ABSTRACT

Dissertation for the degree of Doctor of Philosophy (PhD)
on speciality 6D071900 - "Radio engineering electronics and telecommunication"

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DESIGN OF AN ONBOARD CONTROL SYSTEM FOR THE NANOSATELLITE ORIENTATION SYSTEM BASED ON FPGA

Relevance dissertation. With advances in component miniaturization technologies and performance, new horizons are opening up for the development of nanosatellites with a wide range of capabilities. These missions include communication, earth observation, scientific research and many others. In this paper, the efficient design of an on-board control system for nanosatellite attitude control system based on FPGA becomes an integral part of successful mission realization.

In this field-programmable gate array (FPGA) in the on-board control system becomes a key element to provide high flexibility and performance. The FPGA in the on-board control system facilitates the implementation of complex orientation control algorithms.

Its high computing power and energy efficiency are especially valuable for resource-constrained nanosatellites. Even with limited computational resources, the FPGA in the BCU can effectively implement real-time control algorithms, ensuring stable orientation of the nanosatellite.

A distinctive feature of nanosatellites is their compact size and low mass compared to traditional satellites. This helps to minimize the cost of launching them. Optimal attitude control maximizes the use of sensors and control mechanisms, which in turn contributes to further cost reductions. Based on the above, the topic of research aimed at the development, modelling and analysis of the nanosatellite orientation control system based on FPGA in the on-board control system becomes highly relevant.

The aim of the research is to develop a new algorithm programmer for the orientation system of the on-board nanosatellite control complex (OBC).

The idea of the work is to improve the efficiency of the guidance system and reduce the cost of its development and operation, making such systems affordable and attractive for nanosatellite space missions.

Research Objectives:

In accordance with the objective, the thesis formulates the following tasks:

1. Development of a mathematical model of nanosatellite orientation system using sunlight and magnetic pointers.

2. Modelling and investigation of nanosatellite with trend dynamics of the mathematical model proposed orientation system.

3. Experimental verification of its operation based on the methodology of synthesis and simulation modelling of the on-board control complex based on the board.

The main statements put forward for defense are:

1. Mathematical model of nanosatellite orientation based on the combined method reflecting the dynamics of the orientation system.

2. Modelling of the nanosatellite orientation system in VTS, Matlab programs using the developed mathematical model.

3. Laboratory model of on-board control system using Arduino, Quartus Prime to test and verify the operation of the orientation system.

The main results of the study are:

1. A mathematical model of nanosatellite orientation system using solar and magnetic readings was constructed.

2. The nanosatellite dynamics of the mathematical model proposed orientation system was modelled and investigated.

3. Its operation was experimentally verified and the results obtained were processed based on the synthesis and simulation modelling methodology of the on-board control complex based on board.

The objects of research are on-board control complex of nanosatellite.

The subject of research are methods and systems for determining the orientation of nanosatellites based on data obtained from solar and magnetic sensors, as well as simulation modelling of on-board control complexes based on FPGA to verify the proposed techniques.

Methodological basis of scientific research.

When performing scientific research for the processing of experimental data and feasibility study of various technology options, methods of complex analysis, including analysis and generalization of scientific and technical information, theoretical research, methods of mathematical modelling, methods of mathematical statistics, correlation and regression analysis in the creation of software modules, as well as methods of empirical and object-oriented programming were used.

Novelty of the topic

1.To develop and investigate the algorithm for determining the direction of an almanac satellite by solar and magnetic readings using a combined method.2.To present the laboratory model of the on-board control complex with the software and mathematical algorithm. The practical significance of the work lies in the improvement of navigation and orientation, t. The developed method allows nanosatellites to determine their orientation with high accuracy using data from solar and magnetic sensors, which reduces risks and saves money on space missions. By using quaternions and acquiring data from different sensors, it improves accuracy and reliability even in case of possible errors and noise. Also, the developed method can be implemented in various control and navigation systems of nanosatellites, which creates conditions for the development of the space industry as a whole.

Publications and approbation of the work. The main points of the thesis work at the 28th IEEE International Conference on Electronics, Circuits and Systems (ICECS) (Dubai, UAE 2021), International Scientific and Practical Conference "Journal of Engineering Science and Technology Review, Special Issue on Telecommunications, Informatics, Energy and Management 2019" (Kavala, Greece 2019), at the International Scientific and Practical Conference International Society for Technology, Education, and Science, Paper presented at the International Conference on Education in Mathematics, Science and Technology (ICEMST) (Antalya, Turkey, Apr 1-4, 2021) and at the XI International Scientific and Technical Conference "Energy, Info-communication Technologies and Higher Education" (Almaty, NAO "AUES", 2020).

On the subject of the dissertation 9 printed works have been published. Of them one work was published in the journal included in the 1st quartile, according to the database Scopus (Scopus), one work - in the journal included in the 3rd quartile, according to the database Scopus (Scopus), three works - in the journal recommended by CCSON MES RK, four works - in the conference materials. Doctoral student made a worthy contribution to each published article. They reflect the thoughts put forward for defense, the results obtained by the doctoral student in the course of research.

The scope and structure of the work. The dissertation consists of an introduction, three chapters, conclusion, list of used sources and appendices. The volume of the dissertation is the list of references, including 129 pages of typewritten text, 19 tables, 71 figures, 46 titles and 1 appendix.

Main content of the work.

The work consists of five chapters.

In Chapter I a complete analysis and synthesis of nanosatellites in CubeSat design is made. The motion of aerodynamically stabilized nanosatellites is investigated. The peculiarities of nanosatellite tendency in low orbits are due to both atmospheric effects and their mass and inertia characteristics. To date, nanosatellite launches have been analyzed. The following was found: Compared to larger satellites with higher mass, nanosatellites have shorter lifetimes and the angular acceleration generated by aerodynamic momentum is much higher. The main features of nanosatellite as a product are discussed.

In Chapter II, a mathematical model of the nanosatellite orientation determination system based on sunlight and magnetic indicators is developed. The mathematical model of passive orientation of the nanosatellite as well as the orbit model is described in detail.

Chapter III discusses the use of hardware and software reconfigurable architecture based on Arduino MKR Vidor 4000 SoC field-programmable gate array (FPGA) in the context of space nanosatellites. A strategically important solution that combines logic programming flexibility with processing power and integration into a single device is described, enabling efficient alignment of data processing with efficiency and reliability requirements in the space environment.

Furthermore, the results of an experiment evaluating the efficiency of different types of solar panels when using a solar tracker on different days are presented. Finally, the architecture of the on-board nanosatellite control system is discussed, describing the main components and principles of the proposed architecture.

Chapter IV details the architecture of the on-board nanosatellite control complex, which is a key element in the construction and operation of spacecraft. The chapter is divided into several parts, including an overview of the on-board complex algorithm, a description of the main components and principles, and a detailed study of the orbital motion modelling and analysis process.

Chapter V provides a detailed description of the architecture of the nanosatellite attitude control system, including the connection to the sensor and integration with the microcontroller. The main components of the system, such as solar panels, magnetometer and SD card for data storage, are described, and the powering of the device and electronic circuit design are discussed. The chapter ends by presenting the results of laboratory experiments conducted to validate the nanosatellite attitude control system.

The conclusion presents the obtained results and conclusions of the thesis research, and reflects the plans for further work in the chosen direction.