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GOLIAT SPACE MISSION: EARTH OBSERVATION AND NEAR EARTH ENVIRONMENT MONITORING USING NANOSATELLITES

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Abstract

The purpose of this paper is to present the concept of the GOLIAT space mission. The project's primary scientific goal is to validate the design and implementation of an advanced scientific payload, consisting of Earth observation and near space monitoring experiments, onboard a CubeSat type nanosatellite. Reaching this main scientific objective by obtaining useful data from onboard sensors will demonstrate that CubeSat missions can exceed their educational purpose and nanosatellites can be used in scientific missions with a significant decrease of costs. During the CubeSat GOLIAT development phase, a high integration factor was obtained by customizing COTS components and using in-house design for specific subsystems. In this way, a momentum wheels attitude control system was integrated together with tree scientific experiments including micrometeorites detection, total dose of radiation measurement and a high resolution camera integrated with a 6^0 solid angle lens mount. Starting from the GOLIAT CubeSat concept, a future more complex nanosatellite formation flying mission is scheduled for 2010.

CUBESAT STANDARD

CubeSats are a type of nanosatellites based on a cubic shape, measuring typically 100 x 100 x 100 millimeters and having a less than 1 kg mass. Originally developed by the Stanford University, and the California Polytechnic State University – CalPoly, the CubeSat Standard is currently being used by more than 100 educational and commercial institutions from all around the globe [1]. Due to the small size, CubeSats offer scientist a relatively low cost opportunity for developers to take their experiments to space using "*commercial off-the-shelf*" (COTS) components, and a chance for teachers to offer their students a complete space mission experience.

OVERVIEW OF THE GOLIAT PROJECT

Goliat is a single unit CubeSat type satellite developed by students from the University of Bucharest and the University Politehnica of Bucharest under the direct supervision of the Romanian Space Agency and the Romanian Institute for Space Sciences. The project also received support from industry in fields of radio communication, in-house testing, custom optics systems and micromechanics manufacturing.

The project's main goal is to obtain a multidisciplinary student team which, by the end of the project, shall be able to design integrate and operate a full nanosatellite mission.

From a scientific point of view, the Romanian CubeSat will integrate three experiments in LEO:

- Dose-N – determining the total dose of radiation using a PIN diode and a scintillating material
- SAMIS – micrometeorites detection in orbit using a Piezo impact sensor
- Ciclop – a 3MP digital camera equipped with a custom 57 mm focal length lens mount.

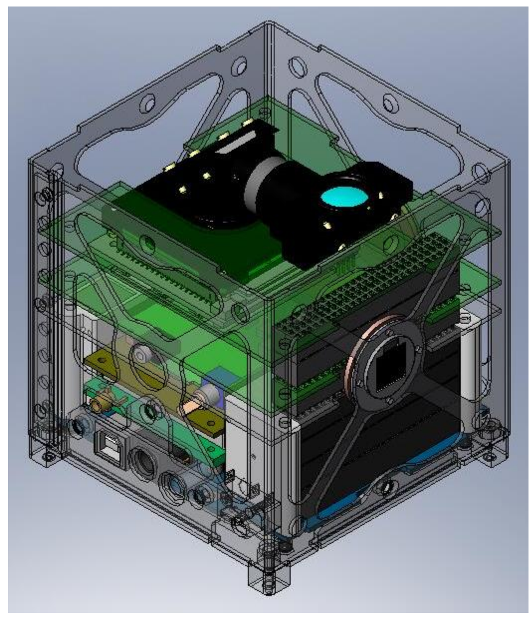

Fig. 1 The Goliat nanosatellite

Of equal scientific importance are the new solutions and technologies that Goliat will be testing: the low noise power supply, the attitude determination algorithm (GPS, magnetometer, TLE) and the attitude control system (reaction wheels).

SATELLITE BUS

The Goliat satellite is based on the Pumpkin CubeSat Kit, using the skeletonized version of the chassis and the MSP430 processor on the Flight MCU [2].

Communication System

A two transceiver architecture was chosen for the onboard communication system of the Goliat satellite: one to serve as a beacon (70 cm radio amateur band) and other as a data transmission module (2.4 GHz ISM band).
As a redundancy feature, the two communication modules will function independently and they will be commanded by two distinct processors: the data module will be commanded by the Flight MCU MSP430 processor, while the beacon will be controlled by a second MSP430 processor which handles the onboard experiments and the attitude determination and control system as well.

	Beacon	**Data module**
Transceiver	Radio amateur	Microhard MHX-2400
Frequency	437.485 MHz (IARU coordinated)	ISM 2.4 GHz spread spectrum
Projected data rate	1200 bps	up to 115 kbps
Projected Output Power	100 – 300 mW	up to 1 W
Protocol & modulation	AX.25 AFSK / FM CW	GFSK (private protocol)
Operation mode	Transmit mode only Receive mode as back-up	Transmit only when in line of sight of the ground station
Data type	Telemetry & identification	Data from the onboard experiments

Table 1 Specification table for the two onboard transceivers

Although, initially, the beacon is set only to transmit telemetry and identification data at specific time intervals, a redundancy protocol in the main software can enable the receiving of commands from the ground station trough this module and, eventually, all satellite data can be transmitted on this path, at the cost of the data rate.
The MHX-2400 transceiver is primarily set to transmit all data generated from the payload and detailed diagnosis data from various subsystems, while also receiving new commands and parameters from the ground station. Although the initial data rate for the this transceiver is set at 9600 bps at 1 W output power, depending on the link performance during operation an increase in data rate or even a decrease of the output power are being considered (data rates up to 115 kbps are possible).
Of extreme importance for the radio communications system are the two antennas and the deployment mechanisms required to be fitted on the satellite. If the 2.4 GHz, ~30 mm quarter wave monopole antenna can be fitted on either side of the satellite, a similar antenna in the 437 MHz band should measure ~160 mm, being considerably larger than the 100 mm length of the side of a CubeSat. A deployment mechanism was therefore developed to deploy the two folded antennas after the CubeSat is ejected from the P-POD.

Power Supply Unit

18 triple junction Ga/In/As 24% efficiency solar cells provide the necessary power for Goliat. Cells are serially connected two by two forming 9 pairs linked in parallel. Each pair is integrated with a diode in order to avoid short circuit. The average estimated power of 2W is stored in two packs of Li-Ion batteries.
A battery pack is formed by two serially connected 1000 mAh batteries charged using a dedicated Li-ion BQ2405 battery charger.

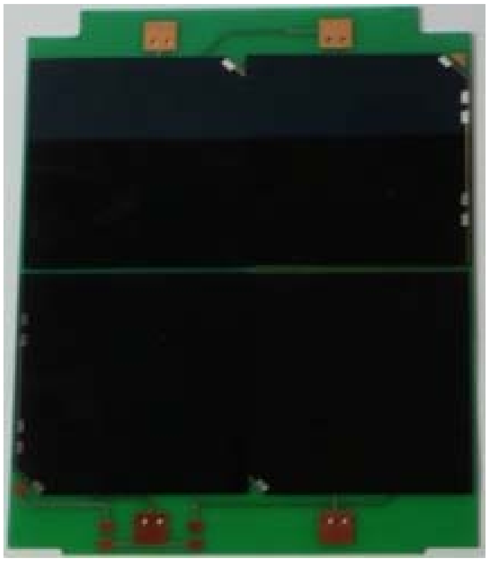

Fig. 2 Solar panel with 4 solar cells

The system is designed to work in a ping – pong mode: when a battery pack is directly charged by solar panels the other pack supplies the satellite with the necessary power. This architecture was designed in order to avoid the noise produced by the switching DC to DC converter to alter the experimental data measured by the micrometeorite detector. In case of battery failure a backup circuit was implemented in order to directly connect the power supply board to the solar cells.

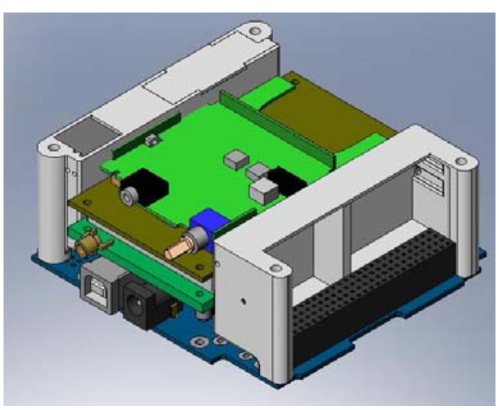

Fig. 3 Battery pack placement on the CubeSat Kit

The system is designed to avoid cable connection between solar panels and the power supply board.

Attitude Determination and Control System

Because the on-board payload represents a secondary objective of the project, a complex system for attitude determination and control is not vital for the functioning of the satellite. The concept of reliability (keep the system as simple as possible) and redundancy lead to choosing a simple attitude determination system, easy to use and integrate.

The attitude determination and control system (ADCS) is divided into two parts: the attitude determination system (ADS) and the attitude control system (ACS).

The first one is based on a 3-axis magnetometer and a GPS receiver. The GPS data (latitude, longitude, altitude) will be inserted in the IGRF database (International Geomagnetic Reference Field), and after several calculations the values of the magnetic intensity on the three axes will be obtained. This data will be compared with the ones provided by an onboard magnetometer (vector measurements at the same GPS position) and after this comparison two angles giving the orientation of the satellites will result: the declination angle (D), and the inclination angle (I).

The use of an *off the shelf* GPS receiver, led to the implementation of a a backup algorithm that computes the position of the satellite using the Keplerian elements of the orbit (two line elements – NORAD) uploaded from the ground station.

For the attitude control system, a two axes reaction wheels system has been chosen.

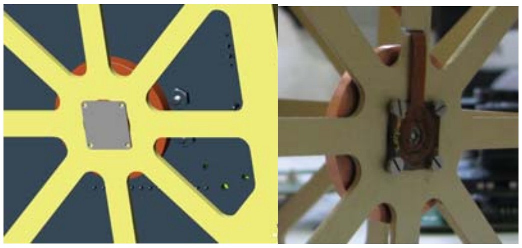

Fig. 4 Reaction wheels mounted on the mechanical structure. CAD model (left) and real model (right)

This system requires a high background level in the dynamics space field, the resulted data being very useful from an educational point of view.

Demonstrating the functionality of a closed loop feedback reaction controller will be a real success for a CubeSat, the telemetry data obtained by this subsystem being necessary for ulterior studies on space dynamics.

PAYLOAD

Three experiments are the scientific payload onboard Goliat: an imaging experiment, a micrometeorites flux determination and a total dose of radiation measurement.

CICLOP

The satellite's onboard photo camera is one of the in-house design subsystems. It consists of tree distinctive parts:

1. Camera sensor board CSB
2. Camera processor board CPB
3. Camera lens mount

The CSB and the CPB are commercial off-the-shelf parts developed by Devitech and satisfy the mass, volume and power restriction onboard Goliat. The CSB comes with a up to 3MP high resolution color sensor in the 4/3 image format (the sensor can be also set for a lower resolution).

Fig. 5 Sample image. Range: 9 Km; Exposure: 1/2500; IR filter: N/A

Integrating an 8 MB flash memory, the CPB is built on a powerful 600 MHz dual core, 64 MB RAM digital signal processor capable of real time JPEG compression and it is running a μClinux operating system.

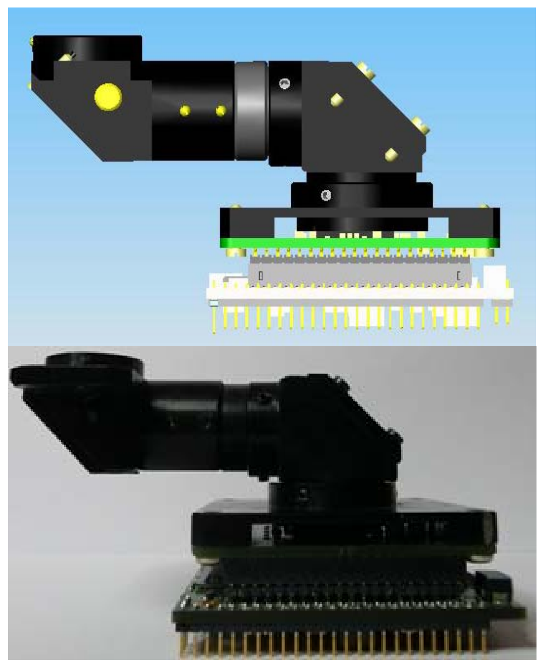

Fig. 6 The Goliat Camera. CAD view (top), real model (bottom)

The camera lens mount is an in house, custom made system. The periscope shape allows the achieving of a 6^o viewing angle. In this case, assuming a 600 Km orbit, a maximum ground resolution of 25 m/pixel can be obtained for a 3 MP digital image.

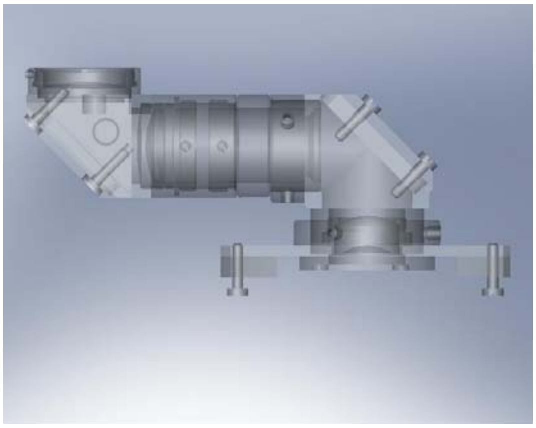

Fig. 7 CAD representation of the lens mount

SAMIS

SAMIS is the name of one of the experiments conducted on orbit by the Goliat satellite. Its main objective is to study micrometeorites using a highly sensible 50 x 37 mm piezo-film situated on the +Z face of the CubeSat. The 110 µm thick film serves as an impact sensor. Each collision of a micrometeorite with the sensible area will generate an electrical impulse proportional with the energy generated at the impact.

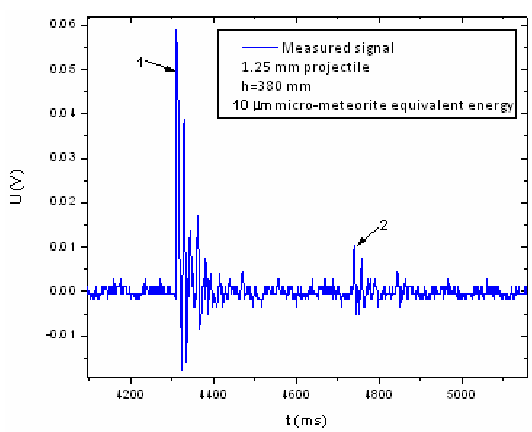

Fig. 8 Signal obtained by dropping a 1.25 mm sphere from 380 mm (energy equivalent of a 10 µm meteorite impact at 8 km/s); the second signal is generated by the bouncing of the projectile.

The generated signal first passes trough a charge amplifier and it is received at one of the ADC channels of the onboard computer, stored and transmitted to the ground operation center.

Unlike the other two experiments onboard Goliat, the measured data will be acquired continuously, but only signals above a certain threshold value shall be stored and relayed back to the ground station for further processing.

By studying the amplitude and the signal characteristics, an estimate of the micrometeorites flux shall be obtained for the satellite's specific orbit.

Prior to the space mission, measurements conducted in the Bucharest laboratory confirm detection for particles of energies equal with high velocity micrometeorites measuring 10 µm and less.

DOSE-N

Dose-N is the name of the total dose measurement experiment on the Goliat satellite. Total dose measurements will be stored at regular time intervals during the operation of the spacecraft in orbit, resulting in a full set of data for the specific orbit of Goliat.

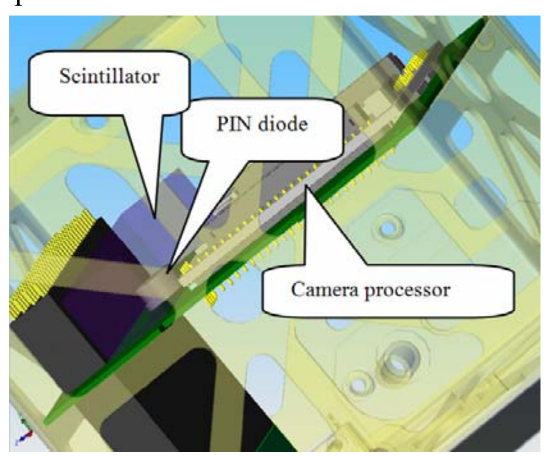

Fig. 9 Positioning of the detector inside the Goliat nanosatellite

As a sensor, a photo sensible PIN diode is used in conjunction with a solid state scintillator. The cosmic radiation interacting with the scintillator volume will generate photons with the wavelength in the sensible spectral domain of the diode. The electrical pulse generated by the diode will be proportional with the dose of radiation that produced it, and the proportionality coefficient is determined by calibrating the measurement chain with a known source of radiation.

The diode and the scintillator material are mounted on a PCB inside the satellite, near the magnetometer and the camera processor.

GROUND STATION

On the ground two radio stations were equipped for communicating with the satellite:

- A 437 MHz station at the University's of Bucharest Physics' Department, near Bucharest
- A 2.4 GHz station at a remote location in the Carpathian Mountains, near Cluj-Napoca, Romania

The 437 MHz Bucharest radio station is fully functional since February 2007 and numerous contacts have been made to operational CubeSat type satellites currently in orbit. Relevant tests for the Romanian CubeSat team happened during the first days after the 2007-014 and the 2008-021 CUBESAT launches when the Bucharest ground station actively participated in tracking, identifying and relaying received packages from the newly launched satellites to developing teams from Germany and Japan.

There were no opportunities to test the 2.4 GHz station because the satellites using the MHX-2400 are less numerous than those using ham protocols.

Currently, the University of Bucharest ground station is being equipped for 2.4 GHz operations as well and we expect it to be soon functional.. The use of two ground stations situated in distinct locations (several hundred kilometers apart) increases both the chance of an initial contact and the communication window with the Goliat satellite.

	The UHF Bucharest radio station	**2.4 GHz radio station**
Antenna	Two UHF (70 cm) coupled Hygain antennas having 14 dB gain each	4 m parabolic dish
Rotators	Yaesu G5500: azimuth (0^0-450^0) and elevation (0^0-180^0) control Yaesu GS-232B interface	Azimuth and elevation rotators
Radio	Icom IC-910H	MHX-2400 module
Modem	Kamtronics Kam-XL	Amplifier
Computer	Running the tracking software, rotators control, radio command (Doppler shift compensation) and data recording software.	Running the tracking, rotators control and data recording software. (The Doppler shift is automatically adjusted by the transceiver.)

Table 2 Ground station equipment

Fig. 10 UHF Control Equipment (up left). UHF antennas (up right). 2.4 GHz Dish (down)

LAUNCH

Early in 2008, the team developing the first Romanian nanosatellite entered a competition organized by the European Space Agency – ESA for CubeSat developers in Europe. The 1st dedicated European CubeSat workshop, *Vega Maiden Flight CubeSat Workshop*, gathered developers from Universities in Europe looking to receive a free launch opportunity onboard the new VEGA rocket.
The European Space Agency is developing the VEGA launch vehicle for taking multiple small satellites (300 – 2000 kg) into polar and low Earth orbit (LEO) [3].
For the first demonstrative flight of the new vehicle, ESA chose to offer a free launch to 9 CubeSats currently being developed at universities in Europe.
Following the Workshop and the Call for Proposal, the Goliat nanosatellite was among the 9 CubeSats selected for the 1st Vega Flight. First scheduled for late 2008/early 2009 the launch was rescheduled for November 2009 due to delays in developing the launcher.
Goliat will be placed on a high inclination (71^{o}) elliptical orbit having the apogee at 1447 km and the perigee at 357 km after the main payload will be put on orbit.

CONCLUSIONS

Recent progress in the developing of CubeSats has proven the versatility of such low-cost small spacecrafts. Scientific experiments, earth observations or space qualification of products or technologies proved beyond any doubt that CubeSats have long surpassed their educational purpose and offer valuable results at unprecedented low costs. From this point of view the Goliat nanosatellite is a demonstrative unit to be built upon.
Complex applications have been proposed to take advantage of the low cost, high redundancy and reduced deployment periods. Furthermore, a new nanosatellite project was started in September 2007 in order develop a more advanced cube equipped with cold gas propulsion system and a new powerful DSP processor. The second cube is part of an ambitious nanosatellite formation flying project – PLURIBUS schedule for launch late 2010. The nanosatellites shall be able to communicate in a decentralized broadband network used as

support for a GRID middleware and data fusion algorithms implementation. In parallel, work is currently underway at a new satellite, with the launch planned in July/August 2009. Its dedicated purpose is to validate the onboard bus systems, mainly the in house developed reaction wheels attitude control system, prior to GOLIAT's VEGA launch.

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