Development of mobile aircraft control system model with additive technologies

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Abstract. The article describes the parameter evaluation of mobile spacecraft control systems and identifies their main advantages in comparison with stationary assets. The model and the mobile spacecraft control system mock-up using additive technologies were developed with existing methods for prototyping complex technical systems. This model performs experimental operations of the prototype of the mobile control system, accompanies the spacecraft in the area of its radio visibility, simulates the implementation of technological cycles of spacecraft control, evaluates the parameters of the target equipment, analyzes the characteristics of the antenna system and the layout, conducts experiments and eliminates abnormal situations. It also optimizes the spacecraft testing based on the use of artificial intelligence techniques.

1. Importance

The analysis of the programs for the development of space systems, as well as the launches of payloads into nearspace for 2019-2021, allows us to draw conclusions about the miniaturization of the space assets used and the prospects for the transition of solving problems in space and from space to small spacecraft [1]. At the moment, unmanned aerial vehicles are rapidly developing in various fields of human activity [2]. Technological progress creates prerequisites to increase the traffic on existing controls [3] and to create high-tech new tools that provide spacecraft with solutions to their intended tasks.

At the same time, there is a need to optimize the experimental method of the performance of target tasks by spacecraft and to increase the efficiency of their control.
Spacecraft control is a complex technological process that consists of interconnected, but time-distributed control operations to spacecraft perform tasks in accordance with its purpose. A ground segment provides control of spacecraft. The analysis of its characteristics allows us to conclude that mobile assets have a number of advantages over stationary means [4, 5], namely: mobility, a wider radio visibility zone due to rapid changes in location, operational planning of information exchange with the spacecraft, the ability to locate the systems in areas with difficult terrain.

However, developing a mobile spacecraft control system is difficult and expensive. At the same time, the antenna control system, task control or tracking equipment can be upgraded, the parameters and characteristics of itself movement or the coordinates of the location of the means can change depending on the changing terrain.

One of the options for developing modern control systems is to develop its model – small size representation of an object [6].

2. Model development
Prototyping is the process of creating a prototype of any object [7]. This method corrects errors made at the design stage, works out algorithms and eliminates errors in sophisticated technical systems, tests the use of various technologies in the develop and operation of systems, etc. Initially, prototyping was carried out using the methods of milling, forging, turning, etc. But in the 80s, scientists developed a different approach, which consists in the layer-by-layer formation of the object [8-11]. It is this technology that has formed the basis of modern additive manufacturing.

Additive manufacturing over the past 20 years have formed a rapidly developing innovative segment of mechanical engineering technology: significant practical results have been achieved, a global market for technologies, equipment and services has been formed, a wide front of research and development works has been deployed, training of qualified personnel has begun, scientific and educational literature has appeared [12, 13].

The progress in the development of additive manufacturing has contributed to the production of many useful things for everyday life, human health and safety [14].

In order to create a prototype of a mobile aircraft control system, research was conducted to evaluate the existing characteristics of such systems.

Based on the analysis of methods for creating various types of prototypes and the identified features of mobile spacecraft control systems, a model was developed.

3. Model development of mobile spacecraft control system
Modeling is based on the mathematical theory of similarity, according to which absolute similarity can take place only when one object is replaced by another, exactly the same [15].

Absolute similarity is impossible to achieve, when modeling sophisticated technical systems. The main goal of the simulation is to create a model that accurately represents the functioning of the simulated system.

Based on the conducted research, a model of a mobile spacecraft control system was developed, which consists of mobile and permanent modules (figures 1).

Permanent module consists of the following components:

- Personal computer with specially designed software, planning and conducting experimental method of its control and tracking, control of changes in the antenna and mobile module position, as well as the ability to connect libraries of task equipment.
- Subsystems interface unit.
- Communications subsystem that provide information exchange between modules.

Mobile module consists of the following components:
• Task equipment subsystem, which allows to work out technological cycles of spacecraft control, to measure trajectory parameters of motion, to receive data from telemetry system depending on the task of experimental methods to control the spacecraft and its systems depending on the equipment installed on the mobile module of the model.

• Antenna pointing subsystem, which uses engines to change the antenna model position in azimuth and elevation, depending on the parameters coming from the permanent module.

• Mobile module control subsystem, which allows you to change its location depending on the control data from the personal computer with specially designed software.

• Navigation subsystem, which determines the current location of the mobile module based on GLONASS and GPS navigation signals and transmits the coordinates to the permanent module via the communications subsystem.

• Communications subsystem that provide information exchange between permanent and mobile modules.

![Figure 1. Structure diagram of a mobile spacecraft control system model.](image1)

4. Development of specially designed software for spacecraft control system

Special software was developed for the control of the system, the interface of which is shown in figure 2.

![Figure 2. Interface of the special software.](image2)
The special software consists of the following components:

- in the upper part of the graphical interface, there is a service control unit for the program;
- in the middle part – blocks for displaying changes in the positions of the satellite point of the spacecraft and the mobile module on the world map (left), as well as the current angles of change in the azimuth and the elevation of the antenna position (top right and bottom right, respectively);
- in the lower part of the graphical interface of the program window, there are blocks for entering data for the initial position of the model with the display of its current coordinates (on the right) and entering the initial conditions for the antenna position (on the left).

The service control unit of the program consists of the following buttons:

- the "Menu" button, which is intended for saving and loading the initial data of experimental method of spacecraft control, printing reports and completing the program;
- the "Choose spacecraft" button, which allows you to open a list of spacecraft for modeling motion, conducting experimental method of their control, editing the values of the orbit parameters;
- the "Settings" button, which allows you to manage the general settings of the program, adjust the parameters of the interface subsystem with the PC, test the main subsystems of the mobile module, adjust the antenna, enter the control and information processing modules of the target equipment, change and adjust the initial data of the experimental method;
- the "Simulation" button, which starts and stops the experimental method of the spacecraft control, depending on the initial data.

In the data input blocks of the model initial position and the initial conditions of the antenna position, it is possible to manually enter the initial parameters. After pressing the "Set" buttons, the mobile module and the antenna move to the set values. After reaching the required values, the corresponding indicators light up in green.

The "Model actual parameters" block receives coordinate values from the navigation subsystem of the model mobile module.

In the antenna control unit "Present position", the values are calculated based on the change in the position of the antenna relative to the zero positions of the antenna obtained during the adjustment.

5. Model development of mobile module

Additive manufacturing was used to create elements of the mobile module. It is the development of products on a 3D printer based on a virtual model [16]. This process is considered innovative and contrasted with traditional methods of industrial production [17]. Creating a model involves a number of steps:

- product modeling using computer-aided-design (CAD) systems that fully describe their geometric shape and dimensions of the external surface;
- convert virtual 3D models to files for processing by a 3D printer;
- uploading files from a PC to a 3D printer and processing them in a printing machine;
- setting up 3D printer printing;
- manufacturing a model on a 3D printer;
- removing a model from a 3D printer;
- processing (post-processing) of the surface of the resulting model [18].

Virtual models of all the elements were created in special software for solid-state modeling to produce the details of the mobile control system model [19].
The virtual model of the airframe antenna is shown in figure 3. The airframe was designed taking into account the placement of radio-electronic elements of the task equipment and antenna control subsystems and the engine for changing the position of the antenna in azimuth [20].

To fix the antenna reflector and change its position by the elevation, a frame was designed, the virtual model of which is shown in figure 4. A feature of the design of the frame was the requirements for minimizing its mass and ensuring the retention of the antenna reflector at various angles [21].

Additional parts were designed to attach the antenna reflector to the frame. A virtual model designed in CAD for attaching the antenna feeder to the antenna reflector is shown in figure 5.

A virtual model of mounting the antenna reflector to the frame is shown in figure 6.

![Figure 3. Airframe antenna model.](image)

![Figure 4. Antenna stand.](image)

![Figure 5. Attaching antenna feeder to antenna reflector.](image)

![Figure 6. Attaching antenna to frame.](image)

The design of the platform for mounting the frame was carried out taking into account the placement of the radio-electronic equipment of the mobile module [22] (the list of elements is shown in figure 1).
At the same time, the features of attaching the platform to the existing mobile platform on wheels were taken into account. A virtual three-dimensional model of the mobile module platform is shown in figure 7.

After developing all the elements of the mobile module, files in the Stereo Lithography format (STL files) were generated in CAD, which allow describing the external closed surfaces of the created product models for calculating the printing of layers based on the application of additive manufacturing.

Then all the resulting STL files were uploaded to the 3D printer, where the positioning and orientation of the printing elements was performed.

Also, before starting the manufacture of each element, the 3D printer was configured, during which the thickness of the printing layer, the limits of the use of materials and other parameters necessary for the manufacture of products were set.

![Figure 7. A virtual three-dimensional model of the mobile module platform.](image)

After printing each model element, they were removed from the printer and further processed, since after printing, technological surfaces and irregularities remained on the products that needed to be removed.

Then all the parts were assembled into a model in accordance with the assembly drawing developed at the design stage. The appearance of the mobile module model is shown in figures 8-9.

![Figure 8. Mobile module model (side).](image)  
![Figure 9. Mobile module model (front).](image)
6. The functioning method of spacecraft mobile control complex model and its experimental method

To control the antenna and the mobile module, information about the initial parameters is entered into special software by entering data or from program database [23].

Then the program sends data via the RS-485 interface to the interface unit of the device and the PC based on the microcontroller. The interface unit converts the data and transmits it to the communication module via the SPI bus. The communication module uses GFSK modulation at 2.4 Hz to transmit the initial parameters to the mobile module [24]. Communication takes place at a speed of up to 2Mbps over a distance of up to 2 km in the line of sight.

The communication module in the mobile module receives data and transmits the received information to the model and antenna control subsystems via the SPI (Serial Peripheral Interface) bus.

After receiving the control commands, the antenna control subsystem generates control signals that are fed to the drivers for controlling the stepper motors [25]. The electrical signals received from the drivers are transmitted to the motors, which, using the developed mechanisms, rotate the antenna to a assigned elevation and azimuth. At the end of the antenna rotation, a signal is issued, which is transmitted back to the PC via the communication modules and the interface unit.

If the control subsystem of the mobile module receives commands to move, the controller sends signals to the collector motor for moving the mobile module and the steering wheel rotation servo in accordance with the route calculated for the PC. At the same time, the speed of movement and the smoothness of rotation of the layout are constantly adjusted.

Data on the present position of the mobile module is determined in the navigation equipment by GLONASS/GPS signals and transmitted through the communication module and the interface device to special software on the PC.

Also, to control the spacecraft, an automated calculation of the optimal location of the mobile module or a group of them is provided with the determination of the initial antenna conditions based on the use of intelligent algorithms that, depending on the position, the model and environmental factors, form and transmit control signals to the mobile module.

To evaluate the performance and confirm the characteristics of the model, an experiment was conducted.

The current position parameters of the mobile module were obtained.

The conditions for the location of the mobile module, the position of the antenna and the spacecraft were set with the on-screen buttons of the program (figure 10).

![Simulation of spacecraft control](image)

**Figure 10. Simulation of spacecraft control**
After issuing commands from the PC, the mobile module reached the coordinates specified in the program with an error of about one meter, after which it began to change the antenna positions along the route of the spacecraft with an error in azimuth and the elevation of about 0.3 degrees. After the end of the spacecraft visibility zone, the mobile module and the antenna took their initial positions.

7. Conclusion
Thus, a model was developed based on the use of additive manufacturing. The mobile control system model consists of a mobile module and special software.

The development of the elements of the mobile module model was carried out using CAD, printing parts – using a 3D printer.

The developed special software was used to simulate the flight of the spacecraft, process data on the current location of the mobile module of the model and control it.

Depending on the flight parameters (altitude, orbital inclination) and the location of the antenna, special software was used to change the position (correction) of both the mobile module and the antenna in azimuth and elevation. At the same time, the antenna provided spacecraft tracking with a sufficiently high accuracy to confirm the technical requirements for mobile spacecraft control systems, as well as in the future to conduct experiments to evaluate the functioning of the task equipment for transmitting and receiving information between the model and the spacecraft.

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