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SELECTION OF ELEMENTS AND COMPONENTS FOR THE IMPLEMENTATION OF ONBOARD MEANS FOR MEASURING MOTION PARAMETERS AND DETERMINING THE SPATIAL ORIENTATION OF MOBILE ROBOTIC PLATFORMS

The structure of means for measuring motion parameters and determining the spatial orientation of mobile robotic platforms (MRP) for use in conditions of incomplete information and interference has been developed. The main components on the basis of which the means for measuring motion parameters and determining the spatial orientation of the MRP are synthesized have been determined: a set of navigation sensors; radar meter of MRP movement parameters; GPS module; module for analysis and recovery of lost navigation data; a module for neural network improvement of the accuracy of measuring the parameters of the MRP movement; a module for neural network improvement of the accuracy of determining the geographical coordinates of the MRP; module for neural network forecasting of geographical coordinates and route of movement of the MRP; module for collecting and storing navigation data. It has been determined that the performance of computer components, the amount of memory, power consumption, the frequency of information updates, communication interfaces, measurement accuracy, cost, weight, dimensions, temperature range, reliability, resistance to special factors, etc., are the main criteria by which the selection of the element base and components is carried out. It is shown that these criteria quite fully characterize the element base and have an unambiguous concept, and are focused on the implementation of onboard radio-electronic means of measuring movement parameters and determining spatial orientation with high operational indicators. The existing element base and navigation components used for the implementation of means for measuring motion parameters and determining the spatial orientation of the MRP are analyzed. It is shown that in order to implement intelligent means of processing data from radar motion parameter meters, inertial navigation components, and GPS modules, it is necessary to use neurochips, digital signal processing processors, systems on a chip, microcontrollers, and FPGAs. It is proposed to normalize partial criteria for the selection of the element base and navigation components according to the method of minimax standardization. An additive model and normalized partial selection criteria are selected to calculate the integrated assessment of the effectiveness of the use of the element base. The method of selecting the element base and components for the implementation of onboard radio-electronic means of measuring motion parameters and determining spatial orientation has been improved, which, due to the use of a normalized additive model with the maximum value of the integrated efficiency assessment, provides the choice of the most effective element base and components that meet the requirements of the terms of reference.

Keywords: normalized additive model, threshold coefficient method, navigation sensors, radar meter, motion parameters, measurement accuracy.

Introduction

In the military field, for the transportation of weapons, reconnaissance, special military, and rescue operations, an important problem is to increase the accuracy of measuring movement parameters and determining the spatial orientation of mobile robotic platforms (MRP) under the influence of obstacles. To solve such problems, onboard radio-electronic means of measuring movement parameters and determining the spatial orientation of the MRP are needed. The use of modern navigation components (gyroscopes, digital compasses, lidars, GPS modules and radar motion parameter meters) and modern element base (microcontrollers, microprocessors, microcomputers, systems on a SoC chip, user-programmable FPGA valve arrays) in the development of such onboard motion measurement devices and determination of spatial orientation provides an increase in measurement accuracy, data update frequency with a simultaneous decrease weight, dimensions, energy consumption and cost. Basically, the choice of the element base and navigation components is carried out by taking into account the set of partial criteria that sufficiently fully characterize them. For partial criteria, the values of weight coefficients are determined by an expert. The value of the weight factor is determined by the importance of the criterion for the functioning of onboard instruments for measuring motion parameters and determining the spatial orientation of the MRP. In most cases, the choice of the element base and navigation components for the implementation of motion parameters measurement tools and determining the spatial orientation of the MRP is carried out on the basis of an integrated efficiency assessment, which takes into account partial criteria and their weights.

Therefore, an urgent task is the selection of the element base and navigation components for the implementation of onboard radio-electronic means for measuring the parameters of the MRP, which take into account the requirements of a specific application and provide high technical and operational characteristics.

The object of research is the processes of analysis and selection of the element base and components for the implementation of onboard radio-electronic means for measuring movement parameters and determining the spatial orientation of the MRP.

The subject of the study is methods for evaluating the characteristics of the element base and components, choosing the element base for the implementation of onboard radio-electronic means of measuring movement parameters and determining the spatial orientation of the MRP.

The purpose of the work is to develop the structure of onboard radio-electronic means for measuring movement parameters and determining spatial orientation, and to improve the method of selecting the element base, components for their implementation with high technical and operational characteristics.

To achieve this goal, the following *main objectives of the study* are defined:

- to develop the structure of means for measuring the parameters of motion and determining the spatial orientation of the MRP;
- to determine the criteria for selecting the element base and components for the implementation of onboard radio-electronic means for measuring movement parameters and determining the spatial orientation of the MRP;
- to analyze the element base and components for the synthesis of onboard radio-electronic means of measuring motion parameters and determining the spatial orientation of the MRP;
- to improve the method of selecting the element base and components for the implementation of onboard radio-electronic means of measuring movement parameters and determining the spatial orientation of the MRP.

The following research methods were used when conducting research and solving the assigned tasks:

- the method of multi-criteria analysis for the formation of criteria for the selection of the element base and components;
- the method of minimax (extreme) standardization for normalization of partial criteria for the selection of the element base and components;
- normalized additive model – for calculating an integrated assessment of the effectiveness of using the element base, which allows for correctly aggregating heterogeneous indicators into a single integrated assessment;
- the method of threshold coefficients – for selecting a set of options for the element base and components;
- the method of expert assessments – to determine the value of weighting factors for partial criteria for selecting the element base and components;
- the method of a normalized additive model with maximum integrated estimation for the selection of a specific element base and components.

Analysis of recent research and publications. The analysis of works [1, 2] shows a continuous increase in requirements for onboard radio-electronic devices for measuring movement parameters and determining the spatial orientation of MRP, both in terms of functional and operational parameters. In the works [3, 4], it is shown that the main ways of creating such equipment are the use of modern elements and the latest navigation components with high technical characteristics.

The analysis of the work [5, 6] shows that onboard radio-electronic means of measuring motion parameters and determining the spatial orientation of the MRP are implemented on the basis of a problem-oriented approach, which involves the use of a universal processor core supplemented by specialized hardware and software. Microcontrollers or SoCs are used to implement a universal processor core, and programmable logic integrated circuits, such as FPGAs (Field Programmable Gate Arrays), are used to implement specialized tools. The works [7, 8] show that the combination of universal and specialized, software and hardware will ensure the implementation of equipment for measuring movement parameters and determining the spatial orientation of the MRP, taking into account the limitations that are put forward in the terms of reference regarding weight, dimensions, energy consumption and cost.

The papers [9–12] consider the problems of choosing the element base in the design of radio-electronic equipment for measuring the parameters of the MRP movement. It is shown that the technical and technical-operational indicators of radio-electronic equipment largely depend on the quality of the element base. A limited set of quality indicators has been allocated, which sufficiently fully characterizes the element base used in the creation of radio-electronic equipment. This group includes the following main indicators: the cost of the element base, speed, measurement accuracy, power consumption, temperature range of the element base, dimensions, weight, noise immunity, and reliability indicators. The literature analysis [13–17] shows that there is currently no single method for choosing the optimal element base. Basically, the element base is selected based on the following positions: the set of selection criteria must fully satisfy the requirements of the terms of reference; selection criteria should have the same meaning for each element. The number of selection criteria should be limited, which will simplify the optimization task. The literature [18–20] shows that for civilian equipment, the priority criterion for the effectiveness of the element base is the cost while ensuring the necessary reliability. For military equipment, the priority criterion for efficiency is meeting the terms of reference requirements while minimizing the cost.

The literature [21] shows that the choice of the element base and navigation components for onboard equipment for measuring movement parameters and determining the spatial orientation of the MRP should be based on an integrated approach, which includes measurement methods and modern methods for evaluating the effectiveness of the use of the element base. The paper [22] proposes using a method based on integrated efficiency assessment to select the element base and navigation components. The calculation of the integrated assessment of the efficiency of using the element base for the synthesis of equipment for measuring motion parameters and determining the spatial orientation of the MRP is carried out based on a multi-criteria analysis and an integrated approach that takes into account its functional efficiency, manufacturability, reliability, economy and energy consumption.

Therefore, an urgent problem is to improve the method of selecting the element base and components for the implementation of onboard radio-electronic means of measuring movement parameters and determining the spatial orientation of the MRP.

Research results and their discussion

Development of the structure of means for measuring motion parameters and determining the spatial orientation of MRP

The means of measuring motion parameters and determining the spatial orientation of MRP should provide accurate measurement of motion parameters and prediction of the geographical coordinates of MRP in conditions of incompleteness of information and interference. The structure of means for measuring the parameters of movement and determining the spatial orientation of the MRP in conditions of incompleteness of information and interference, which is shown in Fig. 1.

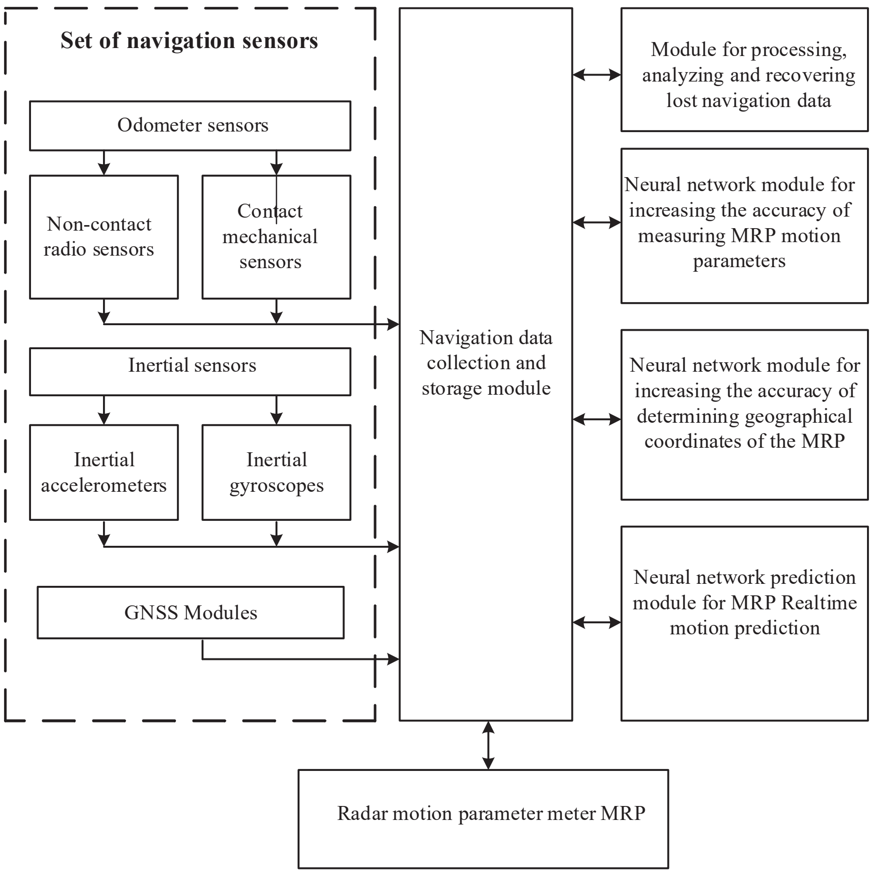

Fig. 1. Structure of means for measuring movement parameters and determining spatial orientation of MRP

The main components of the structure of means for measuring motion parameters and determining the spatial orientation of MRP in conditions of incompleteness of information and interference are: a set of navigation sensors; radar meter of MRP movement parameters; GPS module; module for analysis and recovery of lost navigation data; a module for neural network improvement of the accuracy of measuring the parameters of the MRP movement; a module for neural network improvement of the accuracy of determining the geographical coordinates of the MRP; module for neural network forecasting of geographical coordinates and route of movement of the MRP; module for collecting and storing navigation data.

The set of navigation sensors includes: single-metric sensors; accelerometers, which measure the linear aceleration of the MRP in three axes; gyroscopes that measure angular velocities and allow you to track the orientation of the MRP.

Radar Motion Meters (RMM) are used to determine speed, assess the direction of travel, support autonomous navigation, detect obstacles, monitor surfaces, and ensure traffic safety. The main components of such meters include: an antenna system used to emit and receive radio waves; a transmitter that generates a high-frequency signal emitted by an antenna; a receiver that receives the reflected signal from the object, a local oscillator and a mixer that ensure the conversion of the frequency of the received signal into an intermediate frequency for further processing; signal processing processor; synchronization and control unit.

The GPS module is used for navigation, positioning, and autonomous movement of MRPs.

The module for collecting and storing navigation data provides the collection, storage of data, and results of processing and forecasting the geographical coordinates and route of movement of the MRP. Such a module is implemented on the basis of a multiport memory (MPM) with conflict-free access to the storage environment. To ensure conflict-free access, the principle of distributing access time to the memory medium is used.

The module for processing, analyzing, and recovering lost navigation data provides the computation of such data coming from navigation sensors operating in interference conditions.

The neural network module for improving the accuracy of measuring MRP motion parameters uses singular spectral analysis, which is based on the study of the time series by the principal component method to improve the accuracy of real-time measurement of parameters.

GNSS's Neural Network Geographic Coordinate Measurement Accuracy Enhancement Module uses singular spectral analysis to improve real-time measurement accuracy. Measurement of geographic coordinates using GNSS is performed at least once per second.

The neural network module for predicting the geographical coordinates of the MRP route provides forecasting of geographical coordinates for the duration of interference. The module compares the predicted coordinates with real coordinates and, based on the comparison, corrects the forecasting process. This module, based on data on the state of the environment and the coordinates of the target, predicts the route of the MRP.

Criteria for the selection of the element base and components for the implementation of onboard radio-electronic means of measuring motion parameters and determining the spatial orientation of the MRP

Modern MRPs are actively used in various fields of activity, including defense, industry, medicine, etc. One of the key aspects of the effective functioning of such platforms is the accurate measurement of movement parameters, determining their spatial orientation under the influence of electronic warfare and incompleteness of information. Accordingly, the selection of the element base and components for the creation of onboard radio-electronic means for measuring motion parameters and determining spatial orientation plays a critical role in ensuring the reliability, accuracy, and energy efficiency of the system. The development of onboard radio-electronic means for measuring movement parameters and determining spatial orientation requires the widespread use of modern navigation components and element base. To implement such tools, the following element base is used: microcontrollers, microprocessors, microcomputers, SoC systems, and user-programmable FPGAs. The main components used for the synthesis of onboard radio-electronic means of measuring motion parameters and determining the spatial orientation of MRPs are: gyroscopes, digital compasses, lidars, GPS modules, and radar meters of motion parameters of ground MRPs.

Synthesis of effective onboard radio-electronic means of measuring motion parameters (MMPM) and means of determining spatial orientation (DSOM) for MRPs on the basis of modern components and the element base requires the development of new intelligent methods for processing navigation data in real time.

The choice of the element base for the synthesis of MMPMs and DSOMs is carried out taking into account the following:

- a set of criteria should ensure the selection of the element base for the synthesis of MMPMs and DSOMs with high technical and operational indicators;
- selection criteria should have an unambiguous interpretation for components and element base;
- number of criteria for selecting components and the element base should be limited.

We will form a group of criteria for the selection of components and element base, which characterize it quite fully and are focused on the implementation of MMPMs and DSOMs with high technical and operational indicators. It is advisable to include the following criteria in this group:

1. The cost of components and the element base, which is approximately one-third of the cost of the MMPMs and DSOMs, significantly affects its competitiveness.
2. Accuracy and stability of radar meters of ground MRP movement parameters and inertial navigation components (gyroscopes, accelerometers, magnetometers).
3. Performance that determines the ability to implement intelligent algorithms for processing navigation data in real time.
4. Power consumption, which determines the requirements for power supplies and characterizes the temperature regime.
5. The coefficient of manufacturability, which determines the cost of technological equipment for the development and debugging of MMPMs and DSOMs.
6. The temperature range of the element base, which affects the operating conditions of the MMPMs and DSOMs.
7. The number of components and microcircuits required for the synthesis of MMPMs and DSOMs, which determines their reliability and manufacturing cost.
8. Overall indicators of components and element base, which determine the dimensions of MMPMs and DSOMs, which are relevant for onboard applications.
9. Criteria for the mass of components and element base determine the mass of the MMPMs and DSOMs, and are of great importance for on-board equipment.

10. The criterion of noise immunity of components and element base, which is determined by the voltage values of log.0 and log.1.

11. Indicators of the reliability of components and the element base, namely the failure rate and the probability of trouble-free operation.

12. The coefficient of vibration resistance of the element base, which characterizes resistance to mechanical stress.

Analysis of the element base and components for the synthesis of onboard radio-electronic means for measuring motion parameters and determining the spatial orientation of the MRP

Intelligent means of processing data from radar meters of ground MRP movement parameters, inertial navigation components, and GPS modules were implemented by software and hardware using neural chips, digital signal processing processors, systems-on-a-chip, microcontrollers, and FPGAs. Let's take a closer look at the base element listed.

Neurochips. Recent studies show that it is advisable to use neural chips for the implementation of intelligent tools for processing navigation data, since they are focused on the execution of neural network algorithms and provide high speed when performing neural network operations. The main advantage of using neural chips for the implementation of intelligent tools is to ensure the processing of navigation data in real time. Neural chips are capable of implementing one neural network algorithm for a specific application, while general-purpose neural chips can implement more than one neural network algorithm. They may also contain schemes for adjusting the scales during training or provide for external loading of scales. According to the type of information processing, they are divided into digital, analog, and hybrid.

One of the advantages of digital neural chips is the use of simple manufacturing methods, storage of weighting coefficients in memory, and development flexibility. The biggest challenge for developers is implementing a device for calculating the scalar product of neuron inputs and weighting coefficients, which is usually the slowest processing element in the network. The following categories of digital neurochips are distinguished: bit-modular, with one instruction stream and many data streams (SIMD), and systolic matrices.

When using a bit-modular architecture, each module is designed to handle several bits of the machine word, and the word as a whole is processed by a group of modules or sections connected to each other. Examples of such neurochips are Micro Devices MD1220 Neural Bit Slice, Philips Lneuro chip and Neuralogix NLX-420 Neural Processor.

SIMD class systems are focused on using data parallelism to improve performance and are suitable for the implementation of intelligent navigation data processing. In such tools, several data streams are processed by separate elements, but under common control. An example of such neurochips is the Adaptive Solutions N64000 with 64 processor elements.

The main characteristics of neurochips are: architecture, production technology, performance, power consumption, memory capacity, and learning algorithms.

Digital signal processors (DSPs). The advantages of DSP are high performance, hardware implementation of the multiplication operation with accumulation, a large number of technological tools for software development and debugging. There is a wide variety of DSP processors, so the choice of one or another processor is an urgent and multi-criteria task, which directly depends on the end application. They are used for various applications, so when choosing, you should take into account the requirements that apply to the entire system as a whole. Compared to other element bases, the main advantages of DSP processors are focused on the basic operation of digital signal processing – multiplication with accumulation, and the presence of a hardware multiplier that allows you to multiply at least two numbers in one cycle.

DSP processors in MMPMs and DSOMs are used to solve problems of digital filtering and the discrete Fourier transform in real time. The first places in the market of DSP processors are occupied by Texas Instruments and Analog Devices. The best option in terms of quality / cost is processors from Analog Devices (similar processors from Texas Instruments are more expensive).

DSP processors of different manufacturing companies are conventionally divided into two classes that differ significantly in price: cheaper microprocessors for processing data in a fixed-point format and more expensive ones that support operations on data in a floating-point format. It should also be noted that different types of processors are used for different applications. For example, for portable devices such as mobile phones, portable digital players, cost, degree of integration, and power consumption are the most important, and high performance is often not necessary (since it requires a significant increase in power consumption, without giving advantages when processing low-speed audio data). At the same time, for sonar or radar systems, the determining parameters are the speed of operation, the presence of high-speed interfaces, and a convenient development system, while cost is a secondary criterion. Most fixed-point DSP processors have a small amount of internal memory and a low bit depth of external data buses. At the same time, floating-point DSP processors usually involve working with large amounts of data and complex algorithms and have either a built-in large memory or a large bit depth of address buses for connecting external memory (and sometimes both). Therefore, the choice of the type and amount of memory should be the result of a thorough analysis of the area of application in which DSP processors are used.

Programmable Logic Integrated Circuits (Programmable Logic ICs). Programmable Logic ICs are an effective resource for the hardware implementation of basic algorithms for processing navigation data. The main advantages of using Programmable Logic ICs are: low cost due to mass production, availability, high speed, performance and reliability, versatility, variety in the choice of supply voltage and I/O signal parameters, as well as low power consumption, which is especially important for the implementation of portable equipment, availability of a variety of well-developed and effective software tools for computer-aided design and reducing the time of design and debugging of projects, reconfiguration, which provides great design flexibility. However, the implementation of a digital processing system with a large number of neurons on a Programmable Logic IC is associated with problems in realizing all the necessary connections.

Programmable Logic ICs are divided into four classes: SPLD (Simple Programmable Logic Devices); CPLD (Complex Programmable Logic Devices); FPGA (Field Programmable Gate Arrays), and FPGAs with combined architecture. Most often, FPGAs are used to implement navigation data processing algorithms, which often include FPGAs with a combined architecture, since they have a large number of logical blocks compared to other classes. For example, SPLDs contain several hundred logic gates, while FPGAs contain several million.

The essential features of the latest generations of FPGAs are the provision of partial reconfiguration in the process of operation. In particular, FPGA-based systems can be adapted to the requirements of specific configurations. Compared to the FPGAs of the previous generation, there is a significant decrease in the level of power consumption with an increase in productivity. For example, the use of FPGAs of the Artix-7 family compared to Spartan-6 allows you to reduce power consumption by 2 times and increase performance by 30 %. Similarly, using Kintex-7 instead of Virtex-6 also allows you to halve power consumption.

System-on-a-chip SoC. An SoC system is an integrated circuit that contains all the main components of a computer system. An SoC may include the following components: central processing unit (CPU), graphics processing unit (GPU), random access memory (RAM), and I/O controllers.

Analysis of the component market shows that to ensure competitiveness in the market, modern SoCs must have:

- a unique set of functions;
- developed user interface;
- high performance of the base platform, which will provide the ability to upgrade the system;
- support for embedded operating systems;
- low power consumption;
- the ability to store large amounts of data, in particular in non-volatile memory and on external media;
- a full set of wired and wireless interfaces.

Today, there is a wide variety of ready-made SoCs on the market from the world's leading manufacturers: Intel, Freescale, Texas Instruments, Marvell, Analog Devices, Altera, Atmel, NXP, Xilinx, Cirrus Logic, RDC, Cypress, Sharp, NetSilicon, etc. There are a number of signs by which SoC systems can be classified, namely:

- processor core: ARM, MIPS, PowerPC, x86, etc.;
- core performance and system bus frequency;
- a set of interfaces;
- the cost of the crystal and its minimum functions;
- SoC system manufacturer.

Microcontrollers. Microcontrollers (MC) are compact computing devices on a single chip containing a central processing unit (CPU), random access memory (RAM), permanent memory (ROM/Flash), timers, peripheral interfaces, and other functional blocks. Today, microcontrollers are produced by a number of companies. The main manufacturers of microcontrollers are: Microchip Technology – PIC (8, 16, 32-bit microcontrollers), AVR (including ATmega, ATtiny, ATxmega), SAM (ARM-based controllers); STMicroelectronics – STM8 (8-bit), STM32 (32-bit based on ARM Cortex-M); Texas Instruments (TI) – MSP430 (energy-efficient 16-bit), Tiva C (32-bit ARM Cortex-M), C2000 (DSP controllers for motor control); NXP (formerly Freescale) – LPC (ARM Cortex-M), Kinetis (a wide range of 32-bit), i.MX RT (a hybrid of a microcontroller and a microprocessor); Renesas Electronics – RL78 (energy-efficient 8/16-bit), RX (32-bit), RA (ARM Cortex-M), RZ (high-performance 32-bit); Infineon – XMC (ARM Cortex-M), AURIX (Car Controllers), PSoC (Flexible Programmable SoC); Nordic Semiconductor – nRF52 and nRF53 (microcontrollers with Bluetooth Low Energy); Espressif Systems – ESP8266 (Wi-Fi module / controller), ESP32 (Wi-Fi + Bluetooth, powerful, for IoT); Silicon Labs – EFM32 (energy-efficient ARM Cortex-M), EFR32 (wireless controllers).

According to the processor architecture, MCs can be grouped into two classes: CISC (Complex Instruction Set Computer) with a complex set of instructions and RISC (Reduced Instruction Set Computer) with a simplified set of instructions. MCs are characterized by the following parameters: processor bit depth (8/16/32/64 bit); clock frequency (MHz, GHz); memory capacity – RAM, Flash and EEPROM; the number and types of peripheral interfaces; power consumption; temperature range, and body type. These characteristics are decisive when choosing an MC for a particular task.

Microcomputers. A microcomputer is a full-featured computer in compact dimensions, containing a microprocessor, memory, input / output devices, and can work under the control of an operating system. The manufacturers of microcomputers most often used for processing navigation data are: Raspberry Pi Foundation – manufacturer of popular Raspberry Pi single-board computers; Intel – produces Intel NUC series microcomputers; ASUS – Tinker Board line; BeagleBoard.org – manufacturer of single-board computers BeagleBone; Hardkernel – ODROID series; NVIDIA is a series of Jetson microcomputers.

The main characteristics of a microcomputer are: performance, which is determined by the clock speed of the processor, the number of cores, and the amount of addressable memory; the amount of RAM and its performance; interfaces and ports.

Components of inertial navigation. Inertial navigation components provide the location of the MRP without the use of external signals, based on the measurement of accelerations and angular velocities. The following components are used in the MRP for the synthesis of an inertial navigation system: accelerometers, which provide measurements of the linear acceleration of the MRP in three axes, and gyroscopes, which measure angular velocities and allow tracking the orientation of the MRP.

Accelerometers are produced by many companies, including both large international electronics manufacturers and specialized companies. The main manufacturers of accelerometers for MRPs are: Analog Devices (ADI) – ADXL series (for example, ADXL345, ADXL362); STMicroelectronics (ST) – LIS series (e. g. LIS3DH, LIS2DW12); Bosch Sensortec – BMA series (e. g. BMA280, BMA400); Invensense (now part of TDK) – MPU series (e. g. MPU-6050, MPU-9250); Texas Instruments (TI) – MMA series (e. g. MMA8452Q).

The following parameters are used to select acelerometers: measurement range (±g), which determines the maximum acceleration; sensitivity (LSB/g or mg/LSB) – determines the accuracy of acceleration measurement; the number of axes (2D or 3D) to measure motion in two planes (X, Y) and three planes (X, Y, Z); communication interfaces – I2C or SPI; power consumption; the sampling rate determines the frequency of data updates; noise level; temperature range.

Gyroscopes are produced by many companies specializing in sensors and navigation systems. According to the principle of operation, gyroscopes are mechanical, optical (laser, fiber-optic FOG), MEMS, and quantum. They differ in the principle of operation, accuracy, and application.

The main manufacturers of accelerometers for MRP are: Bosch Sensortec (Germany) – BMG250, BMI088; STMicroelectronics (Switzerland) – L3GD20, LSM6DSO; Analog Devices (ADI) (USA) – ADXRS450, ADIS16490; InvenSense (part of TDK) (Japan) – MPU-6050, ICM-20948; Honeywell (USA) – GG1320AN, HG1700; Murata (Japan) – SCC1300-D02; Northrop Grumman (Litton) (USA) – LN-200, LN-250; KVH Industries (USA) – DSP-1750; Colibrys (TE Connectivity) (Switzerland) – MS1000.

The following parameters are used to select gyroscopes: sensitivity (°/s/LSB), which determines the minimum change in angular velocity; measurement range (°/s), which determines the maximum angular velocity that the sensor can detect (e. g. ±250, ±500, ±2000°/s); noise (Noise Density, °/s/√Hz) – determines the accuracy of measurements; drift (Bias Instability, °/h) – determines long-term accuracy; refresh rate (Hz) of data; power consumption; communication interfaces – SPI, I2C, UART.

GPS modules. In MRPs, GPS modules are used for navigation, positioning, and autonomous movement. The main manufacturers of GPS modules for MRP are Quectel, Trimble, Transystem, u-blox, and Holybro. For MRP, the most commonly used GPS modules are Ublox NEO-6M and Ublox M8N, which use satellite signals (GPS, GLONASS, Galileo, BeiDou). To select GPS modules, the following parameters are used: receiver sensitivity when capturing a signal and when tracking a signal; location time; positioning accuracy; data update frequency; power consumption; the number of supported satellite systems GPS (USA), GLONASS (Russia), Galileo (EU), BeiDou (China) and QZSS (Japan); connection interfaces; Dimensions; operating temperature.

Radar motion parameter meters. In MRPs, radar motion meters (RMM) are used to determine speed, assess the direction of travel, maintain autonomous navigation, detect obstacles, control the surface, and ensure traffic safety. The main components of such meters include: an antenna system used to emit and receive radio waves; a transmitter that generates a high-frequency signal emitted by an antenna; a receiver that receives the reflected signal from the object, a local oscillator and a mixer that ensure the conversion of the frequency of the received signal into an intermediate frequency for further processing; signal processing unit; synchronization and control unit.

Analog Devices offers a wide range of integrated RMM solutions covering both analog and digital components. The main components produced by Analog Devices are: a four-channel beamforming chip for phased array antennas ADAR1000 operating in the frequency range from 8 to 16 GHz; compact front ADTR1107 module covering the frequency range from 6 to 18 GHz, with integrated power amplifier, low-noise amplifier and SPDT switch; The ADAR4000 transmitting module, operating in the 2 to 18 GHz band, contains a true time delay unit (TDU) and a digital attenuator (DSA).

Infineon Technologies is a leading manufacturer of integrated radar solutions for a variety of industries, including automotive, ground-based MRP, and the Internet of Things (IoT). Infineon offers automotive radar modules operating in the 76–77 GHz band, which are suitable for various applications and support the use of the upper 77–81 GHz band. This contributes to the development of autonomous driving functions, autonomous driving, and raising vehicle safety standards.

For the development of experimental units of radar motion meters, Silicon Radar offers development kits: SiRad Easy Evaluation Kit and SiRad Simple Evaluation Kit. The SiRad Easy Evaluation Kit includes the following set of elements: two 24 GHz and 120 GHz radar boards, a motherboard with Wi-Fi, a lens (for 120 GHz radar), and a Nucleo64 board from ST Microelectronics.

When choosing a specific RMM, the following characteristics are taken into account: operating frequency range, which affects detecting range, accuracy and immunity to interference; measurement range, at which it is possible to accurately determine the parameters of movement; measurement accuracy, which depends on signal processing methods and hardware characteristics; resolution to distinguish between closely spaced objects; frequency of updating information about the movement of MRP; power consumption; dimensions and weight; antenna type; the ability to integrate with other navigation systems; resistance to mechanical stress (vibration, shock); temperature range of operation; price.

The choice of a specific RMM depends on the requirements of a particular application.

Improvement of the method of selection of the element base and components for the implementation of onboard radio-electronic means of measuring movement parameters and determining the spatial orientation of MRP

The choice of the element base and components for the implementation of onboard radio-electronic means of measuring motion parameters and determining spatial orientation is proposed to be carried out on the basis of the theory of multi-criteria analysis, integrated assessment of the effectiveness of the implementation of MMPMs and DSOMs on the existing element bases and components, taking into account requirements of a specific application (performance, memory capacity, power consumption, data transfer rates, frequency of information updates, cost, weight, dimensions, temperature range, reliability, resistance to special factors, etc.). The integrated assessment of the efficiency of the implementation of MMPMs and DSOMs on the existing element base and components includes the following factors: functional (compliance of parameters with the terms of reference), economic (cost of components, cost of production, energy efficiency), technological (complexity of installation and manufacture, possibility of automation of production, unification), energy (energy consumption, heat generation and cooling efficiency), dimensional and mass characteristics (dimensions device, weight and the possibility of miniaturization), perspective and scalability (the possibility of modernization, adaptation to new technologies).

To calculate an integrated assessment of the efficiency of equipment use in the implementation of MMPMs and DSOMs on the existing element base and components, taking into account functional, operational, technological, energy, and dimensional-mass selection criteria, we will use a normalized additive model. A feature of such a model is that it reduces all indicators to a dimensionless form and ensures their aggregation.

The method of selecting the element base and components for the implementation of the MMPMs and DSOMs on the basis of the normalized additive model is carried out in stages. At each stage, the following actions are performed:

1. Formation of a list of partial criteria for the selection of the element base and components.
2. The scale of changes in the numerical values of partial criteria for the selection of the element base and components is determined.
3. A set of variants of the element base and components that meet the requirements of the terms of reference is determined.
4. Values of weight coefficients are established, which determine the relative importance of the first partial selection criterion.
5. Normalization of partial criteria for the selection of the element base and components is performed.
6. An integrated assessment of the efficiency of each *j-th* element base and components is calculated.
7. Comparison of integrated efficiency assessments is carried out, and on this basis, the selection of the element base and components for the synthesis of MMPMs and DSOMs is carried out.

Table 1. List of partial criteria for selecting the element base and components for the synthesis of means for measuring motion parameters

No.	Criterion name	Denomination
1	Performance of the computing component of the MMPM	C_{1CC}
2	MMPM Memory Capacity	Q_1
3	Bit depth of the MMPM computing component	D_{1CC}
4	Clock speed of the MMPM computing component	F_{1CC}
5	The power consumption of the MMPM compute component	P_{1CC}
6	Reliability of the MMPM computing component	H_{1CC}
7	External interfaces of the MMPM computing component	R_{1CC}
8	Availability of software development tools for the MMPM computing component	B_{1CC}
9	RMM Operating Frequency Range	F_{PB}
10	RMM measurement accuracy	V_{PB}
11	Refresh rate in RMM	F_O
12	RMM Power Consumption	P_{PB}
13	RMM Weight	M_{PB}
I14	RMM Dimensions	S_{PB}
15	Maximum MMPM Operating Temperature	$t_{\max MMPM}$
16	Minimum MMPM Operating Temperature	$t_{\min MMPM}$
17	MMPM Weight	M_{MMPM}
18	MMPM Dimensions	S_{MMPM}
19	MMPM resistance to special factors (radiation, etc.)	K_{MMPM}
20	MMPM Reliability	H_{MMPM}
21	MMPM Cost	C_{MMPM}

At the first stage of choosing the element base and components for the synthesis of MMPMs and DSOMs, a list of partial criteria is formed. The list of partial criteria for the selection of the element base and components for the synthesis of MMPMs is given in the Table 1, and for the synthesis of the DSOMs is given in Table 2.

Table 2. List of partial criteria for selecting the element base and components for the synthesis of means for determining spatial orientation

No.	Criterion name	Denomination
1	DSOM Computing Component Performance	C_{2CC}
2	DSOM Memory Capacity	Q_2
3	Bit depth of the DSOM computing component	D_{2CC}
4	DSOM Computing Component Clock Speed	F_{2CC}
5	Power consumption of the DSOM computing component	P_{2CC}
6	Reliability of the DSOM computing component	H_{2CC}
7	External interfaces of the DSOM computing component	R_{2CC}
8	Availability of software development tools for the MMPM computing component	B_{2CC}
9	GPS receiver sensitivity	Z_{GPS}
10	GPS positioning accuracy	L_{GPS}
11	GPS Information Update Frequency	F_{OGPS}
12	GPS Connectivity Interfaces	R_{GPS}
13	GPS power consumption	P_{GPS}
14	GPS Weight	M_{GPS}
15	GPS dimensions	S_{GPS}
16	Maximum DSOM Operating Temperature	$t_{maxDSOM}$
17	Minimum DSOM Operating Temperature	$t_{minDSOM}$
18	DSOM Weight	M_{DSOM}
19	DSOM dimensions	S_{DSOM}
20	Resistance of DSOM to special factors (radiation, etc.)	K_{DSOM}
21	DSOM Cost	C_{DSOM}

At the second stage of the selection of the element base and components for the synthesis of MMPMs and DSOMs, the scale of changes in the numerical values of the partial criteria for the selection of elements and components is determined. The formation of the scale of changes in the numerical values of the partial criteria is carried out on the basis of the terms of reference for the development of MMPMs and DSOMs.

At the third stage of selection of the element base and components for the synthesis of MMPMs and DSOMs, a set of variants of the element base and components that meet the requirements of the terms of reference is determined. To select such a set of options, threshold coefficients are used. The selection of a set of variants of the element base and components that can be used for the synthesis of the MMPM is carried out according to the following formulas:

$$W_{MMPM} = \{W_{MMPMj}, 1 \le j \le N\}, W_{MMPMj} \neq 0,$$

$$W_{MMPMj} = c_{1CCj} \times q_{1CCj} \times d_{1CCj} \times f_{1CCj} \times p_{1CCj} \times h_{1CCj} \times r_{1CCj} \times b_{1CCj} \times f_{PBj} \times v_{PBj} \times f_{Oj} \times p_{PBj} \times m_{PBj} \times s_{PBj} \times t_{maxMMPMj} \times t_{minMMPMj} \times m_{MMPMj} \times s_{MMPMj} \times k_{MMPMj} \times h_{MMPMj} \times c_{MMPMj},$$

where W_{MMPMj} is the *j-th* variant of the element base and components, N is the number of variants of the element base and components, c_{1CCj}, q_{1j}, d_{1CCj}, f_{1CCj}, p_{1CCj}, h_{1CCj}, r_{1CCj}, b_{1CCj}, f_{PBj}, v_{PBj}, f_{Oj}, p_{PBj}, m_{PBj}, s_{PBj}, $t_{maxMMPMj}$, $t_{minMMPMj}$, m_{MMPMj}, s_{MMPMj}, k_{MMPMj}, h_{MMPMj}, c_{MMPMj} – threshold coefficients of the *j-th* element base and components, respectively, in terms of performance, memory capacity, bit depth of the computing component, clock speed of the components, power consumption of the components, reliability of the components, interfaces of the components, tools for the development of components, range of operating frequencies of the RMM, accuracy of measurement of the RMM, frequency of updating information in the RMM, power consumption power of the RMM, mass of the RMM, dimensions of the RMM, maximum operating temperature of the MMPM, minimum operating temperature of the MMPM, mass of the MMPM, dimensions of the MMPM, stability of the MMPM to special factors, reliability of the MMPM and the cost of the MMPM. The values of threshold coefficients for the selection of the element base and components for the synthesis of MMPM are determined as follows:

$$c_{1CCj} = \begin{cases} 0, & if \quad C_{1CCj} < C_{z1CC} \\ 1, & if \quad C_{1CCj} \ge C_{z1CC} \end{cases}, \tag{2}$$

$$q_{1j} = \begin{cases} 0, & if \quad Q_{1j} < Q_z \\ 1, & if \quad Q_{1j} \ge Q_z \end{cases}, \tag{3}$$

$$d_{1CCj} = \begin{cases} 0, & if \quad D_{1CCj} < D_{z1CC} \\ 1, & if \quad D_{1CCj} \ge D_{z1CC} \end{cases}, \tag{4}$$

$$f_{1CCj} = \begin{cases} 0, & if \quad F_{1CCj} > F_{z1CC} \\ 1, & if \quad F_{1CCj} \le F_{z1CC} \end{cases}, \tag{5}$$

$$p_{1CCj} = \begin{cases} 0, & if \quad P_{1CCj} > P_{z1CC} \\ 1, & if \quad P_{1CCj} \le P_{z1CC} \end{cases}, \quad (6)$$

$$h_{1CCj} = \begin{cases} 0, & if \quad H_{1CCj} < H_{z1CC} \\ 1, & if \quad H_{1CCj} \ge H_{z1CC} \end{cases}, \quad (7)$$

$$b_{1CCj} = \begin{cases} 0, & if \quad B_{1CCj} < B_{z1CC} \\ 1, & if \quad B_{1CCj} \ge B_{z1CC} \end{cases}, \quad (8)$$

$$f_{PBj} = \begin{cases} 0, & if \quad F_{PBj} > F_{zPB} \\ 1, & if \quad F_{PBj} \le F_{zPB} \end{cases}, \quad (9)$$

$$v_{PBj} = \begin{cases} 0, & if \quad V_{PBj} < V_{zPB} \\ 1, & if \quad V_{PBj} \ge V_{zPB} \end{cases}, \quad (10)$$

$$f_{Oj} = \begin{cases} 0, & if \quad F_{Oj} < F_{zO} \\ 1, & if \quad F_{Oj} \ge F_{zO} \end{cases}, \quad (11)$$

$$p_{PBj} = \begin{cases} 0, & if \quad P_{PB} > P_{zPB} \\ 1, & if \quad P_{PB} \le P_{zPB} \end{cases}, \quad (12)$$

$$m_{PBj} = \begin{cases} 0, & if \quad M_{PBj} > M_{zPB} \\ 1, & if \quad M_{PBj} \le M_{zPB} \end{cases}, \quad (13)$$

$$s_{PBj} = \begin{cases} 0, & if \quad S_{PBj} > S_{zPB} \\ 1, & if \quad S_{PBj} \le S_{zPB} \end{cases}, \quad (14)$$

$$t_{maxMMPMj} = \begin{cases} 0, & if \quad t_{maxMMPMj} > t_{maxzMMPM} \\ 1, & if \quad t_{maxMMPMj} \le t_{maxzMMPM} \end{cases}, \quad (15)$$

$$t_{minMMPMj} = \begin{cases} 0, & if \quad t_{minMMPMj} > t_{minzMMPM} \\ 1, & if \quad t_{minMMPMj} \le t_{minzMMPM} \end{cases}, \quad (16)$$

$$m_{MMPMj} = \begin{cases} 0, & if \quad M_{MMPMj} > M_{zMMPM} \\ 1, & if \quad M_{MMPMj} \le M_{zMMPM} \end{cases}, \quad (17)$$

$$s_{MMPMj} = \begin{cases} 0, & if \quad S_{MMPMj} > S_{zMMPM} \\ 1, & if \quad S_{MMPMj} \le S_{zMMPM} \end{cases}, \quad (18)$$

$$k_{MMPMj} = \begin{cases} 0, & if \quad K_{MMPMj} < K_{zMMPM} \\ 1, & if \quad K_{MMPMj} \ge K_{zMMPM} \end{cases}, \quad (19)$$

$$h_{MMPMj} = \begin{cases} 0, & if \quad H_{MMPMj} < H_{zMMPM} \\ 1, & if \quad H_{MMPMj} \ge H_{zMMPM} \end{cases}, \quad (20)$$

$$c_{MMPMj} = \begin{cases} 0, & if \quad C_{MMPMj} > C_{zMMPM} \\ 1, & if \quad C_{MMPMj} \le C_{zMMPM} \end{cases}, \quad (21)$$

where C_{z1CC}, Q_{z1}, D_{z1CC}, F_{z1CC}, P_{z1CC}, H_{z1CC}, R_{z1CC}, B_{z1CC}, F_{z1PB}, V_{z1PB}, F_{z1O}, P_{z1PB}, M_{z1PB}, S_{z1PB}, $t_{maxzMMPM}$, $t_{minzMMPM}$, M_{zMMPM}, S_{zMMPM}, K_{zMMPMj} H_{zMMPM}, C_{zMMPM} – parameters specified in the terms of reference: performance, memory capacity, bit depth of the computing component, clock speed of the components, power consumption of components, reliability of components, interfaces of components, tools for the development of components, operating frequency range of the RMM, accuracy of measurement of the RMM, frequency of updating information in the RMM, power consumption power of the MMPM, mass of the MMPM, dimensions RMM, maximum operating temperature of the MMPM, minimum operating temperature of the MMPM, weight of the MMPM, dimensions of the MMPM, resistance of the MMPM to special factors, reliability and cost of the MMPM.

The selection of a set of variants of the element base and components that can be used for the synthesis of the DSOM is carried out using the criteria given in Table 2 according to the following formulas:

$$W_{DSOM} = \{W_{DSOMj}, 1 \le j \le N\}, W_{DSOMj} \ne 0,$$

$$W_{DSOMj} = c_{2CCj} \times q_{2CCj} \times d_{2CCj} \times f_{2CCj} \times$$
$$\times p_{2CCj} \times h_{2CCj} \times r_{2CCj} \times b_{2CCj} \times z_{GPSj} \times l_{GPSj} \times$$
$$\times f_{OGPSj} \times r_{GPSj} \times p_{GPSj} \times m_{GPSj} \times$$
$$\times s_{DSOMj} \times k_{DSOMj} \times c_{DSOMj},$$
$$p_{2CCj} \times h_{2CCj} \times r_{2CCj} \times b_{2CCj} \times z_{GPSj} \times$$
$$\times l_{GPSj} \times f_{OGPSj} \times r_{GPSj} \times p_{GPSj} \times m_{GPSj} \times$$
$$\times s_{GPSj} \times t_{maxDSOMj} \times t_{minDSOMj} \times$$
$$\times m_{DSOMj} \times s_{DSOMj} \times k_{DSOMj} \times c_{DSOMj}, \quad (22)$$

where W_{DSOMj} is the *j*-th variant of the element base and components for the synthesis of the DSOM, N is the number of variants of the element base and components, c_{2CCj}, q_{2j}, d_{2CCj}, f_{2CCj}, p_{2CCj}, h_{2CCj}, r_{2CCj}, b_{2CCj}, z_{GPSj}, l_{GPSj}, f_{OGPSj}, r_{GPSj}, p_{GPSj}, m_{GPSj}, s_{GPSj}, $t_{maxDSOMj}$, $t_{minDSOMj}$, m_{DSOMj}, s_{DSOMj}, k_{DSOMj}, c_{DSOMj} – threshold coefficients of the *j*-th element base and components, respectively, in terms of performance, memory capacity, bit depth of the computing component, clock speed of the components, power consumption of the components, reliability of the components, interfaces of the components, tools for the development of the components, sensitivity of the GPS receiver, accuracy GPS positioning, GPS information update frequency, GPS power consumption, GPS weight, GPS dimensions, maximum operating temperature of the DSOM, minimum operating temperature of the DSOM, weight of the DSOM, dimensions of the DSOM, resistance of the DSOM to special factors, reliability and cost of the DSOM.

The values of the threshold coefficients for the selection of the element base and components for the synthesis of the DSOM are determined in the same way as the determination of the threshold coefficients for the selection of the element base and computational components for the synthesis of the DSOM.

At the fourth stage of selecting the element base and components for the synthesis of MMPMs and DSOMs, we determine the value of the weight coefficients w_i for the partial selection criteria. The value of the weight coefficients is determined by the importance of the criterion for the functioning of MMPMs and DSOMs. When determining the weight coefficients, it must be taken into account that the sum of all weight coefficients must be equal to one $\sum_{i=1}^{n} w_i = 1$, where n – the number of partial criteria. Determination of weight coefficients is carried out by an expert survey. In the process of synthesizing MMPMs and DSOMs, the method of assigning points or the ranking method is often used.

At the fifth stage of the selection of the element base and components for the synthesis of the MMPMs and DSOMs, the normalization of partial selection criteria is performed. In the process of normalization, all partial selection criteria are reduced to a dimensionless form. For useful partial criteria (the more, the better), which include performance, bit depth, clock speed, external interfaces, reliability, memory capacity, accuracy, refresh rate, normalization is performed by dividing the value of the partial criterion by its maximum value. For cost indicators (the less, the better), which include weight, dimensions, energy consumption, and cost, normalization is performed by dividing the minimum value by the value of the partial criterion. Normalization of useful partial criteria for the selection of the element base and components for the synthesis of MMPM is carried out according to the following formulas:

$$C_{n1CCj} = \frac{C_{1CCj}}{C_{max\,1CC}}, \quad (23)$$

$$Q_{n1j} = \frac{Q_{1j}}{Q_{max\,1}}, \quad (24)$$

$$D_{n1CCj} = \frac{D_{1CCj}}{D_{max\,1CC}}, \quad (25)$$

$$F_{n1CCj} = \frac{F_{1CCj}}{F_{max\,1CC}}, \quad (26)$$

$$H_{n1CCj} = \frac{H_{1CCj}}{H_{max\,1CC}}, \quad (27)$$

$$R_{n1CCj} = \frac{R_{1CCj}}{R_{max\,1CC}}, \quad (28)$$

$$B_{n1CCj} = \frac{B_{1CCj}}{B_{max\,1CC}}, \quad (29)$$

$$F_{nPBj} = \frac{F_{PBj}}{F_{max\,PB}}, \quad (30)$$

$$V_{nPBj} = \frac{V_{PBj}}{V_{max\,PB}}, \quad (31)$$

$$F_{nOj} = \frac{F_{Oj}}{F_{max\,O}}, \quad (32)$$

Normalization of costly partial criteria for the selection of the element base and components for the synthesis of MMPM is carried out according to the following formulas:

$$\mathrm{P}_{n1CCj} = \frac{\mathrm{P}_{min\,1CC}}{\mathrm{P}_{1CCj}}, \quad (33)$$

$$M_{nPBj} = \frac{M_{min\,PB}}{M_{PBj}}, \quad (34)$$

$$S_{nPBj} = \frac{S_{min\,PB}}{S_{PBj}}, \quad (35)$$

$$M_{nMMPMj} = \frac{M_{min\,MMPM}}{M_{MMPMj}}, \quad (36)$$

$$S_{nMMPMj} = \frac{S_{min\,MMPM}}{S_{MMPMj}}, \quad (36)$$

$$C_{nMMPMj} = \frac{C_{min\,MMPM}}{C_{MMPMj}}. \quad (37)$$

Normalization of useful and costly partial criteria for the selection of the element base and components for the synthesis of the DSOM is carried out in the same way.

At the sixth stage of the selection of the element base, an integrated assessment of the effectiveness of MMPM and DSOM for synthesis on the *j-th* element base and components is calculated. The calculation of the integrated assessment of the efficiency of the MMPM for the *j-th* element base and components is performed according to the following formulas:

$$\begin{gathered} \mathrm{I}_{MMPMj} = \lambda_C C_{n1CCj} + \lambda_{Q1} Q_{n1j} + \lambda_{D1} D_{n1CCj} + \\ + \lambda_{F1} F_{n1CCj} + \lambda_H H_{n1CCj} + \lambda_R R_{n1CCj} + \\ + \lambda_B B_{n1CCj} + \lambda_{F2} F_{nPBj} + \lambda_V V_{nPBj} + \lambda_{P1} P_{n1CCj} + \\ + \lambda_{M1} M_{nPBj} + \lambda_{S1} H_{nPBj} + \lambda_M M_{nMMPMj} + \\ + \lambda_S S_{nMMPMj} + \lambda_C C_{nMMPMj}. \quad (38) \end{gathered}$$

The calculation of the integrated assessment of the efficiency of the DSOM for the *j-th* element base and components is performed in the same way.

At the seventh stage of selection, a variant of the element base and components is determined, on the basis of which MMPMs and DSOMs will be synthesized. From the set of options for the element base and components that meet the requirements of the terms of reference, the element base is selected, the integrated assessment of the effectiveness of which is the largest $I_{MMPMj}max$ and $\mathrm{I}_{DSOMj}max$.

Discussion of the results obtained. The analysis of the problems of creating onboard means for measuring motion parameters and determining the spatial orientation of mobile robotic platforms requires solving the problem of choosing the appropriate element base and components for such implementation. The basic structure of means for measuring movement parameters and determining the spatial orientation of mobile robotic platforms, which are intended for use in conditions of incompleteness of information and interference, has been proposed.

The main components for the creation of these means of measuring motion parameters and determining spatial orientation are the primary set of navigation sensors, the radar meter of motion parameters of the MRP, and the GPS/GNSS module.

Further processing is carried out by the module for analysis and recovery of lost navigation data, the module for neural network improvement of the accuracy of measuring parameters of the MRP movement, and the module for neural network improvement of the accuracy of determining the geographical coordinates of the MRP. Additional components of onboard facilities are a module for neural network forecasting of geographical coordinates and route of movement of the MRP, and a module for collecting and storing navigation data.

The main criteria for the selection of the element base and computing components are defined: performance of computing components, memory capacity, power consumption, frequency of information updates, communication interfaces, measurement accuracy, cost, weight, dimensions, temperature range, reliability, resistance to special factors, etc. These criteria sufficiently characterize the existing element base, have an unambiguous interpretation, and are focused on the implementation of onboard radio-electronic means of measuring movement parameters and determining spatial orientation, taking into account the requirements of the specified operational indicators.

The existing element base and available navigation components for the implementation of means for measuring motion parameters and determining the spatial orientation of the MRP have been analyzed. To implement intelligent means of processing data from radar motion meters, inertial navigation components, and GPS modules, it is advisable to use neurochips, digital signal processing processors, systems on a chip, microcontrollers, and FPGAs.

It is advisable to use the method of minimax normalization to normalize partial criteria for the selection of the element base and navigation components, and to calculate the integrated assessment of the efficiency of using the element base – the additive model and normalized partial selection criteria. With the use of a normalized additive model with the maximum value of the integrated efficiency assessment, the method of selecting the element base and computational components for the implementation of onboard radio-electronic means of measuring motion parameters and determining spatial orientation has been improved, which ensures taking into account the requirements of the terms of reference and the selection of the most effective element base and components from the set of available ones.

The scientific novelty of the obtained research results is that the method of selecting the element base and components for the implementation of onboard radio-electronic means of measuring motion parameters and determining spatial orientation has been improved, which uses a normalized additive model with the maximum value of the integrated efficiency assessment and thus provides the choice of the element base and components that most fully meet the requirements of the terms of reference.

The practical significance of the research results is the use of the proposed criteria for the selection of the element base and components, the normalization of useful partial criteria and the standardization of cost indicators, as a result ensures the selection of the most effective for the implementation of onboard radio-electronic means of measuring motion parameters and means of determining spatial orientation.

Conclusions

The structure of means for measuring motion parameters and determining the spatial orientation of MRP, which will provide accurate measurement and forecasting of motion parameters and spatial coordinates, is designed to function in conditions of incompleteness of information and interference.

It has been determined that the main components on the basis of which the tools for measuring the parameters of motion and determining the spatial orientation of the MRP in conditions of incompleteness of information and interference are synthesized, are a set of navigation sensors, a radar meter for the movement parameters of the MRP, a GPS module, a module for analysis and recovery of lost navigation data, a module for neural network improvement of the accuracy of measuring the parameters of the MRP movement, a module for neural network improvement of the accuracy of determining the geographical coordinates of the MRP, a module for neural network forecasting of geographical coordinates and route of movement of the MRP, a module for collecting and storing navigation data.

The main criteria for selecting the element base and components (performance of computing components, memory capacity, power consumption, information update frequency, communication interfaces, measurement accuracy, cost, weight, dimensions, temperature range, reliability, resistance to special factors, etc.) have been selected, which characterize it quite fully, have an unambiguous interpretation and are focused on the implementation of onboard radio-electronic means of measuring motion parameters and determining spatial orientation with high technical and operational indicators.

It is proposed to normalize useful partial criteria (the more, the better), which include performance, bit depth, clock speed, external interfaces, reliability, memory capacity, accuracy, refresh rate, by dividing the value of the partial criterion by its maximum value.

It is proposed to normalize cost indicators (the less, the better), which include weight, dimensions, energy consumption, and cost, by dividing the minimum value by the value of the partial criterion.

It is shown that the implementation of intelligent means of processing data from radar motion parameter meters, inertial navigation components, and GPS modules requires the use of neurochips, digital signal processing processors, systems on a chip, microcontrollers, and FPGAs.

An additive model and normalized partial criteria for the selection of the element base and components for calculating an integrated assessment of the effectiveness of the implementation of onboard radio-electronic means of measuring movement parameters and determining spatial orientation are selected.

The method of selecting the element base and components for the implementation of onboard radio-electronic means of measuring motion parameters and determining spatial orientation has been improved, which, due to the use of a normalized additive model with the maximum value of the integrated efficiency assessment, provides the choice of the most effective element base and components that meet the requirements of the terms of reference.

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ВИБІР ЕЛЕМЕНТНОЇ БАЗИ ТА КОМПОНЕНТІВ ДЛЯ РЕАЛІЗАЦІЇ БОРТОВИХ ЗАСОБІВ ВИМІРЮВАННЯ ПАРАМЕТРІВ РУХУ І ВИЗНАЧЕННЯ ПРОСТОРОВОЇ ОРІЄНТАЦІЇ МОБІЛЬНИХ РОБОТОТЕХНІЧНИХ ПЛАТФОРМ

Розроблено структуру засобів вимірювання параметрів руху і визначення просторової орієнтації мобільних робототехнічних платформ (МРП) для використання в умовах неповноти інформації та дії завад. Визначено компоненти, на основі яких створюють засоби вимірювання параметрів руху і визначення просторової орієнтації МРП: набір навігаційних давачів; радіолокаційний вимірювач параметрів руху МРП; модуль GPS; модуль аналізу та відновлення втрачених навігаційних даних; модуль нейромережевого підвищення точності вимірювання параметрів руху МРП; модуль нейромережевого підвищення точності визначення географічних координат МРП; модуль нейромережевого прогнозування географічних координат і маршруту руху МРП; модуль збирання та збереження навігаційних даних. Визначено, що продуктивність обчислювальних компонентів, обсяг пам’яті, потужність енергоспоживання, частота оновлення інформації, інтерфейси зв’язку, точність вимірювання, вартість, маса, габарити, температурний діапазон, надійність, стійкість до спецфакторів тощо є основними критеріями, за якими здійснюють вибір елементної бази та компонентів. Показано, що ці критерії достатньо повно характеризують елементну базу, їх трактування однозначне і вони орієнтовані на реалізацію бортових радіоелектронних засобів вимірювання параметрів руху і визначення просторової орієнтації із високими експлуатаційними показниками. Проаналізовано наявну елементну базу та навігаційні компоненти, які використовують для реалізації засобів вимірювання параметрів руху і визначення просторової орієнтації МРП. Показано, що для реалізації інтелектуальних засобів опрацювання даних із радіолокаційних вимірювачів параметрів руху, компонентів інерціальної навігації та GPS модулів необхідно використовувати нейрочипи, процесори цифрової обробки сигналів, системи на кристалі, мікроконтролери та FPGA. Запропоновано виконувати нормування часткових критеріїв вибору елементної бази та навігаційних компонентів за методом мінімаксного нормування. Для обчислення інтегрованої оцінки ефективності використання елементної бази вибрано адитивну модель та нормовані часткові критерії вибору. Вдосконалено метод вибору елементної бази та компонентів для реалізації бортових радіоелектронних засобів вимірювання параметрів руху і визначення просторової орієнтації, який за рахунок використання нормованої адитивної моделі з максимальним значенням інтегрованої оцінки ефективності забезпечує вибір найефективнішої елементної бази та компонентів, які відповідають вимогам технічного завдання.

Ключові слова: нормована адитивна модель, метод порогових коефіцієнтів, навігаційні давачі, радіолокаційний вимірювач, параметри руху, точність вимірювання.

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