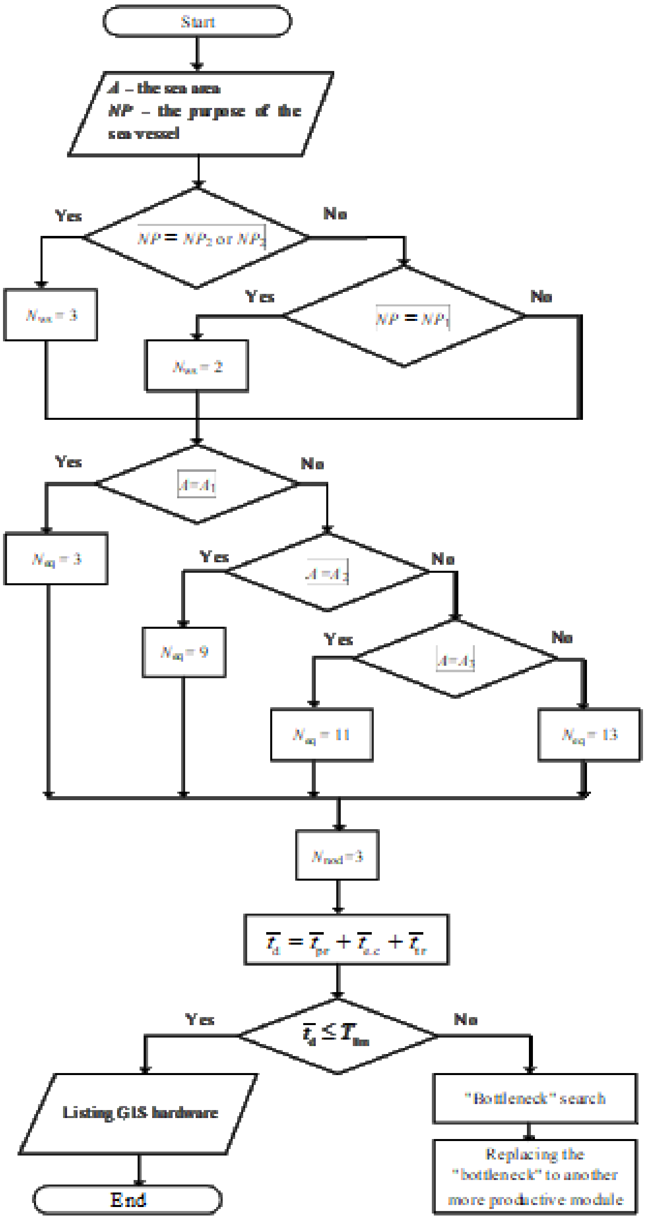

Fig. 5. Block diagram of the algorithm for determining GIS infrastructure of a marine vessel

The choice of the variant of the structural-functional model of the GIS is based on the scenario approach, according to which the search for a rational variant of the model is performed from the source data to the target parameter.

The expert system is built on a modular basis. It consists of the following components [9]:

- working memory also called a database;
- knowledgebase;
- solver;
- knowledge acquisition subsystem;
- explanations subsystem;
- dialogue subsystem.

The database consists of a set of tables that store data on navigation equipment, network components and workstations [10].

The knowledge base defines the rules of the expert system.

The solver determines the number of GIS nodes and estimates the data delivery time to the receiver.

The expert system interface provides for input of initial data in the dialogue mode, selection of the navigation area, the boundaries of which are visualized on the map, access to the solver and the database.

6 Conclusion

The proposed structural-functional model of the marine vessel GIS is characterized by the description of the hierarchy of components that support the functionality of the GIS, which allows performing structural optimization of the GIS when operating the marine vessel for navigation purposes.

It is proposed a methodology of forming a GIS infrastructure. The methodology is a sequence of actions for approaching the structural and functional model of the GIS of a marine vessel to given properties set.

The method of forming the structural-functional model of the marine vessel GIS is implemented as an expert system. The expert system automates the sequence of designing a GIS marine vessel. The expert system allows in the interactive mode to form a list of functional modules and GIS equipment.

The expert system is built on a modular basis and consists of the following components: a database, knowledgebase, solver, knowledge acquisition subsystems, explanations, and dialogue.

The database consists of a set of tables that store data on navigation equipment, network components, and workstations.

The knowledge base determines the rules of the expert system.

The solver determines the number of GIS nodes and estimates the data delivery time to the receiver.

The solver interacts with the database according to the logic recorded in the knowledge base.

References

1. Istomin E. P., Sokolov A. G., Abramov V.M., Gogoberidze G.G., Popov N. N. Geoinformation management as a modern approach to the management of spatially-distributed systems and territories. In International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management (SGEM), Bulgaria, vol. 1, issue 2, 607-614 (2015).
2. Tatarnikova T., Yagotinceva N. Methodology of forming the structural-functional model of the geographic information system on marine vessel. In International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management (SGEM), Bulgaria, vol. 19, issue 2.1, 943-949 (2019).
3. DeMers M. Fundamentals of Geographic Information Systems. – Join Wiley & Sons Inc., (1996).
4. Bernhardsen T. Geographic Information Systems. – Join Wiley & Sons, (1992).
5. Bogatyrev V.A., Parshutina S.A., Poptcova N.A., Bogatyrev A.V. Efficiency of redundant service with destruction of expired and irrelevant request copies in real-time clusters/Communications in Computer and Information Science, vol. 678, 337-348 (2016).
6. Tonenbaum A., Austin T. Structured Computer Organization. 6th ed. – Prentice Hall, (2012).
7. Poymanova E.D., Tatarnikova T.M. Models and Methods for Studying Network Traffic. In Wave Electronics and its Application in Information and Telecommunication Systems, WECONF 2018, pp. 1-5, (2019). DOI 10.1109/WECONF.2018.8604470
8. Tatarnikova T. M. Statistical methods for studying network traffic. Informatsionno-Upravliaiushchie Sistemy, no. 5, 35-43 (2018). DOI: 10.31799/1684-8853-2018-5-35-43
9. Hall A., Ahonen-Rainio P., & Virrantaus K. Knowledge and reasoning in spatial analysis. Transactions in GIS, vol. 18(3), 464- 476 (2014).
10. Mallach E.G. Information Systems. – CRC Press, (2016).