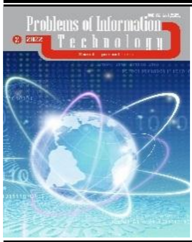

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ALGORITHM DESIGN NANOSATELLITE BASED ON RADIO FREQUENCY AND OPTICAL COMMUNICATION

Mehman H. Hasanov [a], **Nadir A. Atayev** [b]

[a,b] Azerbaijan Technical University

[a] mhasanovnew@gmail.com; [b] nadir.atayev@mail.ru

[a] 0000-0001-5536-9401; [b] 0000-0002-5335-1053

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ABSTRACT

The Nano-Satellite and its component CubeSat platforms, with their technical functionality, are an important part of the scientific, commercial, and military application of the space sector. It is important to conduct research and development processes to improve communication and information exchange subsystems based on existing subsystems in order to meet the main technical aspects of CubeSat platforms. While the radio frequency (RF) communication, which is widely used in existing CubeSat satellite platforms, tries to transmit the daily increasing amount of information through the high-frequency band, challenges such as existing license fragmentation, sources of atmospheric obstruction, and the energy and size requirements of the transmitter and receiver systems hinder this process. As a solution, the application of optical communication (OC) networks, which are widely used in terrestrial systems, in space can be shown. The OC systems used in CubeSat satellite platforms are investigated along the topic developed in this regard, and the operating software algorithms of Nano Satellite subsystems with laser beam control and active transponder system, which include the advantages of this technology, are studied.

1. Introduction

Revising the satellite platform statistics launched over the past decade, we can see that Nano Satellite space systems are in high demand compared to other small and mostly large satellite platforms. Briefly, when we say Nano Satellite platforms, we mean any satellites from 1 kg to 10 kg and size 1U (Unit) 10x10x11cm. CubeSat satellites are considered to be the most diverse group of them (Hasanov & Atayev, 2022).

The following main factors can be attributed to the high-trend design of CubeSat platforms (NASA, 2017):

- Compared to other satellite platforms, costs such as ordering, transportation, design, and launch of internal components are very low;
- Due to the launch of CubeSats mainly in low Earth orbit (LEO), the ability to operate off-the-shelf subsystem components (COTS) instead of very expensive components that are resistant to specific space environment obstacle sources;
- Low degree of difficulty due to preparation on the basis of standardized (U) structure, etc.

In terms of availability and technical functionality, CubeSat platforms, which are mainly used in low earth orbit (LEO), are already being widely used in high-speed and high-volume data exchange missions. However, with the existing traditional radio frequency (RF) communication method, there are difficulties in achieving this (Gibalina & Fadeev, 2017). Optical or laser communication (OC), RF overcomes the mentioned disadvantages by its: a) high data cost, b) ultra-small inter-channel interference, c) better signal-to-noise ratio, d) overall lower power requirement, e) effective protection, taking into account the difficulty of crossing and blocking narrow light rays, and f) being effective for future technological development for quantum communication systems (Muhire et al., 2020).

One of the widely used application fields of optical communication technology is to send large volumes of data received from geostationary (GEO) observation satellites to the ground segment (GS) with low earth orbit (LEO) OC CubeSat satellites using the data-relay/transponder principle (Haughwout et al., 2016). In addition, it is possible to ensure high volume and directional data flow through OC CubeSat platforms arranged according to the radial-node principle around low earth orbit, similar to terrestrial wire communication networks (Kaushal & Kaddoum, 2017).

An example of this can be seen in the same output of strong communication directions in two different directions with the RF and OC technologies of the space segment presented in Table 1 (Toyoshima, 2010).

Along with the advantages mentioned in Table 1 and above about CubeSat platforms with OC technology, there are some disadvantages/shortcomings (Gurgaon, 2017).

Table 1. Practical output power comparison of RF and OC

Contact example	Data volume	Frequency bands		
		Optic	Ka frequency band	Millimeter frequency band
GEO-LEO	2.5 Gb/s			
Antenna diameter		10.2 sm	2.2 m	1.9 m
Weight		65.3 kq	152.8 kq	131.9 kq
Power		93.8 W	213.9 W	184.7 W
LEO-LEO	2.5 Gb/s			
Antenna diameter		3.6 sm	0.8 m	0.7 m
Power		23.0 kq	55.6 kq	48.6 kq
Power		33.1W	77.8 W	68.1 W

The beam generated from OC is coherent and monochromatic, as well as microradian, in other words, it is difficult to direct it to the terrestrial receiving antenna due to the fact that the coverage area of the radiation is ~1600nm wavelength. This mainly leads to an increase in the accuracy of the positioning acquisition and tracking (MMI) subsystems in CubeSat platforms, thus increasing the parameters of the platform such as mass, size, and electrical power (Giggenbach et al., 2012).

2. Proposed Algoritm

Let's take a look at the algorithmic structures of the management programs of the four main subsystems of the initial conceptual model, which is considered effective in solving the MMI difficulties arising on CubeSat platforms with OR technology, hybrid, in other words, combining the advantages of RR and OR technologies (Carrasco-Casado & Mata-Calvo, 2020).

1) Structure of laser beam control and transponder payload subsystem

One of the two modulation principles of CubeSat platforms with OR technology is based on on-off keying (OOK), controlling the constantly produced photon flow by a discrete signal generator connected to it, with the presence of a "1" bit data optical pulse, and the absence of a "0" bit data optical pulse.

The other pulse per minute (PPM) modulation is defined by $M = 2^n$, and n is calculated as the number of bits in one symbol, and the duration of the symbol T_s is divided by the number L in the time interval (Giggenbach et al., 2012).

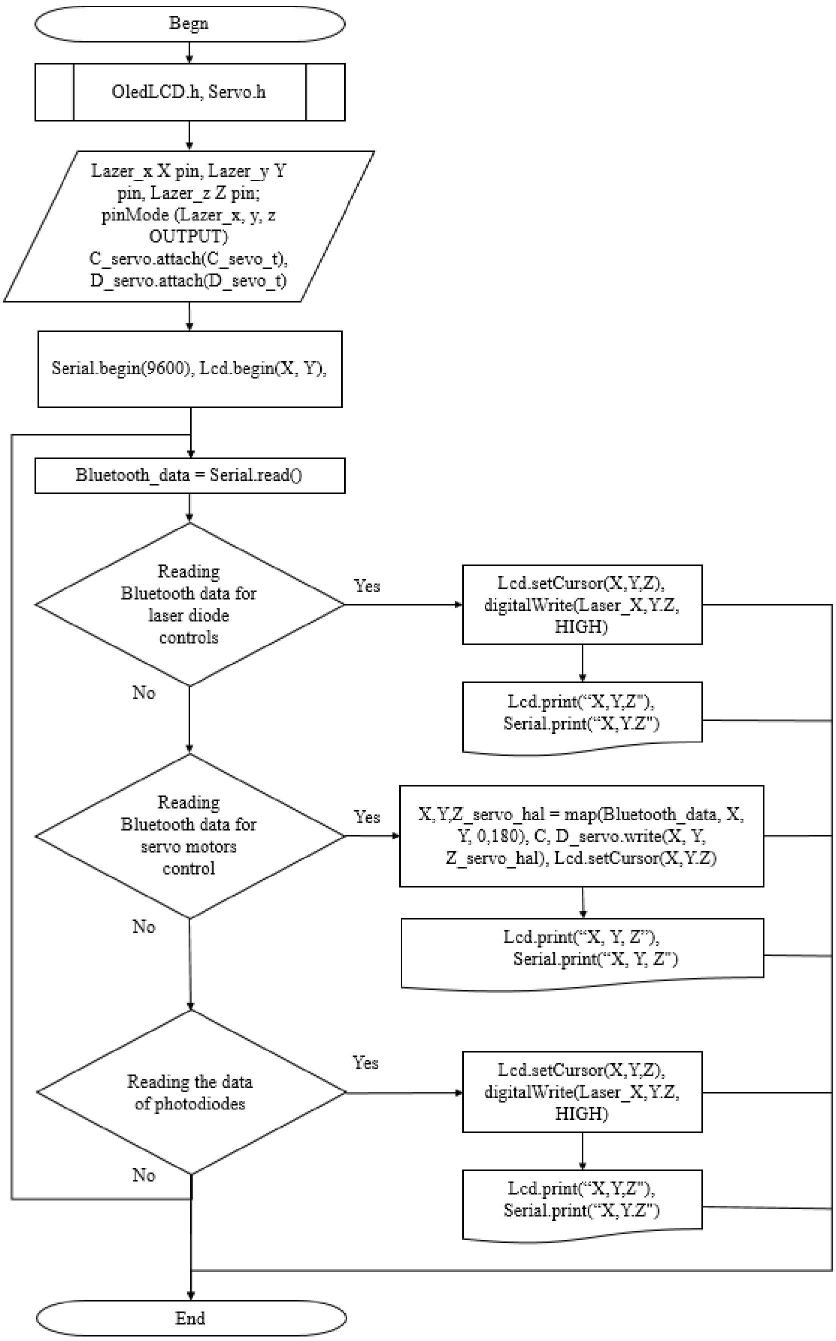

Fig. 1. The algorithm of laser beam control and transponder payload subsystem.

Calculating the communication budget of the OC system is one of the other main stages and is calculated by the following expression (Giggenbach et al., 2020):

$$P_r = P_t \tau_t G_t L_{fs} G_r \tau_r \tau_{rp} \tag{1}$$

Here $P_r(W)$ is the received optical power, $P_t(W)$ is the transmitted optical power, τ_t is the optical loss at the transmitter, G_t is the antenna gain in transmission, L_{fs} is the free space loss, G_r is the gain of the antenna in reception, τ_r is the optical loss in reception and τ_{rp} is the loss in direction to the receiver (Giggenbach et al., 2020):

$$G_t = \frac{16}{\theta_{div}^2} \tag{2}$$

$$L_{fs} = \left(\frac{\lambda}{4\pi z}\right)^2 \tag{3}$$

$$G_r = \left(\frac{2\pi R_x}{\lambda}\right)^2 \tag{4}$$

In the algorithm of the laser beam controller and transponder for the OC given in Figure 1, the necessary software libraries are first included; the physical interfaces of different control components to the microcontroller (MCU) are defined; the data in the serial communication is read and the corresponding control of servo motors with laser diodes and microactuators is started to ensure data radiation and control along the X, Y and Z axes of the system. In the other part, to ensure full-duplex optical communication of the CubeSat platform with the GS, the incident OOK laser beam is processed, modulated by the X, Y, and Z-axis laser diodes, and sent back to the GS (Hasanov, 2019).

This subsystem, as the most important subsystem of the CubeSat platform, combines the new application direction of previous scientific and practical research (New Generation 3D Optical Switch). As a brief reminder, the researched 3D optical switch offered three main advantages compared to other existing optical switches for creating high-speed and efficient communication links in optical communication networks (Hasanov et al., 2021):

- Compact assembly of lenses, depending on the number of beam sources, with laser light sources located together or separately on the 360^0 rotating head (Laser communication in space, 2022);
- Many times the switching time of optical signals entering the semi-transparent mirror platform through two high-precision microactuators;
- The possibility of permanent control of the switchboard through the electronic control and measurement system integrated into the device and effective diagnosis of the problems arisen (Hasanov, 2020);

2) Structure of power harvesting, power, supply and controller.

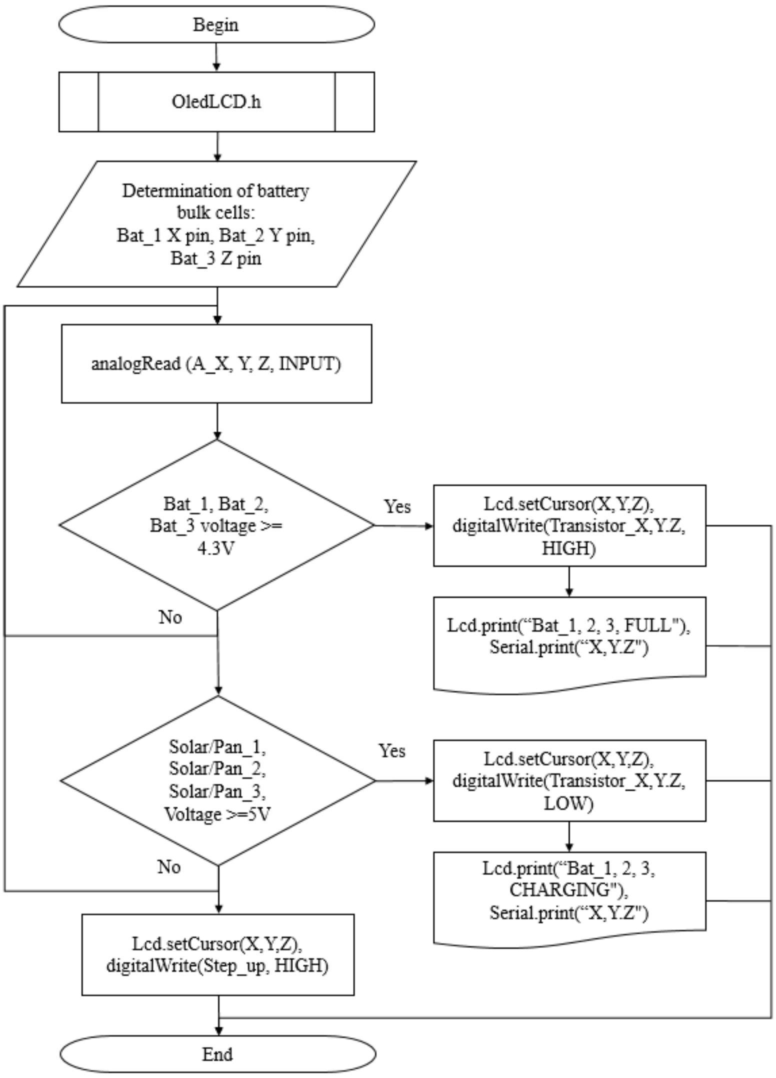

Fig. 2. The algorithm of power harvesting, power, supply and controller.

In Figure 2, the software algorithm of the subsystem providing electrical power to all systems of the CubeSat platform first includes the necessary software libraries; the connected battery pack is set to connect to the appropriate physical interface to be recognized by the MCU; the battery and solar panel voltage values are constantly read and processes such as battery charging, voltage increase/decrease are performed, and the data is printed on serial and LCD screens for monitoring through the central MCU (Muhire et al., 2020).

3) Structure of microcontroller-based on-board computer and position/environment determination system.

In Figure 3, the software algorithm, which includes a central MCU-based on-board computer for data processing and control of all subsystems of the CubeSat platform and another auxiliary MCU for position/environment determination, first adds a set of libraries for the corresponding software structure; input/output physical interfaces of necessary sensors/components are defined; starting to read data from the auxiliary RF module connected to the serial port, the important ones are printed on the LCD screen; the necessary data is collected from the MEMS sensor modules of the position/environment determination part, and the process of sending the GS through the RF and writing to the onboard SD card takes place (Joshi et al., 2017).

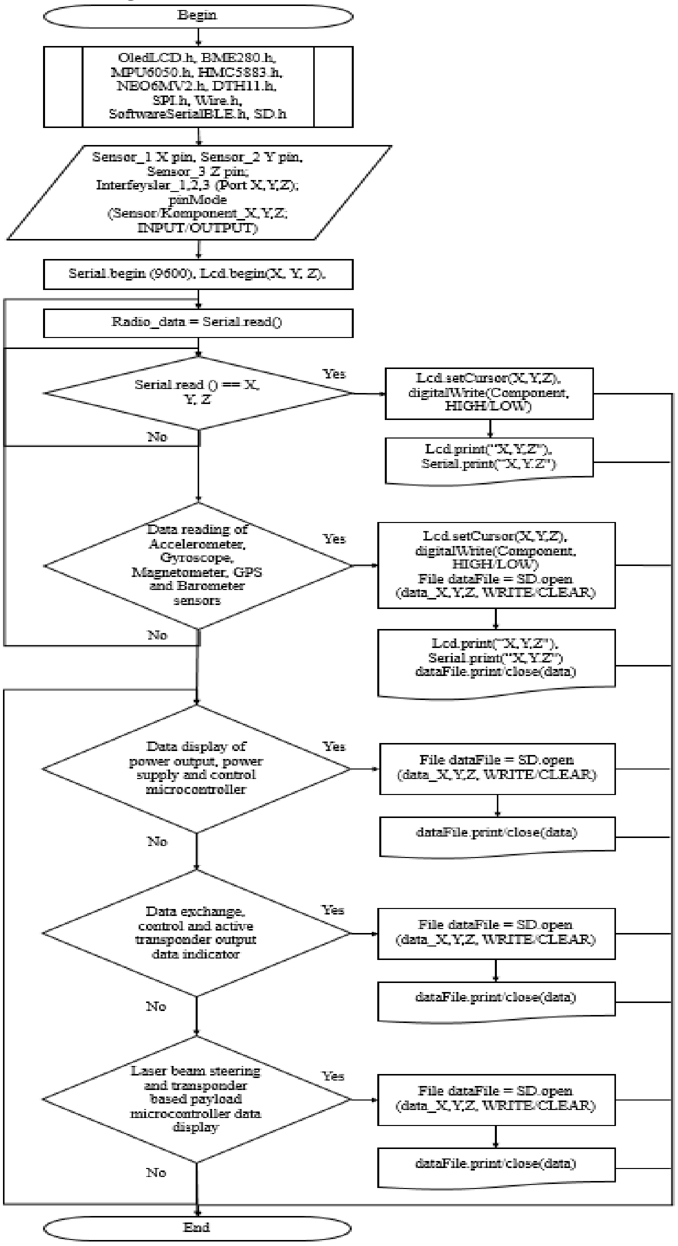

Fig. 3. The algorithm of microcontroller-based on-board computer and position/environment determination system.

The position/environment subsystem on the initial conceptual CubeSat platform performs only self-positioning with high accuracy through a 9-axis accelerometer, gyroscope, magnetometer, GPS, and barometer, capable of accurate and reliable GS transmission of the discussed laser radiation pulses with less technical demands. The aforementioned 1, 2, and 3, as well as SDR-based active RF transporter control MCU, send the data collected by the 3 MCU onboard computers via the "Software Serial" interface, providing data display on the corresponding serial outputs.

4) Data exchange, control, and active transponder structure.

Transceiver subsystems that include one or more RF parameters are widely used for data exchange on various satellite platforms. However, these systems cannot change their parameters only with software if necessary. As a solution, Software Defined Radio (SDR) platforms have been used for several years, for their low power requirement (1W-10W), wide frequency band support (50MHz-8GHz), wide sampling frequency range (32MHz-56MHz), and most importantly, traditional RF physical components in the systems (mixer, modem, codec, filter, etc.) are controlled by software from the FPGA controller, and their small size (0.3-1U) enables wide application in different satellites, mainly CubeSat platforms (Microwave and optical intersatellite links provide real-time command, control, communication, and information processing on battelfield, 2022).

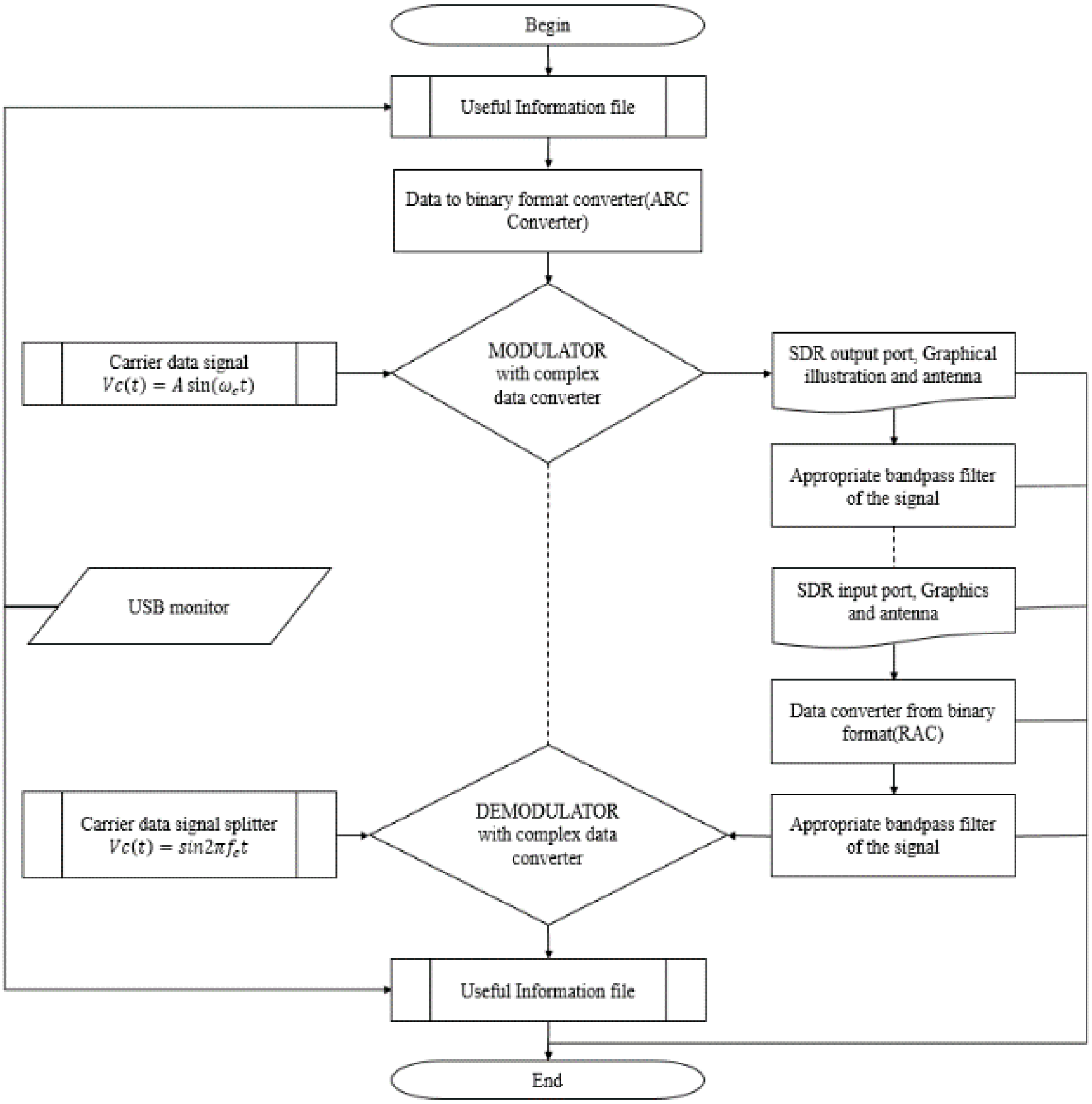

Fig. 4. The algorithm of data exchange, control, and active transponder

The application of SDR-based RF technology in the conceptual model of the CubeSat platform to be developed, the need for communication in the subsystem in addition to OC, the simultaneous high data processing of RR and OR systems when necessary, as well as the automatic tuning of RR-based mobile GS stations to the required frequency band, will allow the weak signal to be actively retransmitted.

One of the widely used modulation methods in RF technology on SDR-based CubeSat platforms is "binary code-based phase shift modulation" (BPSK) by performing transmission of "0" and "1" bit symbols with different carriers signal phases shifted by 180^0 from each other, in one-bit time, the transmitter unit is determined by the following correspondence (Joshi, 2017: p.3):

$$S(t) = Acos(2\pi f_c t) \text{ – for bit 1} \quad (3)$$

$$S(t) = Acos(2\pi f_c t + \pi) \text{ – for bit 0} \quad (4)$$

Here, $t - 0 \leq t \leq T$, and f_c stands for carrier frequency.

Figure 4 is the algorithm of the SDR-based RF subsystem, which will be integrated in addition to the OR technology on the CubeSat platform. First, the low-frequency f(x) data is formed by the RR; the information is modulated by a complex converter and a high-frequency F(x) signal for preparation for transmission; information is extracted from the output SMA-antenna part of the SDR; the useful signal of the information in the input SMA-antenna receiver part of the SDR is separated from the carrier; in addition to the mentioned sequential processes of the algorithm, the USB interface and the computer with GS software ensure the continuity of the process, represent the relevant telemetric data numerically and graphically on the interface, as well as ensure that the information is written in the necessary file format during the process.

3. Conclusion

Along with the studied topic, four subsystems of the new generation CubeSat satellite platform, which include the advantages of the existing RF and OC communication technologies of the NanoSat satellite system, as well as laser beam control, transponder and SDR-based RF active transponder subsystems based on the previous research topic 3D optic switched OC, were theoretically researched and the improvement aspects of the OR technology were taken into account by algorithmically examining the important processes and the application of the whole system.

Based on the nanosatellite prototype model provided with the mentioned functionality, if the final flight nanosatellite (CubeSat) was developed and sent to low earth orbit (LEO, 1000km-2000km), it was possible to apply it in the mentioned areas:

- Provision of high-volume and fast full-optical beam data exchange between a set of nano-satellites located in one orbit and GS;
- Ensuring the retransmission of information from a low-power GS by performing the role of an active transponder of an orbiting nano-satellite.

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