Nanosatellite TUMnanoSat II for tracking and measure of the orbital parameters and decline

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***Abstract* — This paper reflects the development of the TUMnanoSat II nanosatellite at the TUM Space Technology Center with a special research and educational mission - determining the decline of nanosatellite orbit using the optical and GPS positioning method. This project is part of the nanosatellite launch program at the UNOOSA KiboCube International Orbit Station coordinated by JAXA, the Japanese Space Agency.**

***Index Terms* — nanosatellite, educational space missions, CubeSat, space technologies, nanosatellite's subsystem and structure.**

I. INTRODUCTION

The CubeSat Project began as a collaborative effort between California Polytechnic State University and Stanford University's Space Systems Development Laboratory (SSDL). The purpose of the project is to provide a standard for design of picosatellites to reduce cost and development time, increase accessibility to space, and sustain frequent launches. Presently, the CubeSat Project is an international collaboration of over 100 universities, high schools, and private firms developing picosatellites containing scientific, private, and government payloads. A CubeSat is a 10 cm cube with a mass of up to 1.33 kg. Developers benefit from the sharing of information. The primary mission of the CubeSat Program was to provide access to space for small payloads [1-4].

The Centre of Excellence for Space Sciences and Technologies, NCST of TUM, has been established by a consortium of Technical University of Moldova, academic institutions and some high-tech SMEs in order to take advantage of the benefits of space technologies and applications in Earth observation, meteorology and astrophysics. The goal of the NCST of TUM is to exclude the lack of scientists, engineers and technicians on the area of space research and development by dissemination of experiences in the space domain to contribute building of long-term partnerships between peoples from different Europe countries to run sustainable outreach activities which can act as catalysers, motivating pupils and students at different ages and education levels [5, 6].

The RTD activities of NCST of TUM are focused on medium resolution interactive remote sensing and formation flying missions by involving in these projects a most of students at different ages and education levels. These goals are supported by the concurrent development of micro and nano-satellite platforms an advanced ground control infrastructure and satellite integration facilities as well as a multidisciplinary laboratories for developing and testing of satellite systems and components in simulated space environments. This Center provides the students, early career engineers and enthusiasts with educational resources on many aspects of Space Engineering. We actively work to increase usability of educational resources. From these guidelines, the TUM Space Center has aligned this standard with its goal of creating a nanoscale family that could deliver a variety of spatial education and research missions.

II. TUMNANOSAT II'S EDUCATIONAL SPACE MISSIONS

The reason for the small mass of these satellites was mainly due to the limited payload capabilities of the launch vehicles. All satellites were simple satellites and once the launch vehicles became capable of launching larger satellites, satellites became larger and more advanced as well. It is plausible to think that in the decades to follow there was no apparent need for simple satellites like in the first years of space flight. Advanced satellite technology was too big to integrate in a very small satellite. However, in the late nineties this changed due to the availability of low power microelectronics, providing a potential for a high performance over mass ratio. More than half of the pico-and nanosatellites were built with an educational objective: university-class satellite projects. Out of a total amount of 118 university - class satellites, 49 are pico-and nanosatellites [1-4].

The NCST of TUM was created to promote space technology labs for students from many specialties from the Technical University of Moldova. Then it was done for other universities, colleges and high schools as a common center with the following structure: Development Laboratory satellite components; Laboratory simulation and testing of the satellite attitude; Excellence Information Technologies and Communications Center; Laboratory data processing and satellite images; two telemetry ground stations for satellites communication; Main ground station for satellite images receiving; two astronomical observatory [5].

III. TUMNANOSAT II MISSION AND PAYLOAD

NCST of TUM designs a family of nanosatellite called "TUMnanoSAT" in accordance with international CubeSat standard. These nanosatellite missions are to check under real conditions the functionality of various modules and subsystems of the satellite. Nano-satellite "TUMnanoSAT II" is representative of this range. The basic missions of these satellites are:

- to establish effective communication subsystem "satellite-ground station" with the possibility to modify the communication rate range and ensure high reliability;
- to check the communication protocol "satellite-ground station" with different levels of access;
- testing of solar power supply system and the search for the optimal modes of accumulated energy distribution;
- testing of sensors subsystem for satellite attitude determining (magnetometers, micro-gyroscopes, sun sensors) in order to optimize process control satellite attitude;
- endurance testing of the CSOTI electronic components operation in conditions of radiation.

The mission of the proposed for this project CubeSat ”TUMnanoSAT II” is ”optical communication” by the LED and GPS between satellite and network of ground stations, equipped by RF telemetry and telescopes to tracking, measuring satellite speed and its orbital parameters to identify its decline. It can be commanded via network of ground stations using telemetry radio-frequencies. These network of ground stations and astronomical observatories will be taken to schools around the students to have their direct interaction with a satellite [5].

The payload of the CubeSat ”TUMnanoSAT II” for mission realization contains the following components [10]:

1. Power LEDs type CXM-32-65-70-54-AC30-F4-3 with key for switching current include power ttransistor STripFET F7 technology STL135N8F7AG STMicroelectronics for generating of high lumen light impulses for satellite tracking with telescopes.
2. GPS satellite module type piNAV-NG, that will tracking and measure satellite speed and its orbital parameters for determination of the decline. The piNAV-NG is the Next Generation of Ultra Low Power Space-Friendly CubeSat GPS L1 receiver specially designed to provide continuous accurate position determination onboard small satellites in LEO or high altitude balloon missions with limited power and mass budgets.
3. Attitude determination equipment, including the MPU-9150, that combines two chips: the MPU-6050, which contains a 3-axis gyroscope, 3-axis accelerometer, and an onboard Digital Motion Processor™ (DMP™) capable of processing complex Motion Fusion algorithms and the AK8975, a 3-axis digital compass. The part’s integrated 6-axis Motion Fusion algorithms access all internal sensors to gather a full set of sensor data.

IV. NANOSATELLITE TRACKING AND SPEED MEASUREMENT OF ITS ORBITAL PARAMETERS AND DECLINE

Determination of the microsatellite decline orbit idea is based on nanosatellite tracking by two fixed pointed modern computerized telescopes, watching satellite in accordance with TLE data and recalculate position by prediction method. Satellite tracking is performed simultaneously with the video recording of his store azimuth and elevation angles synchronized to the time zone of visibility (fig. ??). At this time, the satellite formed using power LEDs a set of light pulses with a duration of 0.1 sec to 0.75 sec. Being videotaped these of light pulses, they are used for synchronizing video and determination from both angles (azimuth and elevation) for both telescopes.

To use triangulation to determine satellite altitude in orbit, it is necessary to set the exact points of reference. In this case, the reference points will be the telescopes located in Chisinau and Cahul/Branza. With the reference points it measure their exact geographic coordinates: latitude, longitude and height to sea level, which will be used in the following calculations. From the geographic coordinates of T_1 and T_2 telescopes, it calculate the spherical coordinates, then move to Cartesian coordinates in 3 dimensions (with the origin in the center of the Earth), using the following transformation:

$$\begin{cases} x = r\cos\theta\sin\varphi \\ y = r\sin\theta\cos\varphi \\ z = r\cos\varphi \end{cases} \quad (1)$$

where θ is the longitude, φ is the complementary latitude angle, and r is the distance from the reference points to the center of the Earth. Distance ***r*** is calculated by the formula:

$$r = \sqrt{\frac{\left(a^4\cos^2\Phi + b^4\sin^2\Phi\right)}{\left(a^2\cos^2\Phi + b^2\sin^2\Phi\right)} + 2\left(Z + G\right)\sqrt{\left(a^2\cos^2\Phi + b^2\sin^2\Phi\right)} + \left(Z + G\right)^2} \quad (2)$$

where Φ is the latitude, Z is the height from the sea level, G, a and b are the height of the geoid, the large semi-axis and the small semi-axle respectively.

Telescopes located at the reference points are designed to capture satellite images at its orbit. Using an algorithm for image processing and positioning of the telescopes in the direction of the satellite, the horizontal coordinates of the satellite will be obtained from the planes π_1 and tangent to the ellipsoid in T_1 and T_2, respectively. For the convenience of determining spatial position of satellite will be used the third plane π, defined by T_1, T_2 and the vector $\vec{b} = \overrightarrow{T_1T_2} \times \overrightarrow{T_1O}$.

Let’s considering the angles $\alpha_1 = \measuredangle(\pi_1, \pi)$ and $\alpha_2 = \measuredangle(\pi_2, \pi)$. Knowing the horizontal coordinates (azimuth, elevation) of the satellite at both reference points, we can find the angles on the plane π after the formulas (depending on the quadrant):

$$\delta'_{az_1} = \mathrm{arctg}\frac{\sin\delta_{az_1}\cos\alpha_1}{\left|\cos\delta_{az_1}\right|}, \quad (3)$$

$$\gamma'_{el_1} = \gamma_{el_1} + \mathrm{arctg}(\mathrm{tg}\alpha_1\sin\delta'_{az_1}), \quad (4)$$

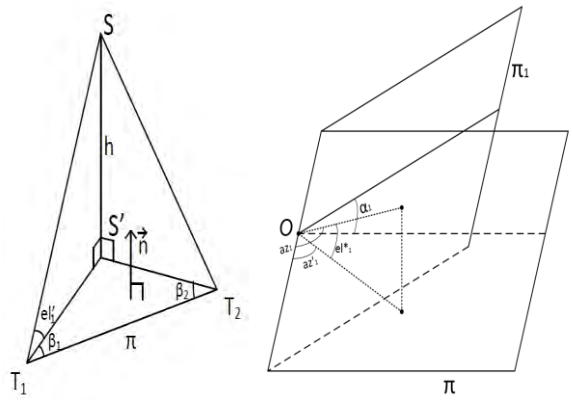
Where δ'_{az_1} is the azimuth on plane π, δ_{az_1} is the azimuth on plane π_1, α_1 is the angle between plane π and π_1, γ'_{el_1} is the plane elevation π, γ_{el_1} - the plane elevation on π_1.

Knowing the T_1, T_2 points and the horizontal coordinates relative to the π plane allows the calculation of satellite orbit altitude (H_S) by the following formula:

$$H_S = \left|\overrightarrow{OS}\right| - R, \quad (5)$$

where $\overrightarrow{OS}$ is the vector, the origin of which coincides with the origin of the coordinate system and the peak is with the position of the satellite in space which is equal to:

$$\overrightarrow{OS} = \overrightarrow{OT_1} + \overrightarrow{T_1S'} + \overrightarrow{S'S}. \quad (6)$$



a) b)

Figure 1. Satellite altitude determination schema by two fixed pointed modern computerized telescopes.

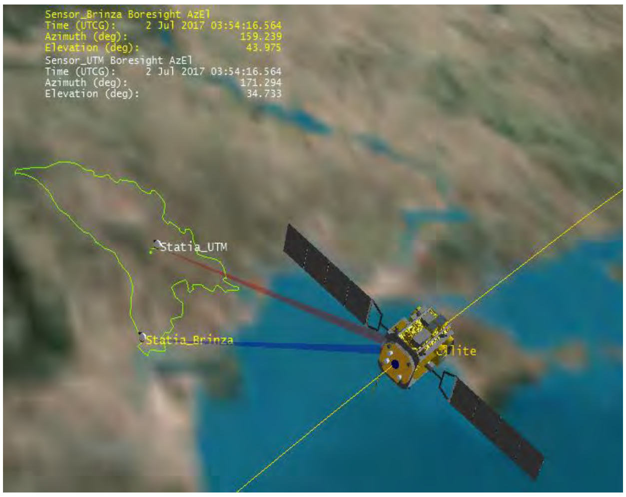


Figure 2. Satellite altitude determination simulation by two fixed observation point.

The points O, T_1, S and S' represent the origin of the coordinate system, the point of support, the position of the satellite and the projection of the position of the satellite on the respective plane, illustrated in fig. 1.

The vector $\overrightarrow{OT_1}$ is found from the knowledge of the T_1 support point coordinates, the coordinates $\overrightarrow{T_1S'}$ of the vector are the equation system solutions (7),

$$\begin{cases} \overrightarrow{T_1S'} \cdot \vec{n} = 0 \\ \cos\beta_1 = \dfrac{\overrightarrow{T_1S'} \cdot \overrightarrow{T_1T_2}}{\left|\overrightarrow{T_1S'}\right| \cdot \left|\overrightarrow{T_1T_2}\right|} \\ \cos(\dfrac{\pi}{2} - \beta_1) = \dfrac{\vec{t} \cdot \overrightarrow{T_1S'}}{\left|\vec{t}\right| \cdot \left|\overrightarrow{T_1S'}\right|} \\ \left|\overrightarrow{T_1S'}\right| = \dfrac{\left|\overrightarrow{T_1T_2}\right| \cdot \sin\beta_2}{\sin(\pi - \beta_1 - \beta_2)} \end{cases} \quad (7)$$

and the vector $\overrightarrow{S'S}$ is calculated by formula (8)

$$\overrightarrow{S'S} = \frac{\vec{n}}{\left|\vec{n}\right|} \frac{\left|\overrightarrow{T_1T_2}\right| \sin\beta_2 \operatorname{tg}\gamma'_{el_1}}{\sin(\pi - \beta_2 - \beta_1)}, \quad (8)$$

where $\vec{t} = \vec{n} \times \overrightarrow{T_1T_2}$ is the normal vector of the plane π, and β_1 and β_2 are the angles represented in fig. 1. Thus, applying the triangulation method, the altitude of the orbit is determined during the passage of the satellite through the range of the telescopes. Monitoring the orbit's altitude allows us to estimate the decline of satellite orbit.

Thus, applying the triangulation method over time, it can determine the degradation of the orbit. Then calculate the distance from the satellite to the origin of the coordinate system and the final result for a specific time is obtained. It should be mentioned that in a single pass the satellite will generate 20 to 25 sets of light pulses, so it will get a vector of values $H_i = \{h_1, h_2, ..., h_n\}$. Repeating this procedure for each passage in the visible area, will build a matrix of values, based on which will determine the evolution orbit altitude, so the decline satellite orbit. The procedure for determining the nanosatellite decline was verified by simulation.

In the AGI System Tool Kit environment, simulation of the nanosatellite transition into orbit was developed. Orbital data of the satellite was taken from the ISS station as reference data. To perform the triangulation in the simulation model it is added two telescopes, one located in the Technical University Park of Moldova and the other in the village of Branza. At the each passage of the satellite, the telescopes will be directed to track it. The targeting is done by an algorithm that receives the theoretical orbital data of the satellite and calculates the azimuth and elevation angles for the telescopes (fig.2).

V. "TUMNANOSAT II"DEPLOYMENT FROM THE INTERNATIONAL SPACE STATION (ISS) JAPANESE EXPERIMENT MODULE (KIBO) "KIBOCUBE"

KiboCUBE is the dedicated collaboration between UNOOSA and JAXA in utilizing the ISS Kibo for the world. KiboCUBE aims to provide educational or research institutions from developing countries of United Nations membership with opportunities to deploy, from the ISS Kibo, cube satellites (CubeSats) which they develop and manufacture. Currently, the only way to deploy CubeSats from the ISS is from Kibo. Kibo's unique capability is comprised of an airlock system and a robotic arm. The first orbital deployment of CubeSats from Kibo was successfully conducted in October 2012 through the Small Satellite Orbital Deployer developed by JAXA [11]. Since then, nano-satellites and CubeSats from various countries around the world have been deployed from Kibo. The deployment of CubeSats from ISS is easier than the direct deployment by a launch vehicle thanks to the lower vibration environment during launch. With this comparatively less demanding interface requirements, UNOOSA and JAXA believe that KiboCUBE will lower the threshold of space activities and will contribute to build national capacity in spacecraft engineering, design and construction (fig. 3).

TUMnanoSAT's nanosatellite family, according to CubeSat's international standard, has designed in the TUM National Space Technology Center. The mission of these nanosatellites is to verify in real terms the functionality of the various satellite modules and subsystems. Nanosatellite "TUMnanoSAT II" is a representative of this range. The mission of the proposed project, "TUMnanoSAT II" consists

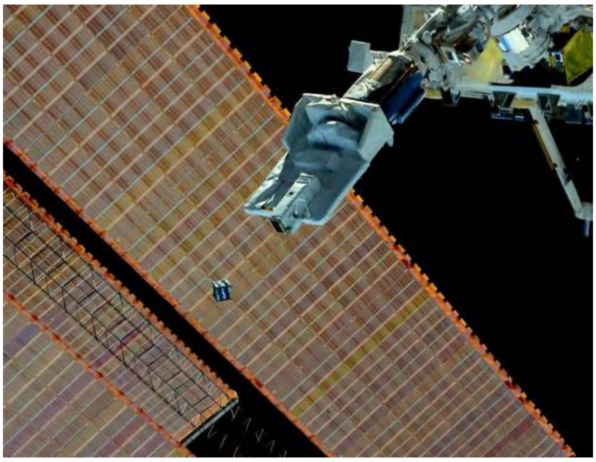


Figure 3. Deployment of a CubeSat from the ISS. Photo: NASA/JAXA [11]

Figure 4. "TUMnanoSAT II" nanosatellite altitude decline project proposal.

of the "optical" and radio communication between the satellite and the terrestrial network of telemetry and telescopes for tracking, measuring the satellite velocity and its orbital parameters to identify the satellite decline. The National Center for Spatial Technology Center presented the project "CubeSat "TUMnanoSat II" in the framework of the United Nations/Japan Cooperation Program on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module "KiboCUBE" for application to second round mission.

VI. CONCLUSION

The pico- and nanosatellites, especially CubeSats, have become popular in the past decade and the amount of developers and projects is increasing. They are not only built by universities but also larger space organizations like NASA, Boeing and the Aerospace Corporation. Technologies in the field of command and data handling and electrical power systems are quite advanced.

Besides educational objectives, which can easily be met if students are working on the projects, technology demonstration objectives are very attractive and successful. ”United Nations/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module "KiboCUBE"” between UNOOSA and JAXA in utilizing the ISS with KiboCUBE to provide educational and/or research institutions from developing countries of United Nations membership and also as Rep. Moldova open the opportunity to deploy the CubeSat ”TUMnanoSat II” developed and manufactured by students in the NCST [10, 12].

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