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On resolution of Digital Two-Coordinate Radar

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***Abstract*—Current paper is about evaluation of measurement errors at distributed digital radar system with limited network bandwidth. Radar system considered under this paper consists of 2 main blocks: ADC convertor that digitalize raw radar signal and block of secondary data processing. Problem is states as following. ADC generates amplitude matrix by signals from radar. The paper refers to comparison of data transmission protocols between 2 physical hardware (PC based) connected into network. The paper presents the results of data transmission experiments on charts. One of the results of the experiments that data transmission speed does not directly depend on CPU, memory, network utilization. Based on the experimental values of data transmission speed as main result of the paper given charts of dependency of maximum size of amplitude matrix and measurement error for typical radar system.**

***Keywords*—radar measurement, digital signal processing, data transfer, distributed information system, measurement error**

I. Introduction

Radar stations (radar) are the most important tool for monitoring the movement of objects of various types [1, 2, 3]. Despite the development of modern satellite navigation aids (for example, the Automatic Identification System (AIS) in navigation [4]), radar systems continue to constitute the information basis of marine and air traffic surveillance systems [5, 6], as they can ensure their uninterrupted and autonomous functioning. For example, coastal and airborne ship traffic control systems necessarily include one or more all-round radars [6].

Currently, the computerization of radar is characteristic. It connects to a computer using special analog-to-digital devices (radar processors [7]).

The radar reflected echo signal is digitized and "entered" into the computer memory (primary signal processing). The received primary digital data is transferred to other components of the information system (usually distributed) for secondary processing.

The instrumental component of the measurement error of the coordinates of the observed objects is usually associated with the following radar characteristics: radiation pattern width, wavelength, probe pulse length and transmission frequency [8]. Computerization of the radar and analog-to-digital conversion of the original echo signal introduces an additional factor that affects the instrumental error of radar measurements.

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The analog-to-digital conversion of an echo signal is characterized by the frequency and range of its sampling. A high frequency and a large sampling range are very desirable, since they allow one to achieve high accuracy in measuring the coordinates of the observed objects and to solve additional problems (for example, to distinguish objects from interference, to recognize the type of an object by its radar image, to evaluate weather conditions, etc.) [9]. Also, high characteristics of the frequency and sampling range lead to significant volumes of data.

The essence of the problem is that the data transfer from the primary processing unit to the secondary processing unit of the distributed information system has speed limits due to the characteristics of the computers used, the software platform and network equipment. Therefore, the choice of certain parameters of the analog-to-digital conversion of the original echo signal is an urgent task.

Industrial surveillance systems are built using specialized computers and software platforms. These factors determine their high cost and limited availability of specialist developers and operators of the necessary qualifications. Therefore, it is advisable to turn to typical computers and general-purpose software if the tasks solved by the monitoring systems do not impose high requirements for reliability and security (for example, research problems).

The present work is devoted to the study of the limitations of the characteristics of surveillance systems created on the basis of computerized radar radars with the use of computer equipment and general purpose software platforms and associated with the finite speed of data transmission in a computer network.

II. Problem statement and Model Representation

Let there be a typical all-round radar with an antenna rotation period T_φ and a transmission frequency ν_φ (sampling frequency in azimuth). With these values, the number of rulers per one revolution of the antenna (i.e., the number of discrete azimuth values) will be $n_\varphi = \nu_\varphi T_\varphi$.

Let the radar range scale correspond to the time of receiving the T_r line. Let each ruler be converted by an analog-to-digital device with a sampling frequency ν_r into an array of values. Then the number of elements in this array of values (that is, the number of discrete range values) for each ruler will be equal to $n_r = \nu_r T_r$.

One rotation of the radar antenna forms a radar image of the observed space, then it is converted by analog-to-digital conversion into a matrix of amplitudes of the reflected echo signal *A* with the number of rows equal to n_φ and the number of columns equal to n_r. The amplitude matrix is updated with each revolution of the antenna, that is, once in a time T_φ.

The information-measuring system based on such a radar has the following architecture. Electrical video and synchronizing radar signals are fed to the input of an analog-to-digital converter (ADC) connected to a computer.

The amplitude matrix *A* obtained as a result of such primary processing is transmitted via a network protocol to another computer for secondary processing, which includes tracking the trajectories of the observed objects, determining their motion parameters and visualizing the navigation environment in the user interface.

The performance of modern typical computers is sufficient to solve the basic problems of primary and secondary signal processing. But data transmission from the primary processing unit to the secondary processing unit via the network protocol is the bottleneck of the computerized radar surveillance system under consideration, given the large volume of matrix *A* and its frequent updating.

The architecture of modern software platforms (operating systems) allows for the construction of distributed information systems through the use of multitasking and data transfer between processes. These processes, which form the software basis of a distributed information system, can be launched in parallel to each other and exchange data on one or on different computers connected by a network.

There are a number of tools for exchanging data between processes [10]: dynamic data exchange interface (DDE interface), mail slots, named pipes (pipes), sockets, memory mapped files.

If we take into account the features of the functionality of the radar monitoring system, for the software implementation of data exchange between the primary and secondary processing units, the most suitable mechanism is named pipes. It is characterized by the ability to synchronize the operation of the secondary processing unit (pipe client) with updating the data of the primary processing unit (pipe server).

It should be noted the methodological commonality of the kernel of the operating system in the implementation of various mechanisms for exchanging data between processes, which leads to the closeness of their performance and resource consumption, including in the context of various operating systems.

In this paper, the task is to assess the characteristic data transfer rate from the primary unit to the secondary processing unit using the named pipes mechanism, and, based on it, to estimate the possible limit values of the sampling frequencies of the radar image in azimuth ν_φ and range ν_r, which determine the dimension amplitude matrices *A*.

We will evaluate the characteristic data transfer rate from the pipe server to the pipe client based on the results of field tests. There are two computers connected by a local network. On one of them, a server program is launched that creates a named pipe and generates and writes data to it. On the second computer, a client program is launched that reads data from the named pipe.

The data transfer speed is determined not only by the configuration of computers and network devices, but also by the operating system used and the degree of loading of computer resources by other system and application tasks. To analyze the data transfer rate under various conditions, we implement the following test scenarios.

Scenario 1. Client and server work without additional load.

Scenario 2. Video files from the hard drive are launched in parallel to the client and server.

Scenario 3. Video from the Internet is launched in parallel to the client and server.

Scenario 4. Resource-intensive applications are launched in parallel to the client and server.

The first scenario conditionally simulates the ideal version of the surveillance system as a software product. The second, third and fourth - various aspects of computer resource loading (processor, memory, network). In the fourth scenario, the role of a resource-intensive application was played by computer games with rich functionality.

III. Numerical and Full-Scale Results

When setting up the experiment, computers with the following characteristics were used: Intel Core i5 processor with a frequency of 2.5 GHz, 4 GB memory, a network adapter with a speed of 1 Gbit / s, OS Win7 (64). Such characteristics are consistent with the definition of "typical general-purpose computer."

In Figure 1 shows a graph characterizing the values of the data transfer rate *C* from the pipe server to the pipe client. Figure. 1a corresponds to the first scenario. And figures 1b, 1c and 1d correspond to the second, third and fourth.

At the moment of time $t = 0$, the server and client processes were started sequentially, at the moment of time $t = 20$ (after stabilization of the distribution of computer resources) data logging began. The graphs show that the data transfer rate is about 50 megabytes per second (which is more than 2 times less than theoretically possible, due to the characteristics of the used 1Gbit / s network adapter).

Velocity fluctuations of the order of 5-10% take place. Data transfer rates are close in all four scenarios, that is, the data transfer rate does not depend explicitly on the load of computer resources, if the load is not extremely high.

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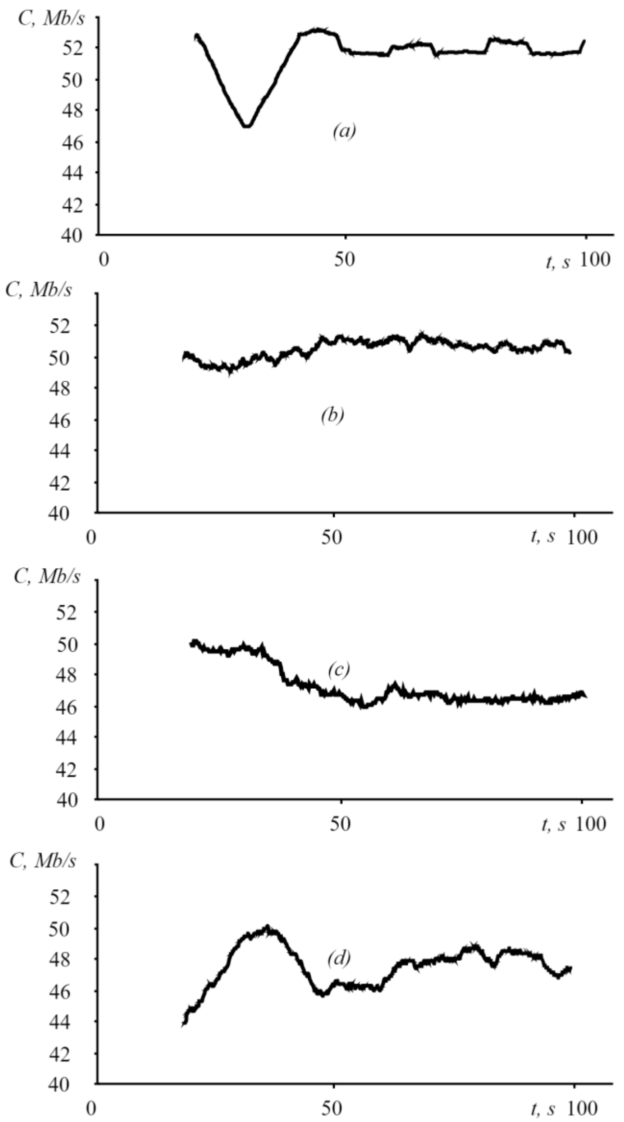

Fig. 1. Client-server data rate

The values of the dimension of the amplitude matrix of the reflected echo signal *A* (the number of rows n_φ and the number of columns n_r) for a known size of one matrix element *s* (determined by the sampling range), the data transfer rate from the primary processing unit to the secondary processing unit *C*, and the radar antenna contact period T_φ ratio:

$$n_r = \frac{CT_\varphi}{sn_\varphi}.$$

The angular and range resolutions due to discretization and expressed in meters for the dimensions of the amplitude matrix $n_\varphi \times n_\varphi$ are, respectively, $\delta_\varphi = 2\pi r / n_\varphi$ and $\delta_r = R / n_r$, where *r* is the distance to the observed object, *R* is the maximum range of the radar (determined by the selected range scale). For small objects whose geometric dimensions are comparable with the radar resolution, the resolution in angle δ_φ and range δ_r can be identified with the instrumental error in measuring the corresponding quantities.

For large, extended objects, the digitized radar image is represented by a certain “submatrix” of the amplitude matrix (Fig. 2 shows an example of such a radar image). Its values are correlated and distributed in a complex way. In this case, the instrumental error in measuring the range and azimuth, of course, depends on the resolution in angle and range, however, one should not directly identify the resolution in angle and range with the instrumental error of measurements.

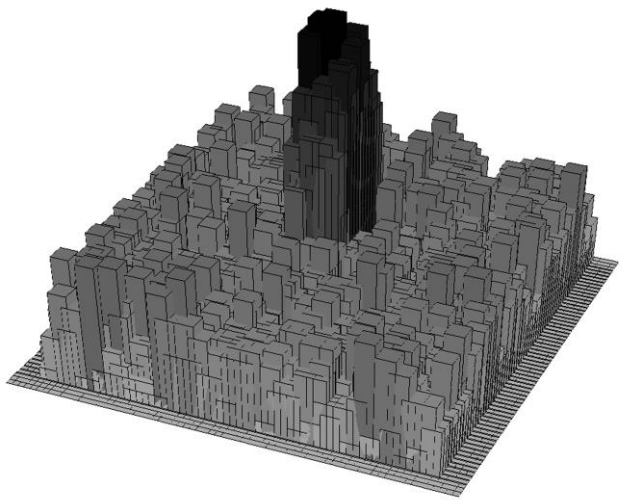

Fig. 2. The radar image of the vessel against the background of interference from sea waves; the height of the bars corresponds to the amplitude of the reflected echo

Figure 3 illustrates the possible values of the measurement errors of the coordinates of the observed objects, if the data transfer rate from the primary processing unit to the secondary processing unit *C* is estimated to be 50 MB / s, the radar antenna T_φ has a revolution period of 3 s, and the size of one element of the amplitude matrix *s* is 2 bytes.

In figure 3a shows the dependence of the maximum number of columns n_r on the number of rows n_φ at the indicated values.

For example, if the frequency of radar transmissions corresponds to 4,000 rulers per antenna revolution, then the maximum possible number of discrete range values is approximately 20,000. In figure 3b shows the dependence of the range resolution on the angle resolution at *r = 30* km and *r = 5* km (solid line), *r = 10* km (dashed line), *r = 15* km (points). The figure shows that, for example, for an object located at a distance of *r = 5* km, with a resolution in the angle δ_φ equal to 4 meters, a resolution in range δ_r is 3 meters.

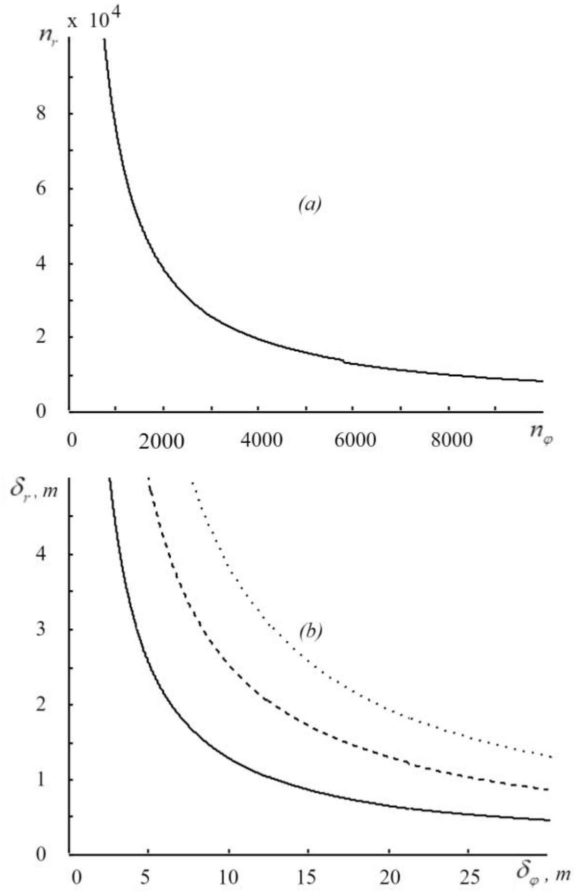

Fig. 3. Amplitude Matrix Sizes and Corresponding Angle and Range Resolutions

IV. Conclusion

As the experiments and calculations presented in the article show, the optimal data transfer rate is about 50 MB / s on a computer with a network adapter speed of 1 Gbit / s. In this case, the resolvability of the radar image of the observed objects at characteristic ranges of 10-15 km due to the discretization of the radar signal is about 10-15 m. Such solvability and the corresponding measurement error are sufficient to solve many surveillance problems, for example, associated with assessing the navigation situation and ensuring the safety of the collective movements of the observed objects [11, 12].

Two orders of magnitude greater data transfer speed of ~ 5 GB / s are needed for tasks requiring an order of magnitude smaller coordinate measurement error of ~ 1 m [13] and for constant transmission of the full matrix of amplitudes to the secondary processing unit. This speed is unattainable for typical general-purpose network equipment. The solution of such problems requires the development of special transceivers and data processing algorithms

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