11TH EUROPEAN CUBESAT SYMPOSIUM

11th September – 13th September 2019

Université du Luxembourg, Maison du Savoir

Organized by the von Karman Institute for Fluid Dynamics and

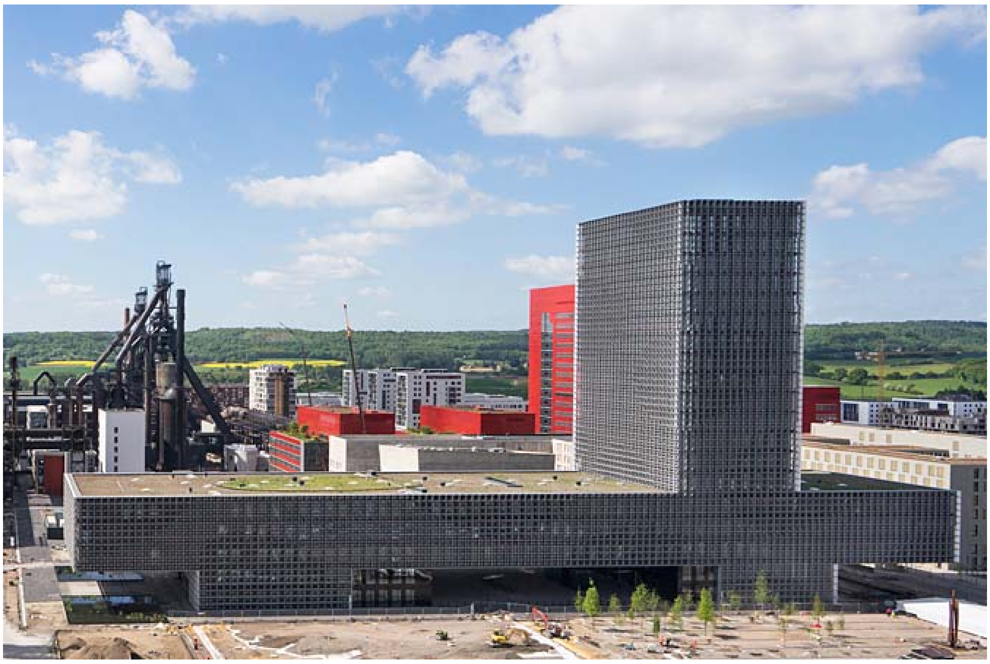
the University of Luxembourg

von KARMAN INSTITUTE FOR FLUID DYNAMICS

UNIVERSITÉ DU LUXEMBOURG

LuxCube
First Luxembourgish student CubeSat mission

BOOK OF ABSTRACTS



FOREWORD

Foreword of the Rector of the University of Luxembourg and the Director of the von Karman Institute for Fluid Dynamics

The University of Luxembourg and the von Karman Institute for Fluid Dynamics are jointly organizing the 11th European CubeSat Symposium on Belval campus in Esch-sur-Alzette from 11 to 13 September 2019.

CubeSat technology is central to today's new space. Since 2016, the government of Luxembourg has taken a number of initiatives – encompassing regulation, tax, research and development regimes – to create a vibrant ecosystem in Luxembourg for space companies extending from innovative satellite operators to those focused on extracting resources from asteroids. In line with the government's space resources initiative, the University of Luxembourg has launched an interdisciplinary space master, which will provide students with the required engineering skills in the space industry, along with both deep and broad knowledge to manage space-related business activities.

The von Karman Institute for Fluid Dynamics is an international educational and scientific organization that has fostered space projects since the beginning of the space race. For instance, QB50 was a recent pioneering project aiming at creating an international network of CubeSats for multi-point, in-situ measurements in the lower thermosphere and re-entry research. Thanks to the European seventh framework program, 36 CubeSats have been launched into orbit in 2017. Qarman, will be the first reentry CubeSat, fully designed and built at the von Karman Institute to be launched to the International Space Station this winter.

This year's symposium will be a worthy successor of the 10th Symposium at ISAE-Supaero in Toulouse, France. We have received many more abstracts than we could accommodate for oral presentation. This trend continues that more and more scientific applications and flight experiences will be presented, clearly showing the maturing of our technology. This is exciting and promises the long-term success of our vision.

We thank all speakers and poster presenters for contributing to the symposium and all other guests for their interest in participating.

We also gratefully acknowledge the symposium sponsors for their support: Nano Avionics, Space Inventor, Anywaves, Bradford Space, DHV Technology, ESA, ISIS, LSA, MACFAB, OHB Cosmos, Patchedconics, SeedX, SAtRevolution, Space BD, Thrustme and wish great success to our exhibitors.

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SESSION 1

BEYOND EARTH: SPACE EXPLORATION MISSIONS WITH CUBESAT

THE MARCO MISSION FROM A TELECOM PERSPECTIVE, HIGHLIGHTING THE FIRST USE OF THE IRIS DEEP SPACE TRANSPONDER

Sarah Holmes[1]

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The story of the Mars Cube One (MarCO) mission begins in 2014, when the Jet Propulsion Laboratory (JPL) approved an ambitious 15-month development and delivery plan for what would become NASA's first deep space CubeSats to fly. The MarCO mission's primary goal was to perform a "real-time" data relay of the InSight lander's entry, descent, and landing (EDL) to the surface of Mars. It would accomplish this with two 6U satellites, which flew independently alongside InSight to Mars. As a technology demonstration, MarCO's secondary goal was to exercise a variety of new onboard technologies, including the Iris Deep Space Transponder.

Leveraging the never-flown Iris V1.0 design, the Iris V2.0 design contained new capabilities and features specifically added for use on MarCO, including a UHF receiver board for InSight's EDL data, and the implementation of a LEON3-FT softcore processor running a single-threaded software application. As a software-defined radio (SDR), the Iris is highly configurable via a series of commands from its host spacecraft. MarCO's tech demo designation enabled the operations team to perform several tests of the various Iris configurations and capabilities, which in turn provided validation for future versions of the radio. MarCO's telecom system was also made up of a set of antennas, including a reflectarray high gain antenna (HGA) and UHF antenna, both specifically developed for MarCO, and through which the bent pipe data relay of InSight's EDL data was performed.

From launch on May 5, 2018, throughout the seven-month cruise to Mars, and all the way to InSight's Mars landing day and beyond, the MarCO mission and its Iris radios enjoyed a variety of successes. These accomplishments included first contact, commanding and telemetry with the Deep Space Network (DSN), tracking and navigation measurements, in-flight antenna calibrations, and completion of the primary goal of bent-pipe data relay direct to Earth during EDL of the InSight lander, including InSight's first image from the surface of Mars.

This talk will briefly describe the MarCO and Iris designs and development before walking through the different stages of MarCO's flight and focusing on its accomplishments and operations, with a particular emphasis on Iris as the telecom perspective.

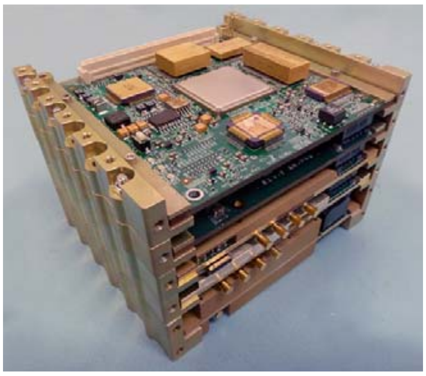

Figure 1: Iris V2.0 for MarCO

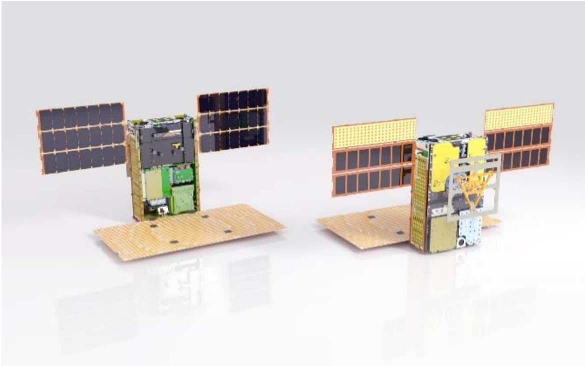

Figure 2: MarCO Subsystems


Figure 3: Image of Mars captured by MarCO-B

MOON CUBESAT HAZARD ASSESSMENT (MOOCHA) – AN INTERNATIONAL EARTH-MOON SMALL SATELLITE CONSTELLATION

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Recent developments in space exploration have reinstated the Moon as a primary target for near future space missions, which include for example the National Aeronautics and Space Administration's Artemis Moon Program, the European Space Agency's Lunar Mission Campaign, and the Chinese Lunar Exploration Program to name a few. The principal reasons for returning to the Moon and this time establishing a continuous presence there, include the Moon being the closest testbed and analogue for interplanetary space missions and the prospect of a scientific lunar base within the next decade. Establishing a lunar base and to have a continuous presence within the cislunar and translunar space requires overcoming a wide range of challenges, and properly analyzing the surrounding phenomena and environment to have successful outcomes and making sure the human exploration missions will be safe for the crew. In the past, space missions have vastly improved our understanding on hazards of human spaceflights, however little is known on the magnitude of threats affecting a prospective lunar base and its instruments and crew.

The known lunar hazards to instruments and crew include radiation effects, and exposure to frequent micrometeorite impacts. The micrometeorite impact flux of the Earth–Moon environment is a phenomena that can be correlated with the near-Earth object flux. The micrometeorite impact hazard has been accepted as an issue which not only will impact both the human exploration mission crew's health and safety but will additionally create long-term issues for the near-future lunar bases, stations and communication equipment. These issues and hazards include degradation and permanent damage of equipment and facilities as well as safety of the personnel in lunar and cislunar space. Near-Earth objects flux is determined by ground-based observations of objects large enough, typically larger than a few centimetres, as well as partly on dust and micrometeoroid flux measurements and impact flash

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observations on the Moon's surface in the recent years [1]. Impact flash observations provide valuable data both for the near-Earth object flux and also for a micrometeorite impact map of the Moon as shown in image 1 [2]. Such ground-based impact flash observations include the NELIOTA and MIDAS projects [1, 3]. Recent findings from these projects suggest that objects sized from a few millimeters to a few centimeters with masses ranging from 0.10 kg to 55 kg are impacting the Moon regularly with high-speed velocities between 16–25 km/s resulting in impact energies within gigajoules. Hence the importance of monitoring the micrometeorite needs to be frequently done within a lunar orbit since ground-based observation of impact flashes on the Moon are profoundly limited. Ground-based observations cannot cover polar regions, are restricted by the magnitude of the impacts, and cover roughly only half of the Moon. [1, 3] Additionally, ground-based observations are only possible with good weather conditions, and limited by atmospheric interferences. Therefore, observations with improved spatial and temporal resolution are imperative for advancing existing hazard models.

Hence, we propose a novel lunar mission concept of a constellation of microsatellites and nanosatellites – similar to the successful international QB50 project – that can both observe larger parts of cislunar and translunar space, and to provide higher temporal resolution of the lunar surface impacts and geological changes [4]. Microsatellite and nanosatellite missions are a cost-effective solution providing data for significant improvement of our current understanding. In addition, the distributed constellation mission can also provide a platform to increase human capital in satellite design amongst young scientist and students worldwide.

Our mission proposal, the Moon CubeSat Hazard Assessment (MOOCHA) mission, shall consist of a large number of microsatellites and nanosatellites designed, built, and operated independently by various academic and partner institution which include commercial companies, universities, and research and space agencies. The MOOCHA satellites shall have a certain level of standardization, which will enable a platform for successful participation to the mission itself while ensuring the scientific measurements carried out. The common factor of the satellites in the mission is to use an identical primary payload package for monitoring the impact flashes, and to be able to accommodate other non-common secondary payloads in the satellites additionally. The mission idea naturally enables the usage of ridesharing using a single launch per multitude of MOOCHA mission satellites to lunar orbits in constellations.

1. Madiedo, José M. & Ortiz, J & Morales, Nicolas & Santos-Sanz, Pablo. (2019). Multiwavelength observations of a bright impact flash during the 2019 January total lunar eclipse. Monthly Notices of the Royal Astronomical Society. 486. 3380. 10.1093/mnras/stz932.
2. https://neliota.astro.noa.gr/
3. Bonanos, Alceste & Liakos, Alexios & Xilouris, Manolis & Boumis, P & Bellas-Velidis, Ioannis & Marousis, A & Dapergolas, Anastasios & Fytsilis, Anastasios & Noutsopoulos, Andreas & Charmandaris, Vassilis & Tsiganis, Kleomenis & Tsinganos, Kanaris & Els, Sebastian & Koschny, Detlef & Lock, Tim & Navarro, Vicente. (2016). NELIOTA: ESA's new NEO lunar impact monitoring project with the 1.2m telescope at the National Observatory of Athens. 991122. 10.1117/12.2232453.
4. D. Masutti, A. Denis, R. Wicks, J. Thoemel, D. Kataria, A. Smith, J. Muylaert. (2018). The QB50 Mission for the Investigation of the Mid-Lower Thermosphere: Preliminary Results and Lessons Learned. 15th Annual International Planetary Probe Workshop (IPPW) 2018, June 11-15, 2018, University of Colorado Boulder, Colorado, USA.

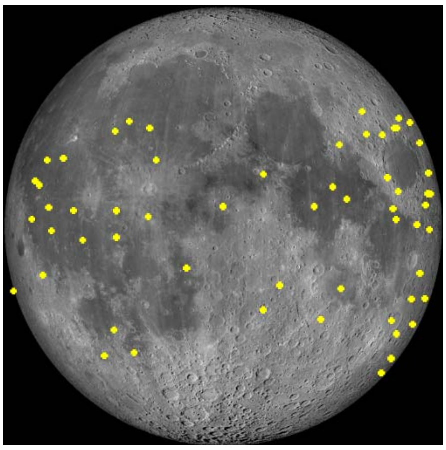

Image 1. Micrometeorite events (58) recorded by NELIOTA in 848 days and 97 observation hours [2].

FEASIBILITY STUDY OF AN INTERFEROMETRIC CUBESAT TO DETECT EXOPLANETS

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Every week, new exoplanets are discovered mostly by the transit method (77.1% of all discoveries according to NASA [1]). Even if this method is efficient at detecting planets, it is limited to a small fraction of the whole expected exoplanets population due to the low probability of planetary transit. Therefore, a direct method is needed to detect and characterize exoplanets around the nearest stars. In this case, the planet and the star are angularly separated and photons are distinguished. It leads to the detection of the planet. Moreover, it allows the possible characterization of the planet surface or its atmosphere.

One way to detect them through direct method is to use interferometry. With at least two sub-pupils (Bracewell interferometer [2]), coherent light from the target is recombined to form interference patterns. The angular resolution depends on the baseline (distance between the two sub-pupils) and not on the diameter of each sub-pupil. Instead of using a single large telescope (around 60 cm diameter), which does not fit into a CubeSat, one can use two small and well separated apertures (around 10 cm each) to synthesize this large telescope. Therefore, it increases drastically the resolution power of CubeSats.

In order to detect an exoplanet and get the direct light coming from it, the light from the star must be mitigated. It is called nulling interferometry. Thanks to a π phase shift induced in one arm of the interferometer, destructive interferences are produced on the line-of-sight in order to suppress the light of the star. The exoplanet, which is on constructive interferences (white fringes), is unveiled.

The Centre Spatial de Liège of the University is developing a space-based interferometer with a CubeSat. Goals are twofold: observe the nearest stars and demonstrate this technology in space, which will be a premiere. It is the first step towards a future large interferometry space-based mission which has the ambition to spectrally characterize Earth-like planets. The CubeSat will demonstrate light injection to optical fibers, recombination of the two beams, control of the delay-lines and detection.

CubeSats offer low-cost demonstrator capabilities with a fixed baseline and with no free-flying concept. Figure 1 represents one of the numerous architectures considered in our study.

Aside the technical challenges, the second part of our researches is focused on the detection possibilities with this type of nanosatellite.

We estimate by numerical simulations the possible science return for such an instrument. Fluxes from the star and the planet are computed as well as the nulling capability of the interferometer. Noises as the thermal background or local zodiacal disk emissions are considered. The integration time is computed to get a signal-to-noise ratio of 5, meaning a detection of the planet.

One major limitation of CubeSats is the baseline length. The maximal size without deployment is 60 cm (1x6x1U) thanks to the deployer from Nanoracks on the International Space Station [3]. However, researches show that this value can be increased up to 1.2 m as shown in Fig. 1.

Another important question for scientific objectives is the target. To simulate possible detections, putative planets are generated by the P-POP algorithm from Kammerer et Quanz (2018) [4]. Thanks to the statistics of the Kepler satellite, who detected more than 2600 transiting exoplanets, it generates potential planets around a catalogue of stars up to a distance of 20 pc. One can deduce an exoplanet detection yield for our CubeSat.

The last considered parameter for such a CubeSat is its orbit. A review of possible orbits was done to have a maximal visibility on the 5 closest stars with confirmed exoplanets (Proxima Centauri, Barnard's Star, Espilon Eridani, Ross 128 and Tau Ceti).

[1] https://exoplanets.nasa.gov (accessed on May 28, 2019)

[2] Bracewell, R. N. « Detecting Nonsolar Planets by Spinning Infrared Interferometer ». *Nature* 274, n° 5673 (août 1978): 780. https://doi.org/10.1038/274780a0.

[3] http://nanoracks.com/products/iss-cubesat-deployment/

[4] Kammerer, Jens, et Sascha P. Quanz. « Simulating the Exoplanet Yield of a Space-Based Mid-Infrared Interferometer Based on *Kepler* Statistics ». *Astronomy & Astrophysics* 609 (2018): A4. https://doi.org/10.1051/0004-6361/201731254.

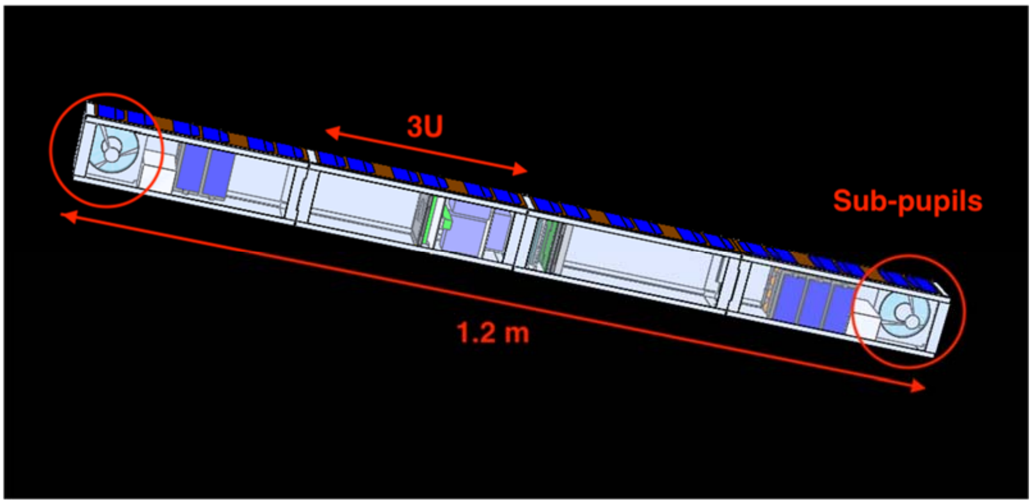

Figure 1 : 3D view of a studied architecture. 12U with deployment mechanisms.

SESSION 2
CUBESAT MISSIONS

IGOSAT -3U EDUCATIONAL CUBESAT FOR MEASURING THE TEC AND DETECTING HIGH ENERGY PARTICLES

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IGOSat (Inospheric and Gamma-ray Observation Satellite) [1] is the first educational 3U CubeSat (10x10x30 cm) developed at Paris Diderot University. It is supported by the LabEx UnivEarthS [2]) and the CNES (French Space Agency) through the JANUS program for educational CubeSats. It has two scientific objectives: measuring the TEC of the Ionosphere and to detect gamma rays and electrons above the poles and the South Atlantic Anomaly (SAA).

APC (AstroParticule et Cosmologie) and the IPGP (Institut de Physique du Globe de Paris) are the main laboratories involved in the development and supervision of students on IGOSat. Since the beginning of the project in 2012 more than 270 students have already participated on IGOSat as interns or within a teaching project.

During internship periods (February to September) the IGOSat project gathers between 10 and 15 French and international students from different engineering background. This requires a complex organization for hiring and managing interns, and a strong capacity of adaptation within a University environment. Organization methods and management tools were implemented to supervise both the project and student work progress as well as to cope with the loss of experience due to the high turnover of the trainees.

Another aspect is that Educational CubeSat projects require contributions from experts in different technical domains. Even if initially it was rather difficult to motivate these experts to work on student projects due to the low return on investment, now more Scientists and Engineers are interested in developing CubeSats within their Laboratory / University.

In my poster, I will present the IGOSat project and its technical progress, the role and benefits of nanosatellites in education and the challenges to manage student CubeSat projects throughout the different phases.

IGOSat is in Phase C/D since September 2017, following a successful Preliminary Design Review, presented by interns in front of CNES experts, in June 2016.

References:

[1] IGOSat website, http://www.igosat.fr

[2] LabEx UnivEarthS website, http://www.univearths.fr

CUBESAT SPACE MISSION OF MOSCOW UNIVERSITY TO STUDY PHENOMENA IN EARTH MAGNETOSPHERE AND ATMOSPHERE

V.L. Petrov[1], M.I. Panasyuk[1], V.V. Bogomolov[1], Yu.N. Dementyev[1], A.F. Iyudin[1], P.A. Klimov[1], I.A. Maximov[1], V.I. Osedlo[1], O.Yu. Peretyatko[1], S.A. Filippychev[1], M.V. Podzolko[1], S.I. Svertilov[1], Yu.K. Zaiko[1]

[1]M.V. Lomonosov Moscow State University, Moscow, Russia

Two nanosatellites of CubeSat form-factor with payload by Lomonosov Moscow State University are prepared for launch in the 2019 year. The payload of both CubeSats includes scintillator phoswich detector of charged particles and gamma rays for the energy release range 0.1…2.0 MeV and geometry factor ~50 cm^2sr. One of the CubeSats contains also an optical detector, which consists of four SiPMs with input windows closed by different light filters. It provides Earth atmosphere observations in a band from UV to IR. These satellites should be launched onto the solar-synchronous orbit with relatively low altitude (500…550 km) that provides favorable conditions for the studying of space radiation in different areas of the near-Erath space including trapped radiation, electron precipitations from the Earth radiation belts, and detection of Atmosphere emissions.

Small satellites are very useful for studying different kinds of physical phenomena, which can affect dangerously on spacecraft components and biological objects. Magnetosphere electrons flux dynamics is a very important factor of natural hazards in the near-Earth space. The scientific concept and mission setup of the CubeSat-based experiment for medium-term and long-term dynamics monitoring of the high-energy charged particle fluxes spatial distribution in large areas of the Earth radiation belts for space weather forecast will be presented. This includes, among others, the estimation of the general scientific concept of small-sat experiment, the determination of optimal orbits and orientations of spacecraft, the verification of technical requirements and specifications for measuring instruments (spectrometers of energetic protons and electrons), requirements for satellite platform and its components, ground segment, general mathematical modeling of the mission.

MISSION OVERVIEW AND DESIGN APPROACH OF FORESAIL-1 CUBESAT

M. Rizwan Mughal, Petri Niemelä, Riwanto Bagus, J. Nemanja, Alexandre Bosser, Jaan Praks and Foresail Team

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FORESAIL-1 is the first in the FORESAIL mission series developed by the Finnish Centre of Excellence for Research in Sustainable Space. The mission objective is to measure radiation belt losses using particle telescope (PATE), demonstrate coulomb drag propulsion (CDP) for deorbiting, test an ultra-sensitive magnetometer, and prepare for high radiation missions. The PATE consists of particle detectors with two telescopes; with collimators on short and long axis. The PATE has the requirement to orient its detector with shorter collimator towards the sun, while the detector with longer collimator to scan the environment. The CDP requires spin control for deploying and maintaining the tension of the tether to demonstrate the de orbiting. A graphical representation of Foresail-1 CubeSat with allocated volumes for avionics and payloads is shown in Fig.1.

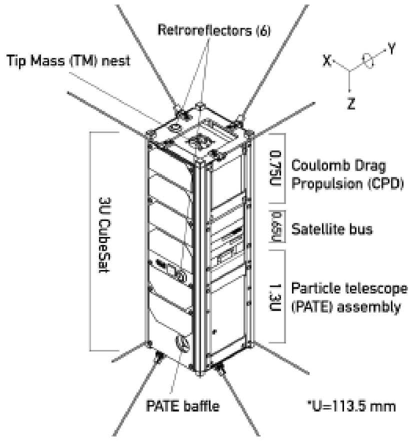

Fig.1 Foresail-1 spacecraft demonstrating PATE and CPD payloads

The avionics subsystems of Foresail-1 is developed in house in order to accomplish the payload requirements. The avionic stack is enclosed in an Aluminum vault to protect against the radiation environment. The science and deorbiting experiments impose the requirement on the platform for maintaining desired spin rate around one of the spacecraft reference axis. The platform subsystems have been designed in accordance with the mission objectives.

The Attitude determination & control subsystem consists of a number of attitude determination sensors and magnetic control actuators to maintain spacecraft orientation. The sun sensors and magnetometers are utilized for attitude determination whereas air core and printed magnetorquers are the magnetic actuators. The magnetorquers are wounded and printed in X, Y and Z-axis of the spacecraft.

The electrical power subsystem consists of solar panels with solar cells in series configuration. The power conditioning chain consists of Buck converters with MPPT to extract maximum allowable power. The EPS operates in predefined nominal modes for effective battery charging and maintaining the bus voltage equal to battery voltage. The power distribution down converts the battery bus voltage to fixed 3.6V for onward distribution to the platform and payload avionics.

The onboard data handling subsystem consist of radiation tolerant onboard computer, external data storage and custom built RS485 based data handling protocol. The telemetry, tele command & communication subsystem consists of radio frequency front end and antennae operating in ultra high frequency (UHF) band for uplink and downlink.

The paper will present a brief overview of the mission, design scheme and status of each subsystem.

QARMAN: A CUBESAT AS AN ATMOSPHERIC RE-ENTRY VEHICLE

Denis A.[1], Umit E.[1]

[1] von Karman Institute for Fluid Dynamics

QARMAN (Qubesat for Aerothermodynamic Research and Measurements on AblatioN) is a 3U CubeSat designed to collect scientific data during its re-entry through the Earth atmosphere. QARMAN is a Von Karman Institute project, funded by the European Space Agency and developed in cooperation with the University of Liege.

The main goal of QARMAN is to demonstrate the usability of a CubeSat platform as "Atmospheric Entry Demonstrator". Spacecrafts descending towards a planet with an atmosphere experience a very harsh environment as extreme aerodynamic heating and exothermic chemical reactions occur due to the gas surface interaction at hypersonic free stream velocities.

Such vehicles are protected with a dedicated thermal protection system (TPS) to survive these harsh conditions. QARMAN is designed to test and qualify such systems. After the success of the mission, different entry vehicle configurations (for example using different TPS materials) can be tested on board at very low costs for scientific exploration and qualification of future missions in order to provide valuable real flight data.

To collect flight data the challenging physics of atmospheric entry to be investigated are down-selected to make scientifically valuable measurements respecting the constraints of CubeSat platforms. Thermal Protection System (TPS) ablation, efficiency, and environment; attitude stability; rarefied flow conditions; off stagnation temperature evolution and finally the aero-thermodynamic environment will be measured on QARMAN using COTS spectrometer, photodiode, temperature and pressure sensors. The feasibility study of an effective TPS that could fit within the external dimensions of a 3U standard CubeSat is one of the challenging parts of this project. It has to manage the thermal environment until ground impact, by keeping the payload bay in a suitable temperature.

The QARMAN mission aims to provide an Earth entry flight data set for a given entry trajectory. This requires an accurate de-orbiting system for QARMAN to reach 7.7 km/s at 120 km altitude. Thus, QARMAN is equipped with another payload called "Aerodynamic Stability and De-Orbiting System (AeroSDS)". The AeroSDS will demonstrate the feasibility of a passive system providing aerodynamic stability for a CubeSat below 350 km of altitude and provide also stability during re-entry.

In 2018, a full-scale test took place in the Scirocco plasma wind tunnel (CIRA, Italy). In 2018-2019, QARMAN has been integrated at the von Karman Institute and qualified for flight. The launch to the ISS is scheduled for end of 2019, for a deployment in Space in early 2020.


Figure 1: Artist's impression of QARMAN orbiting the Earth.

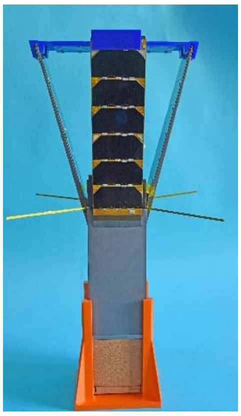
Figure 2: QARMAN flight model in deployed configuration.

SESSION 3
FLIGHT DYNAMICS AND AOCS

FEASIBILITY STUDY OF DUAL-STAGE CONTROL SYSTEM APPROACHES ON SMALL SPACECRAFT USING THE PEET SOFTWARE

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[1] KU Leuven, Leuven, Belgium

As the growth of the small spacecraft market continues, so does the demand for high-quality data gathered from small spacecraft platforms, such as high-resolution images from Earth observation missions or high-speed data transfer by laser communication. This demand, however, imposes stringent jitter requirements on the pointing performance in the range of arcseconds and better. While state-of-the-art Attitude Determination & Control Systems (ADCSs) of small spacecraft are reaching their physical limits, high-pointing accuracy and stability can be provided by dual-stage control system approaches with a payload-in-the-loop configuration in order to further improve the quality of the data.

One concept of such a dual-stage control system approach is to combine a currently existing ADCS with a so-called High-Precision Pointing Platform (HPPP). The basic idea of this concept is to separate the low-frequency (< 10Hz) and high-frequency (> 10Hz) content of the pointing disturbances. While the spacecraft ADCS suppresses low-frequency disturbances, the HPPP deals with the high-frequency phenomena.

This paper will propose two CubeSat scenario's that benefit from a dual-stage control system approach: (1) an Earth observation mission and (2) an astronomy mission. In both scenario's the spacecraft ADCS is equipped with a star tracker and a gyro to measure the pointing error, and a combination of reaction wheels and magnetorquers to control the pointing error, as this configuration represents the majority of existing CubeSat missions.

For the Earth observation mission, the CubeSat is supposed to be an imaging spacecraft with stringent requirements on the absolute and relative pointing error. In this scenario, the HPPP is composed of a two-axis translational piezo-stage on which the payload image sensor is mounted. Based on the accurate information of the star tracker, the piezo-stage can be controlled to counteract the remaining high-frequency relative pointing errors, also known as 'jitter'.

For the astronomy mission, the CubeSat is supposed to have an onboard spectroscopy instrument for which a stringent requirement on the absolute pointing error exist. In this scenario, the HPPP is composed of a fine-guidance sensor which senses the deviation of the targeted star, and a fast-steering mirror that deviates the light onto both the fine-guidance sensor and the payload. In this configuration, the fast and accurate information of the fine-guidance sensor allows to control the fast-steering mirror.

The pointing error budgets of both scenario's is calculated by means of the recently released version of the Pointing Error Engineering Tool (PEET) software. Its computational core is based on standardized rules established in the ECSS Control Performance Standard E-ST-60-10C and on the methodology described in the ESA Pointing Error Engineering Handbook. The software does not rely on the generation of random numbers or numeric simulation and is thus repeatable and fast to compute. This allows to rapidly verify the impact of different system parameters on the pointing performance and to identify dominant error sources.

Since the software only provides steady-state solutions (no transient behavior) of an underlying linear model (no nonlinearities) with several assumptions, the results should be interpreted as an order of magnitude of the different pointing error contributions. Nevertheless these results allow to verify the feasibility of dual-stage control system approaches on small spacecraft.

THE FINAL STRETCH: PREPARING THE ADCS FOR LAUNCH AND OPERATIONS

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This paper discusses the calibration, the test campaign and the preparation for the operational phase of the KUL ADCS within the SIMBA CubeSat mission. SIMBA is a 3U CubeSat that will monitor global warming parameters. The mission is part of the ESA IOD CubeSats and the development and testing is overseen by ESA.

The KUL ADCS is a compact and highly autonomous system that delivers pointing accuracy in the range of one tenth of a degree and knowledge accuracy in the range of arc seconds. The ADCS has three reaction wheels and a star tracker that were developed at KU Leuven. A set of basic sensors (photodiodes, magnetometers, gyroscopes) and three magnetorquers are also fit within the 0.5U of the ADCS.

The ADCS was successfully environmentally tested during a vibration and thermal vacuum test campaign. On top of this, ADCS-specific tests such as measuring the effect of stray light on the star tracker and analyzing the vibrations produced by the reaction wheel were carried out. This test campaign and results will be described in the paper, together with lessons learned for future campaigns.

Calibrating the ADCS is a complex and crucial task. The paper discusses the calibration campaign that was carried out and presents the innovative ways in which the calibration parameters were determined while on ground. A higher level of autonomy can facilitate the operational segment of the mission. The ADCS has a number of different modes that can be switched autonomously. This takes the operator out of the loop, which is a huge time saver once the satellite is in orbit. On the other hand, higher levels of autonomy lead to increased risk. The way this was handled in the KUL ADCS is presented.

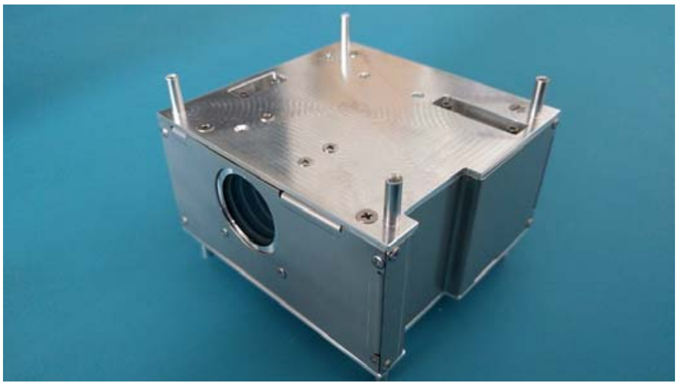

Figure 2 The KUL ADCS

Figure 3 Calibration campaign: The SIMBA CubeSat on a rotation table

RECENT FLIGHT EXPERIENCES OF BLUE CANYON TECHNOLOGIES SPACECRAFT, ADCS, AND COMPONENTS

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Blue Canyon Technologies (BCT) has recently been a part of many successful cubesat, small sat, and micro sat missions. From these missions, BCT has provided a variety of products to contribute to their overall mission success, ranging from individual star trackers to complete spacecraft solutions. The goals of the missions have been extremely various – from Earth weather observation to the first interplanetary cubesats and from government to commercial customers – yet they all utilize the core BCT GN&C hardware and software solutions. Each mission has unique characteristics, considerations, and challenges to provide both a robust control system while maximizing performance for the payload. BCT on-orbit heritage now includes a total of 6 spacecraft, 16 ADCS units, 57 star trackers, and 179 reaction wheels, with many more products to be launched coming shortly.

Some of the recent missions that will be explored are:

- ASTERIA: 6U cubesat and recent winner of the 2018 Smallsat of the Year award. ASTERIA achieved the best pointing cubesat ever at less than 1 arcsecond, with XACT providing a native stability of 1.6 arcseconds
- MarCO: A pair of 6U interplanetary cubesats on trajectory for a Mars flyby. Specific design considerations were made for the change to interplanetary travel, and the XACTs are controlling the thrusters
- HaloSAT: 6U cubesat designed, developed, and operated by BCT. HaloSAT will study missing matter in the Milky Way halo using precision pointing (study by University of Iowa and NASA Goddard).
- TEMPEST-D: 6U cubesat designed, developed, and operated by BCT. TEMPEST-D is a JPL science mission to study Earth weather.
- STP-H5: Extended baffle Nano Star Tracker (NST) mounted on the ISS

This presentation will highlight these recent missions and include details on mission-specific GN&C challenges, on-orbit results, and lessons learned.

Figure 1: XACT 0.5U Attitude Control Module

Figure 2. TEMPEST-D Deployment from ISS

ORBITAL DECAY ANALYSIS OF A TUMBLING 3U CUBESAT

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Low Earth Orbit (LEO) is defined between approximately 160 and 2000 kilometers in altitude. CubeSats have proliferated in LEO since they were first launched in 1998. There have been over 2,000 CubeSat launches, and the number of launches increases every year [1]. In addition to the proliferation of CubeSats, LEO is also being flooded with satellite constellations such as the SpaceX constellation Starlink. SpaceX will launch 2,200 satellites over the next five years as part of the Starlink mission. This is just one constellation launching soon; each constellation consists of thousands of spacecrafts [2]. Each of these constellations' missions requires successful performance of every spacecraft or there will be a loss of operations.

Space debris is the expanding collection of defunct, man-made objects in orbit around the Earth. As spacecraft, space debris, and other objects such as natural meteoroids accumulate in orbit, a positive feedback loop of debris population known as the Kessler syndrome begins to take effect. The Kessler syndrome is a phenomenon where populated orbits create larger potential for more spacecraft collisions, which causes proliferation of space debris in orbit, and the feedback loop continues. As the number of objects in orbit increases, the chance of collision rapidly increases [3]. Therefore, proliferation of CubeSats and launches of spacecraft constellations with thousands of interconnected spacecrafts will push us closer towards a Kessler effect spiral of proliferating space debris. In addition, many CubeSats are launched in orbits where atmospheric drag will not cause reentry for over 25 years, prolonging the time in orbit as nonfunctional space debris [4].

Collisions of space debris with CubeSats also have the potential to damage the CubeSats' hardware and negatively impact the individual CubeSat, or, if it is part of a constellation, the entire constellation's mission. Likewise, if a CubeSat ends its mission and becomes space debris, there is potential for that CubeSat to undergo a damaging collision with functional spacecraft in LEO. Collision avoidance is a complex and expensive endeavor for operational spacecraft to undergo. As CubeSats and other satellites proliferate in LEO, cost of monitoring all objects in orbit will increase, and space traffic management regulations will likely change as a result. Currently, international policy allows defunct spacecraft to remain in orbit for 25 years after mission's end [4]. This policy is expected to change as the number of operational spacecrafts and space debris in orbit increases, and collision management becomes more pressing. CubeSat orbital decay and reentry trajectories, therefore, are an important topic of study, as collision avoidance is prioritized.

CubeSats in LEO experience atmospheric drag which causes orbital decay and inevitable reentry. Once a satellite descends past 180 km, impact is assumed to occur in less than a day [5]. Reentry trajectories therefore develop around this altitude. Below 180 kilometers, the atmospheric flow regime experienced by the reentering spacecraft proceeds from free molecular to transitional, and finally becomes a continuum regime around 100 kilometers. Prediction of aerodynamic forces and moments throughout orbital decay is necessary for accurate determination of reentry trajectories.

Three-dimensional force and moment analyses are presented for a 3U CubeSat returning from LEO at several transition-regime altitudes. Pressure caused by incident atmospheric flow over a 3U CubeSat at an altitude of 120 km is presented in Figure 1. Analysis is conducted using the direct simulation Monte Carlo code MONACO. The DSMC technique does not make any assumptions about equilibrium or quasi-equilibrium and has shown a high degree of accuracy.

There is evidence that uncontrolled spacecraft tumble throughout their orbits, and the effect of this tumbling on reentry trajectories is not well understood. In this study, tumbling of the CubeSat is treated by movement of the relative velocity vector of the flow around the CubeSat. Two tumbling behaviors are examined: a previously assumed rate of rotation of the CubeSat is imposed; and the natural evolution of the CubeSat's orientation from a certain starting orientation is examined at each altitude. A simple orbital decay model is employed to study short-term orbital decay of the 3U CubeSat. The effect of tumbling on loss of altitude is discussed. Future work proposed includes comparison with attitude data from CubeSat constellations, as well as reconstructing complete reentry trajectories of CubeSats from certain points in LEO.

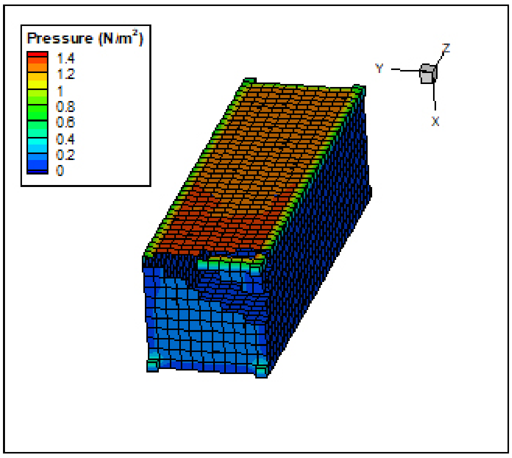

Figure 1: Pressure distribution on 3U CubeSat experienced in LEO at an altitude of 120 km; angle of attack is 15° in the X-Z plane.

References:

[1] Kulu, E., Nanosatellite & CubeSat Database, 2019.
[2] Williams, M., "SpaceX's Starlink Constellation Construction Begins. 2,200 Satellites Willgo up Over the Next 5 years," Universe Today, April 16, 2019.
[3] Wang, T., "Analysis of Debris from the Collision of the Cosmos 2251 and the Iridium 33 Satellites," Science and Global Security, Vol. 18, No. 2, 2010, pp. 87-118.
[4] Reynolds, G.H., "Collision Course: The Need for Better Space Junk Regulations," Popular Mechanics, Hearst Magazine Media, Inc., October 1, 2009.
[5] Clark, S., "NASA: Tracking CubeSats is easy, but many stay in orbit too long," Spaceflight Now, Pole Star Publications Ltd., July 30, 2015.
[6] Kennewell, J., Satellite Orbital Decay Calculations, IPS Radio & Space Services, Sydney, Australia, 1999.

SESSION 4

EARTH OBSERVATION AND NOVEL SCIENTIFIC INSTRUMENTS / SENSORS ON CUBESATS

A COMPARISON BETWEEN CONVENTIONAL EARTH OBSERVATION SATELLITES AND CUBESATS; REQUIREMENTS, CAPABILITIES AND DATA QUALITY

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Keywords: Earth Observation Satellites, Cubesats, Optical Image Sensors, Image quality, Validation, direct Georeference

From its early beginning as an educational tool in 1999, cubesats have evolved into a popular platform for technology demonstrations and scientific instruments. Ideas and innovations sparked from an enthusiastic community led to the development of new Earth Observation (EO) technology concepts based on large constellations of satellites with high-resolution optical imagers previously considered as infeasible. Probably the most significant constellation today is deployed by Planet who are currently operating a fleet larger than 120 3U Dove satellites, which provide an imaging service with up to 3m Ground Sample Distance (GSD). The number of low-cost EO Cubesat systems is constantly increasing. However, for a number of reasons there still seems to be a reluctance to use such data for many EO applications. A better understanding of the capabilities of the current generation of small Cubesats compared to the traditional well-established bigger operational missions of high and medium resolution EO satellites is required. What are the critical capabilities and quality indicators?

Due to the limited size and weight of Cubesats, critical system components, e.g. for navigation and communication, always compete with operational payloads such as optical camera/sensor systems. A functional EO system requires balanced payload, which provides adequate navigational capabilities, that match the requirements of the optical imagers (camera) deployed with the system.

Knowing the exact trajectory of the satellite is an essential requirement to task a successful image acquisition. The navigational data provides the position and orientation of the optical sensor at the time the image is captured. This so-called sensor orientation consists of a 3D position and three rotations, which are usually referenced to the World Geodetic System (WGS84). It is used to directly georeference the image to its exact location on the Earth surface. The current generation of very high-resolution (VHR) optical EO satellites are highly agile and are able to collect images from viewing angles of ±45° off-nadir with a pointing accuracy of less than 500m at the start and finish of the image collection. The image data collected is directly georeferenced with an absolute geolocation accuracy of less than 2.4m RMSE.

The quality of the acquired satellite images depends on the specifications and stability of the optical sensor and its calibration but also the orbital stability and atmospheric interferences. Key parameters are the geometric resolution called ground sample distance (GSD), spectral resolution and the radiometric resolution that is often described as the dynamic range. The spectral resolution specifies the number and width of bands recorded by the sensor within the electromagnetic spectrum. The radiometric resolution covers the 'bit depth' of an image channel. Dedicated optical EO imagers usually include panchromatic (greyscale), multispectral RGB and Infrared channels with a dynamic range of 11bit or higher. Hyperspectral imagers, which can record many 100 spectral channels with a separation of 10-20 nm, are less common but provide important data to many research communities, most often as airborne platforms. Sophisticated sensor models and elaborated calibration procedures ensure the quality of EO imagery from large satellites.

Small and inexpensive Cubesat systems may not match the capabilities and data quality achieved by dedicated EO missions but provide valuable data, which satisfy the requirements of many EO applications or service providers, but may fall short of the higher expectations by science or other sectors requiring very high-quality vetted image data. Continuous advances and innovative components continually push the envelope of Cubesat systems with better navigational control and more capable sensor systems. Planet's Dove constellation and GOMSpace's GomX4 demonstrators provide examples for operational optical EO systems based on Cubesats.

This study reviews the current performance and capabilities of Cubesats for optical EO and compares them to the capabilities of conventional, dedicated high and medium resolution EO systems. We summarise key performance parameters and quality indicators to evaluate the difference between the systems. An empirical study compares recent very high-resolution (VHR) imagery from big EO satellite missions with available images from Cubesats for the use case in disaster monitoring. Small and agile Nanosatellites or Cubesats already show remarkable performance. Although it is not expected that their performance and capability will match those of current bigger EO satellite missions, they are expected to provide a valuable tool for EO and remote sensing, in particular for downstream industry applications.

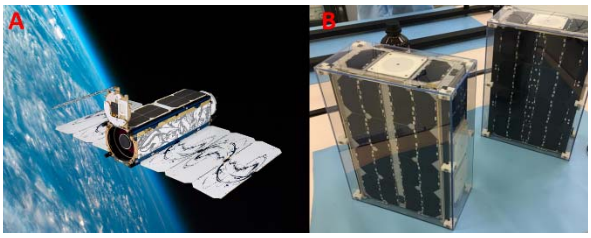

Figure 1: Planet Dove (A) GOMSpace GOMX4 (B)

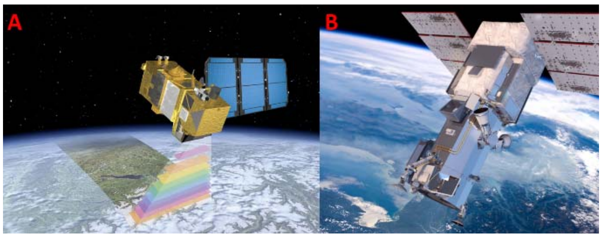

Figure 2: Sentinel 2A (A), WorldView 3 (B)

RAAD: A CUBESAT BASED DETECTOR FOR STUDYING TERRESTRIAL GAMMA-RAY FLASHES

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Topic(s): New Scientific Instruments / Sensors / Subsystems Concepts and Technologies

Keywords: gamma-rays, Terrestrial Gamma-Ray Flashes

The Rapid Acquisition Atmospheric Detector (RAAD) is a gamma-ray detector which will fit within 1U of a CubeSat. RAAD is sensitive to bursts of photons which vary on microsecond timescales such as terrestrial gamma-ray flashes (TGF). Previous detectors have been plagued by issues of deadtime and low time resolution. To account for this using a crystal scintillation detector, dense crystals with fast scintillation decay times are required. We plan to test two 2X2 array detector configurations with good sensitivity in the 15 keV to 2000 keV range and an effective area of ~20 cm^2. One has two Cerium Bromide (CeBr3) crystals and two Lanthanum Bromo Chloride (LBC) crystals and uses standard photomultipler tubes (PMTs). The second consists of 4 Cerium Bromide crystals readout by a set of four Silicon Multi-Pixel Photon Counters (SiPM MPPC) arrays. These arrays are wrapped in a plastic veto layer to reject charged particles which are the main background source. The total size of each array is well within the volume and mass restrictions of a single U of a CubeSat, and we are developing custom electronics which allow operation with a power budget of ~2W per array. With a total parts cost per array of only ~$30,000, this can be a very cost effective solution for multiple scientific applications.

USING A CUBESAT TO IMPROVE IRRIGATION: AN INNOVATIVE THERMAL IMAGER

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Water management has become one of the most important issues since 70% of the fresh water available on Earth is used for irrigation. The growing food demand and the scarcity of water resources lead to the need to carefully monitor water use, considering agricultural fields of thousands of km².

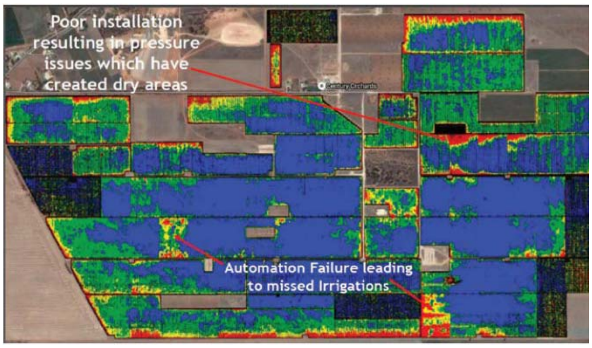
The intrinsic hydric stress of crops is an indicator of their water needs. Better water management and crops healthiness could be achieved if this stress could be measured quickly. Hydric stress can be retrieve by comparing the ground temperature (reference) and the leaf surface temperature (LST) which also depends on the transpiration ability of the plant. Yet, this measure is very unpractical without airborne/spaceborn sensors with good resolution.

This finding has led to the birth of the OUFTI-NEXT mission. The recent advances in the field of nanosatellites and the rising attention they get from the space agencies have convinced the University of Liege to develop its own CubeSat mission to image the LST with thermal infrared light above extensive crops to provide data for irrigation schedule. The aim of the long term mission will be to fly a constellation of CubeSats to ensure daily coverage over various fields with resolution of 50m. In addition, hot singular events data can be retrieved such as forest fire, volcanoes activity, pollutant leaking, etc…

Each CubeSat is a dual-band imager in both the middle wave infrared (MWIR) and the long wave infrared (LWIR). The scientific value of combining these bands is huge since LWIR gives accurate temperature measurements around 300K but with bad contrast, the latter being compensated by the MWIR which allows fine resolution. Each band is also sensitive to different atmosphere condition (humidity, clouds) and using both brings robustness to the mission.

The current step of this ambitious project is to fly a single band 3U technology demonstrator to validate the use of MWIR technologies without space heritage and the scientific value of MWIR images for LST determination. This spectral band is very challenging, as it hardly allows diffraction-limited performances: it requires fast optics, more sensitive to aberrations. For this demonstrator, resolution of 100m without daily coverage is chosen, resulting from is a trade-off between science demonstration and mission size. The “new” infrared technologies include: high operating temperature detector, compact optics, passive athermalization and recent infrared materials.

Solutions to make this challenging mission feasible are promising: The MWIR camera achieved diffraction-limited performances and uses compact hybrid lenses made of chalcogenide materials to reduce thermals effects and manufacturing costs. A very wide range of suitable detectors have been reviewed and the possibility to customize their integration is studied with their manufacturers. The orbit is sun-synchronous to optimize the thermal design and in accordance with both the radiometric budget and the observation strategy.



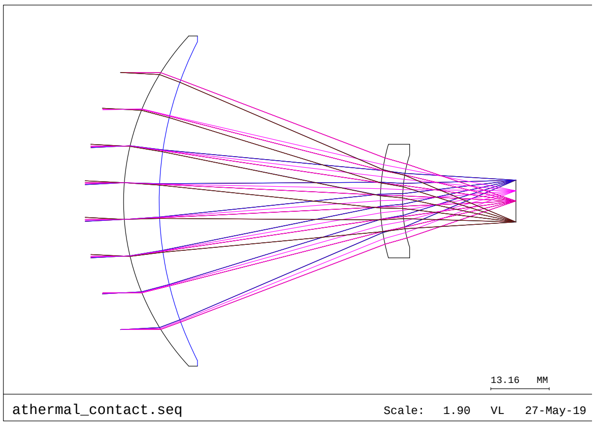


Figure 1: Hydric stress seen in thermal infrared*

Figure 2: refractive-diffractive (blue) optics

* Credit: *Century Orchards, Water stress thermal image. Red = water deficit stress, Blue = low water stress*

VIRTUAL TELESCOPE FOR X-RAY OBSERVATIONS – A X-RAY TELESCOPE WITH 50 MILLI-ARCSECOND ANGULAR RESOLUTION

[1]Kyle Rankin, [2]Asal Naseri, [3]John Krizmanic, [4]Neerav Shah, [1]Steven Stochaj

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The Virtual Telescope for X-Ray Observation (VTXO) is a small sat mission flying a revolutionary new form of X-ray telescope utilizing a Phase Fresnel Lenses (PFLs). PFLs have been shown to have diffraction-limited imaging in the X-ray band, resulting in an angular resolution an order of magnitude better than Chandra, the current state of the art X-Ray telescope. VTXO uses 3 cm diameter PFLs to achieve 50 mill-acrsecond angular resolution, but the PFLs require ~1 km focal length. This long separation leads to flying two separate spacecraft, one with the PFLs, and the other an X-ray detector in a precise formation approximating a rigid structure 1 km apart. In order to minimize fuel consumption, VTXO will be placed into a highly elliptical super-synchronous Earth orbit. During the course of this orbit, observations will only be conducted while VTXO is near apogee, where the gravity gradient forces are small requiring a minimum of fuel to maintain the orbit. During the reminder of the orbit, the two spacecraft will be allowed to move along some fuel optimized path. Additionally, the 90,000 km apogee of the highly eccentric orbit results in the observations being taken while the vehicles are above the radiation belts, which minimizes the trapped electron background on the X-ray detector, significantly improving the imagers signal to noise ratio.

VTXO requires centimeter level position control, and 10’s of microns level lateral position knowledge. In order to meet these precise formation flying requirements VTXO has three fundamental challenges to be addressed, precision control systems, precision actuators, and high precision navigation systems. The control system is fairly simple, as the spacecraft operates in a nearly linear control environment. Linear control systems have existed since the 1920’s, and are well understood, and widely used in industry. The actuator’s for VTXO are small low thrust cold gas systems, while fairly new they are available from several venders at a sufficient technology readiness level for inclusion on VTXO. The primary challenge with cold gas thrusters, is they have a fairly poor specific impulse, which drives the spacecraft size. The second challenge is the minimum specific impulse, which is still fairly high compared to what is needed for the VTXO mission. However, the thrust level can be managed with careful controller design. The final element of this challenge is the navigation, the requirement for range knowledge between the two-space craft is relatively modest, being only around ±1m, this is reasonably achievable with an inter-satellite radio ranging link. The more difficult challenge is determining position in the plane perpendicular to the telescope axis, where the knowledge requirement is on the order of 20 microns (1 sigma). In order to meet this requirement, VTXO will use an optical tracking system based on a star tracker. This star tracker will look at a beacon light on the other spacecraft and compare its position to the background starfield. With a sufficiently high angular resolution star camera, this methodology is sufficient to determine the lateral positioning of the two spacecraft. A star camera with an angular resolution on the order of 10’s of milli-arc seconds has been

identified for this mission; at 1 km separation this will provide adequate lateral positioning knowledge to meet the VTXO requirements.

This paper will provide an overview of the VTXO mission, with an emphasis on the formation flying, capabilities. Beyond VTXO, the formation flying capabilities developed for this mission will in the future will provide key technologies to enable both missions with a larger Phase Fresnel Lenses and a corresponding increase in angular resolution, as well as a distributed aperture telescope, which NASA has identified as one of the key enablers of future telescope missions.

Figure 1: Artist impression of VTXO cruising through perigee.

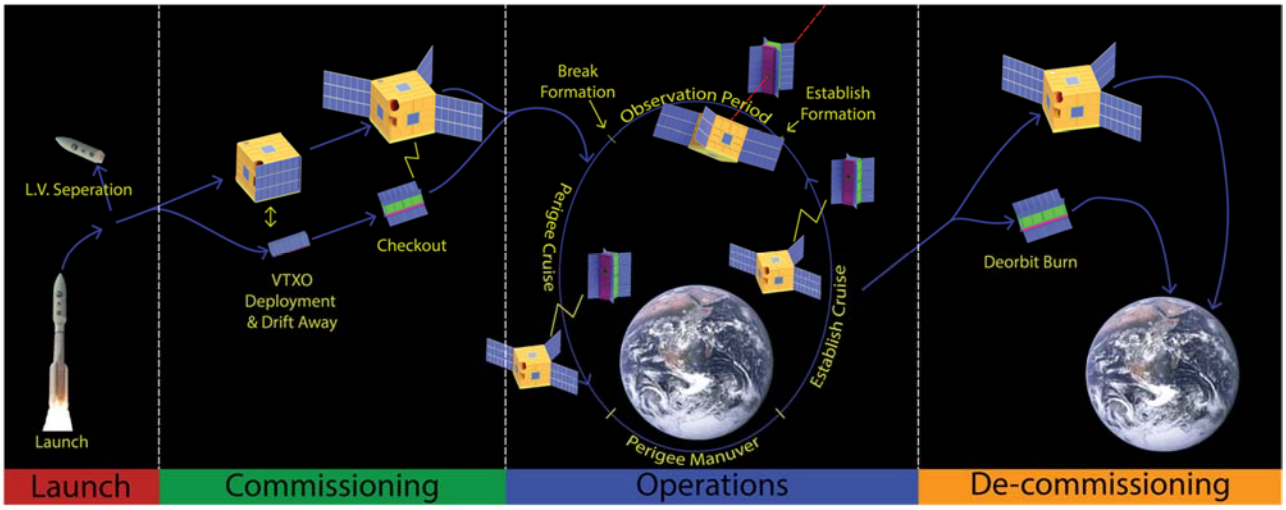

Figure2: VTXO concept of operations (Con-Ops)

MARTINLARA: MILLIMETER WAVE ARRAY AT ROOM TEMPERATURE FOR INSTRUMENTS IN LEO ALTITUDE RADIO ASTRONOMY

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The goal of MARTINLARA project is the design of a demonstration space mission in orbit, and the development of several technologies to be airborne validated, namely radio astronomy and earth observation instrumentation, space photonics and plasma micropropulsion, all of them carried out by research groups and companies in Spain. The project involves the development of a nanosatelite platform for aiborne validations. SENER and AIRBUS companies along with the Astrophysics Institute of Canary Islands (IAC) will participate as associate members of the project, having their own activities. The project has 5 main goals, which involve the development of the experimental technologies and the satellite platform:

1. Development and technological demonstration of a multiband array of mmwave photonic radiometers working with no cooling, for observing the cosmic microwave background.
2. Development and technological demonstration of mmwave photonic radiometers working with no cooling, for earth observation and retrieval of climate change parameters such as the atmospheric humidity and temperature, including the software for data postprocessing.
3. Demonstration of several functional spaceoriented technologies, including photonic technologies, gallium nitride amplifiers, and onboard retroreflectors for laser ranging measurements.
4. Development of the first Spanish electrical micropropulsion system with pulsed plasma, for the maintenance and orbital control of nanosatelites and its lifetime increase in low earth orbits.
5. Development of a versatile nanosatelite for the airborne demonstration of space technologies.

Several applications require the detection of extremely weak signals in the microwave and THz domain. This is challenging specially at higher frequencies due to the thermal noise generated inside the receivers, and the quantum nature of the electromagnetic radiation. The latter sets the so-called "quantum limit" as the maximum sensitivity achievable by any detector. For a detector to approach the quantum limit, it requires to be cooled down to temperatures close to absolute zero, so quantum noise dominates over thermal noise. Detectors may however, be engineered such that at a given temperature, the lowest possible level of thermal noise is generated inside. At room temperature, higher frequency receivers are particularly noisier beyond the fact that blackbody radiation grows with frequency. This suggests there is room for optimizing state-of-the-art microwave and THz receivers if new approaches are followed.

We propose as a new approach [1, 2, 3], the transformation of microwave or THz radiation into optical signals that can be manipulated and detected with commercial optical devices at room temperature. This "up-conversion" can be performed inside resonators made of nonlinear crystals. Hence, a microwave or THz ultra-low noise receiver working at room temperature can be designed under this principle, and achieve similar performance to state-of-the-art receivers operating inside cryostats.

The aim of this project is the development of an u ltra-low noise microwave up-converter working at room temperature suitable for a maximum sensitivity receiver. Some challenges need to be overcome to achieve this. Specifically, the up-conversion efficiency and bandwidth have to be increased from 1 to 3 orders of magnitude with respect to the state-of-the-art upconverters, while reducing the thermal occupation. The proposed concept would set a breakthrough technological advance in three fields of high interest: radio astronomy instrumentation, THz receivers and quantum computing.

It is expected that the developed technologies become a new paradigm for multiple types of space missions. In the short term this implies the development of new capabilities in the research groups, and the creation of a collaboration hub in the Community of Madrid on space technologies. In the mid and long terms it implies the integration in international projects on radio astronomy, earth science, and space micropropulsion, which have a significant impact in the solution of social problems (climate change, prediction of natural disasters such as earthquakes, access to Space). This is a multidisciplinary project that seeks the combination of several disciplines and techniques in the fields of space engineering, telecommunications, astronomy geodesy and geophysics.

[1] Dmitry V. Strekalov et al., "Nonlinear and Quantum Optics with Whispering Gallery Resonators," Journal of Optics, 18, 123002 (2016).

[12] Alfredo Rueda et al., "Efficient microwave to optical photon conversion: an electro-optical realization," Optica 3, 597-604 (2016).

[3] F. Sedlmeir et al., "Efficient Up-Conversion of Weak THz Signals into the Optical Domain Using a Whispering Gallery Mode Resonator," in Conference on Lasers and Electro-Optics (2016).

6S PAYLOAD IN CUBESAT FOR SPACE-BASED INTERNET OF THINGS

Sunquan Yu[1], Lihu Chen[1], Yong Zhao[1], Chengguang Fan[1], Tao Sheng[1], Xin Song[1]

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In this paper, 6S payload for cubesat is designed and utilized in the area of space-based internet of things (IoT). The 6S payload includes the following function. 1) AIS for Automatic Identification System, 2) VDES for VHF Data Exchange System, 3) ADS-B for Automatic Dependent Surveillance-Broadcast, 4) DCS for Data Collection System, 5) BES for Broadband Electromagnetic Spectrum Perception, 6) ESR for Emergency Search and Rescue. The 6S payload is based on the theory of Software-Defined Radio (SDR), and its hardware as well as software framework is suited for CubeSat. A series of ground tests have been implemented, and it is shown that 6S payload is reliable and sensitive. In addition, the prototype of 6S payload has been in-orbit demonstrated in the Nano-satellite, such as TianTuo-1 and Tiantuo-3 in China.

The 6S payload is to achieve a global surveillance of ship and aircraft, to acquire search and rescue information, to perceive the global electromagnetic spectrum, and to explore the construction of space-based IoT by using the CubeSat platform.

The 6S payload consists of a standard 1U integrated electronic module, several high frequency cables, a V-UHF antenna and an L-C antenna. The V-UHF antenna operates in the 156 to 470 MHz to receive AIS（156.8~163MHz), receive and transimit VDES（156.8~163MHz), DCS (400~470MHz) , and BES (406MHz) signals; L band (1090 MHz) is used for ADS-B signal reception; L&C antenna support channel bandwidths from less than 1GHz to 6GHz which is used for ESR.

The integrated electronic module is composed of three RF and one baseband boards: 1) RF front-end boards includes microwave switch, diplexer and low noise amplifier (LNA) of each channel. They select, amplify and filter the RF signals in multi-channel circuit. After that, they are easily accessible with today's SDR hardware like the Analog Devices AD9361/AD9371 integrated RF Agile Transceivers. 2) Baseband processing module includes a high-capacity FPGA and ARM proccessor. The FPGA is used for multi-protocol and multi-system terminal signal modulation and demodulation, and ARM can realize telemetry and remote control (TT&C). Each PCB board can be assembled by interboard connectors and then installed in the mechanical shell to ensure a good electromagnetic compatibility and mechanical properties.

Finally, 3S (AIS, ADS-B and DCS) is flying on orbit, and 6S payload will be demonstrated on-orbit by June 2020. By now, all functions have been validated by ground test, since authors have developed ground test simulators and the results show that the design can meet the space-based requirements.

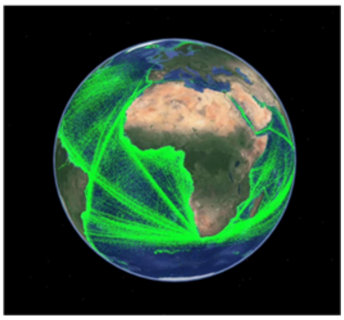

Figure 1: TianTuo-3 AIS stack

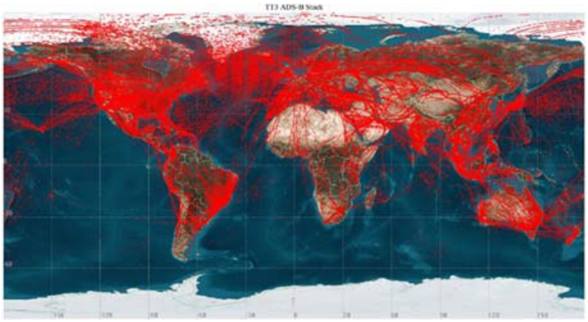

Figure 2: TianTuo-3 ADS-B stack

Figure 3: 3S payload for in-orbit demonstration

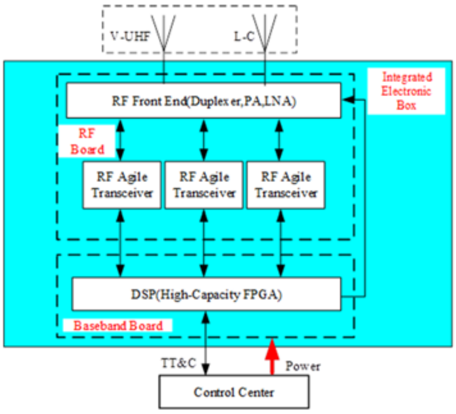

Figure 4: 6S payload hardware design

DEVELOPMENT OF SHARJAH-SAT-1: AN IMPROVED X-RAY DETECTOR ONBOARD A 3U CUBESAT

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Muhammad Mubasshir Shaikh[1], Alim Rüstem Aslan[2], Emrah Kalemci[3]

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SHARJAH-SAT-1 is a 3U CubeSat with a dual payload onboard: (i) improved X-ray Detector (iXRD) and (ii) a camera. The main scientific targets of the mission are the solar coronal holes and bright X-ray sources in our Galaxy. The main technological aim of this project is to develop a CubeSat, from A to Z, operational in the hard X-ray regime. Since X-ray radiation is absorbed by the Earth's atmosphere, instruments to detect X-rays must be positioned in space. Low Earth Orbit (LEO) offers this opportunity for many CubeSats. The SHARJAH-SAT-1 would be the first CubeSat mission to be developed by the Sharjah Academy for Astronomy, Space Sciences, and Technology (SAASST) students and researchers, with the aim of not only designing, fabricating, testing & launching the CubeSat itself, but also building the capacities and expertise for future CubeSat missions as well.

At present, small satellites constitute a crucial part of the satellite development throughout the world. CubeSats have started to play a vital role in the field of complex space engineering applications. The fixed mass of a 1U CubeSat is 1.33 kg per unit (U) and based on the use, it could consist of multiple 10 cm × 10 cm × 10 cm units (U). Several critical CubeSat missions were proposed and supported by various space organizations/agencies, research centers, and Universities throughout the world for expanding the utilization of CubeSat Competency. Our 3U CubeSat (34 cm × 10 cm × 10 cm, resulting in less than 4.0 kg) will consist of the science payload and the bus. Figure 1 shows a 3D model of SHARJAH-SAT-1, revealing the payload (X-ray detector) and the major subsystems, e.g., EPS, ADCS, OBC, solar panels, etc. on board. The ADCS unit (having a volume of 0.8U) will provide, with a 3-axis control, an accuracy of around ~1 degrees. This accuracy is the minimum requirement for the two payloads to perform their missions. Another major subsystem, namely the communications, is vital to receive telemetry, instrument health, science data, and send commands. The communication with the ground station will be established via SAASST ground station operating in VHF, UHF, and S-Band, to be also established during the coarse of the project. Moreover, the downlink of science data and images will take place through the S-band due to the demanding amount of scientific data. For the project SAASST is working in close collaboration with the Istanbul Technical University, Space Systems Design and Test Laboratory (ITU-SSDTL) who has already developed and launched 5 CubeSats in to low earth orbit.

The primary science instrument on board is the iXRD (developed by the Sabanci University in collaboration with ITU-SSDTL) which will provide an improved version of XRD on board BeEagleSat, one of QB50 project CubeSats. The leading technology behind iXRD will be a CdZnTe-based crystal, operational in the hard X-rays regime, between 20 and 200 keV energy range. The target spectral resolution of the detector is 6 keV at 60 keV. A summary of the expected performance is given in Table 1. In addition, a collimator specially designed for the mission will be placed on top of the detector, providing an opening angle necessary to fulfil the science objectives. Figure 2 illustrates a possible configuration of iXRD 3D model and the collimator from different views.

The main science goal of the mission is to observe and study the development of solar coronal holes, responsible for driving the stellar wind at an early phase. Moreover, hard X-rays from very bright galactic X-ray sources will be complementary targets. Black Hole candidates and pulsars can emit radiation up to a few 100 keVs making them potential targets. Another target of opportunity is the transient bright events, like gamma-ray burst (GRB), magnetar bursts and nearby tidal disruption events (TDEs).

In conclusion, this mission is being developed by SAASST, the University of Sharjah in close collaboration with ITU-SSDTL and Sabanci University to deliver the first Emirati X-ray CubeSat into space. The anticipated launch is planned for late 2020. The experience gained through the development of SHARJAH-SAT-1 will be transferred to future CubeSats programs.

Table 1 : The iXRD payload properties

Property	**Expected Performance**
Active volume	25.4 × 25.4 × 5 mm^3
Electrode design	36 pixels
Energy Range	20 – 200 keV
Energy Resolution	6 keV @ 60 keV
Readout electronics	RENA 3b ASIC (36 channels) MSP430
Collimator	Tungsten
Power	1 W
Size	10 × 10 × 2 cm^3 + Collimator 2 × 2 × 3 cm^3
Weight	350-400 g with Collimator
Data Rate	To be Defined

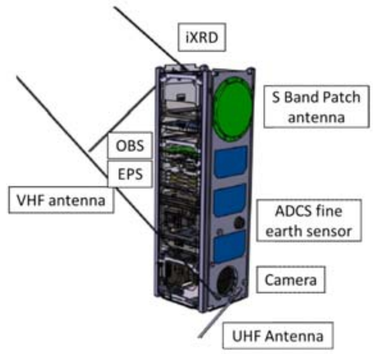

Figure 1: A 3D model of the SHARJAH-SAT-1 CubeSat with the relevant subsystems

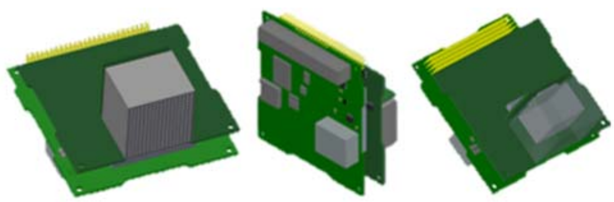

Figure 2: A 3D model of the main payload, improved X-Ray Detector (iXRD) on board SHARJAH-SAT-1

SESSION 5
CUBESAT SUBSYSTEMS AND TECHNOLOGIES

SPIN MAKES FOR COOLER SATELLITES

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Satellite Thermal Systems are; heavy, bulky and more often than we would like, they don't work properly. Thermal modelling of microsatellites uses many approximations and, in the course of many simulations one aspect has been overlooked, the cooling effect of spin. Existing simulations assume a trend towards an equalized surface temperature as spin rate increases. Those simulations of a multi-body system in the transient state neglect the fact that the interferences between materials behave differently in the transient state. The varying modes of heat transfer produce distortion not visible in those overly simplified simulations. Using a finite difference and radiation coupling methods in the transient state an insulating effect of spin has been found.

This paper explores a potential method of actively controlling the temperature of the satellite and the sensitive scientific instruments within while not adding anything to existing subsystems in terms of mass or volume.

Spin has been a known influence on satellite's temperature profile, but not been found to reduce the overall temperature on a satellite. Due to the insulating effect of spin the internal temperature will be raised with higher rotation if the effect of internal heat sources is dominant.

A new means of lowering spacecraft temperature by varying spin allows for removal of bulky insulation and complex active control systems reducing design and launch costs as well as improving survivability. The performance at different orbit inclinations and a range of internal component layouts will be presented. The power requirements of magnetorquers and the spin decay factor will b, but the overall temperature reduction of the total satellite will allow for new mission profiles.

A mathematical relationship between satellite spin and temperature control can be used in providing safer and cheaper spaceflight.

Since the heat capacity of outer layers is greater than zero a rotation there is a delay in heat transmission across an interface akin to a control system response. In a non-spin setting only the thermal capacity of one side and its resistance to conduction is in effect.

Due to very high temperature difference between the sun and satellite reduction in incoming heat flux due to higher temperature is negligible. When instead of one very hot surface you have four more thermally equalized surfaces with lower temperature difference.

Transfer across the layers of the satellite occurs in great respect to radiation, the interface between layers has conduction but in a vacuum conduction between materials is a function of contact pressure and surface finish. This means that when outer temperature is higher the effect on the inner components is to the power of four and not linear as assumed in previous detailed simulations and analytical studies.

DESIGN AND ANALYSIS OF AN ATTITUDE DETERMINATION AND CONTROL SYSTEM FOR THE ORCASAT CUBESAT

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[1] Instituto Superior Técnico, Universidade de Lisboa

[2] Department of Mechanical Engineering, Faculty of Engineering, University of Victoria

The main objective of this work is to provide a robust design for an integrated Attitude Determination and Control System (ADCS) for the 2U CubeSat ORCASat. The launch opportunity is provided through the Canadian CubeSat Project (CCP) of the Canadian Space Agency (CSA), which will deploy the CubeSat into a Low Earth Orbit from the International Space Sation (ISS).

Attitude determination and pointing control in CubeSats is challenging due to the inherent volumetric constraints, high cost of reliable and miniaturized ADCS hardware, and the limited power generation. In the case of ORCASat these challenges are considerably augmented because the 2U CubeSat needs to function as a platform for two distinct calibration payloads – the Airborne Laser for Telescopic Atmospheric Interference Reduction (ALTAIR) and the Canadian Hydrogen Intensity Mapping Experiment (CHIME).

Spacecraft design processes have been well-established in several reference works [1][2]. According to them the design of an ADCS begins with the establishment of system requirements. In this case they are a 10[deg] pointing accuracy off the nadir direction and a 2[deg] pointing knowledge during both the eclipse and sunlit portions of the orbit.

The attitude determination section of the system is based on a multiplicative extended Kalman filter (MEKF), developed for the 3U CubeSat ECOSat-III [3]. The MEKF uses sensor data from sun sensors, magnetometers, and gyroscopes to fulfil the 2[deg] pointing knowledge requirement.

The attitude control section was specifically developed for ORCASat. Firstly, an analysis of the available stabilization architectures was made, which led to the selection of a momentum-bias attitude control - consisting of a momentum wheel and three orthogonal magnetorques. The modes associated with the mission requirements were then defined as a detumbling mode, a nominal nadir pointing mode and safe mode. The detumbling of the satellite is achieved by using a B-dot algorithm. For nominal nadir pointing mode, the selected controller algorithm, used to command the active magnetic actuators, is based on an eigenaxis rotational maneuver controller [4]. The controller consists of a negative feedback loop of quaternion and angular velocity errors, and a direct compensation for the gyroscopic term of Euler's rotational equation.

To characterize the controller gains and to analyze the system's response to environmental disturbances in nominal orbital parameters, a spacecraft ADCS simulator was created using MATLAB and Simulink. The simulator helped verify the designed system and to test for a range of parameters that are difficult to fully define in the early stages of the ORCASat's development and that have a significant impact on attitude control: the spacecraft's magnetic dipole moment and inertia matrix.

As shown in the simulation example of Figure 1, the proposed ADCS is able to achieve an overall pointing accuracy below the 10[deg] requirement for a representative set of parameters. The simulation also demonstrates that even though the system can take several orbits to achieve nominal nadir pointing, once it does it remains within the requirement.

A discussion is then made on strategies to mitigate the disturbing effect of the magnetic dipole moment and how to manage the inertia matrix of the CubeSat's structure, to facilitate the ORCASat's attitude control.

The techniques used in this work indicate the worth of established attitude control approaches for CubeSats, which have ever-expanding roles and demanding requirements.

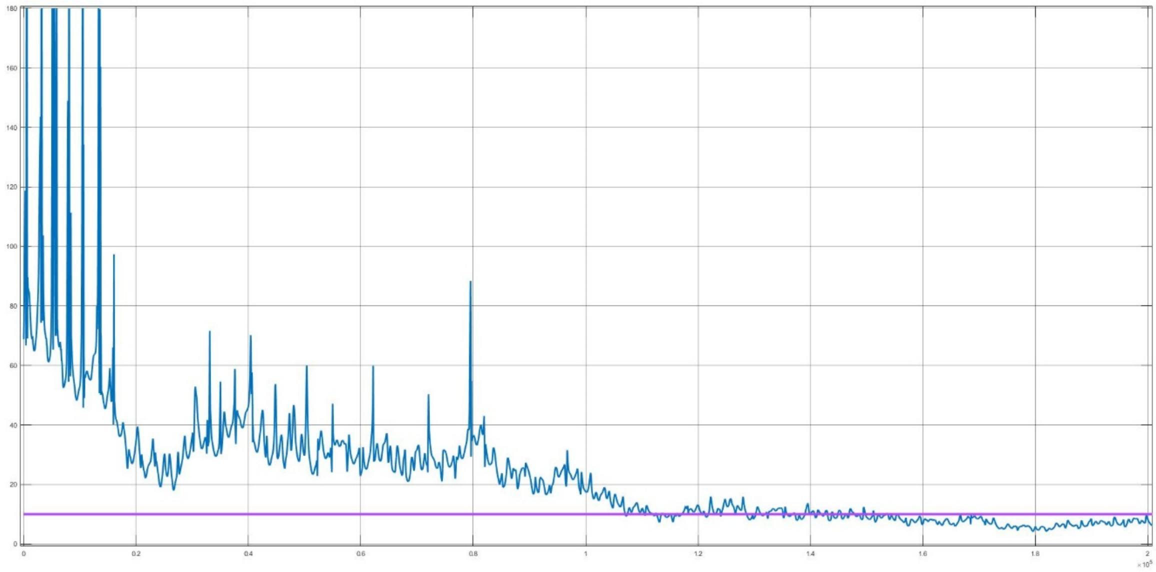

Figure 1: Overall pointing error for a set of representative parameters for ORCASat.

References:

[1] Wertz, James Richard, David F. Everett, and Jeffery John Puschell, eds. *Space mission engineering: the new SMAD*. Vol. 1. Hawthorne, CA: Microcosm Press, 2011.

[2] Markley, F. Landis, and John L. Crassidis. *Fundamentals of spacecraft attitude determination and control*. Vol. 33. New York: Springer, 2014.

[3] Rondão, D. *Modeling and Simulation of the ECOSat-III Attitude Determination and Control System*. Diss. Master's thesis, Instituto Superior Técnico, Lisboa, 2016.

[4] Wie, Bong. Space vehicle dynamics and control. American Institute of Aeronautics and Astronautics, 2008.

ON-BOARD CLOUD COVERAGE ESTIMATION USING DNN TECHNIQUE FOR VISIBLE BAND IMAGERY

Jin-Hyung Kim, Dong-Hyun Cho and Sanghyuck Han

Korea Aerospace Research Institute

In the past, mid-to-large scale satellite companies, such as Airbus D&S, Urthecast, Digital Globe, occupied most of the Earth observation satellite market to meet a few limited clients' requirements. However, nanosatellites are changing the paradigm of the Earth observation satellite market and development environment. Unlike mid-to large-sized satellites which equipped with high-performance and very expensive payloads, it is now possible to shoot wider Earth surface areas more frequently at a lower cost. Moreover, the number of the startups of Earth observation nanosatellite is increasing drastically in recent.

Nanosatellites are designed with tradeoffs between the development cost and performance. In general, in order to maximize the resolution of imagery at limited form factor, the developers give up agility. Due to low attitude control accuracy, the developers choose 2D planer CCD/CMOS array instead of line CCD/CMOS array. Since communication with ground stations is limited, the number of images that can be transmitted to the ground is limited due to the limitation of the performance of the on-board communication system. Thus, we need to take an efficient downlink strategy, such as setting priority of download.

Meanwhile, according to NASA's research, the 67% of Earth surface is constantly covered with cloud. Cloud has more dynamic characteristic compare to fixtures on land surface which is containing what customers want to see. According to KARI's report, only 25% of the downloaded images taken by KOMPSAT-1 were not contaminated by cloud. It means there was 75% of waste in communication downlink.

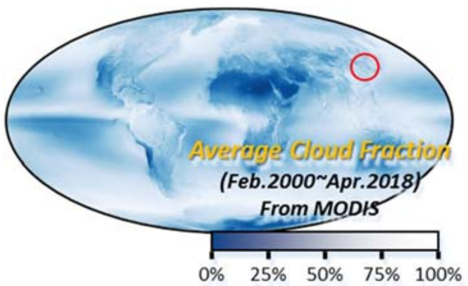

Figure 1: Average cloud fraction from MODIS

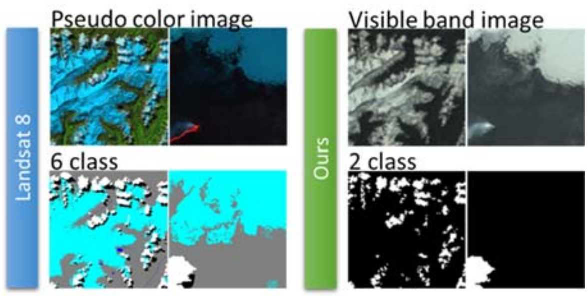

Figure 2: Construct Dataset

In this research, we are developing the on-board cloud coverage estimation algorithm based on machine learning technique for visible band imagery, which are composition of RGB, in order to overcome the fundamental problem with limited COTs product. We use the cloud-annotated open dataset of OLI(Operational Land Imager) and TIRS(Thermal Infrared Sensor) data from Landsat8. Because the open-dataset imagery are based on multi-spectral band, we create a new dataset by extract visible band which is consisted with RGB bands. The figure shows the modification of dataset. Since the modified dataset loses thermal information, cloud detection is harder than Landsat8 dataset. Our algorithm estimates cloud coverage with three phase. First, it filters out the trivial saturated or cutoff images using texture measurement such as standard deviation of image. Then, SqueezeNet based neural network classifies whether the input image is saturated with cloud or contained with no cloud or has nominal cloud amount. The SqueezeNet is chosen because it is a light neural network. After that, U-Net based neural network estimates for images which contain nominal or no cloud finally. Since the U-Net is very heavy network, we took two strategies to decrease complexity of the network. First, we decreased depth of the U-Net and the number of filters in layers. Second, we pruned out for low activating filters in layers. We've achieved to develop algorithms with relatively less computational complexity while preserving performance. In the future, we plan to port the algorithm to FPGA appropriately to mount on OBC.

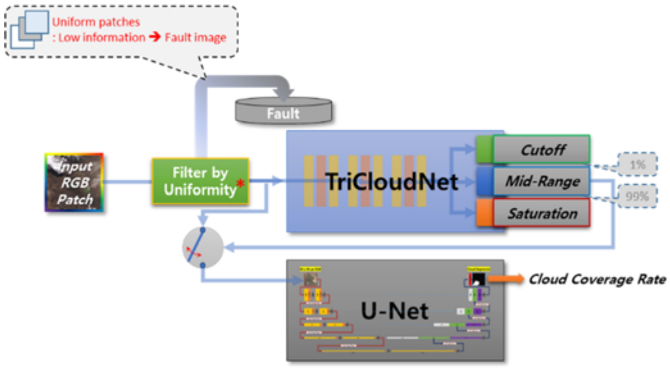

Figure 3: Overall procedure of proposed algorithm

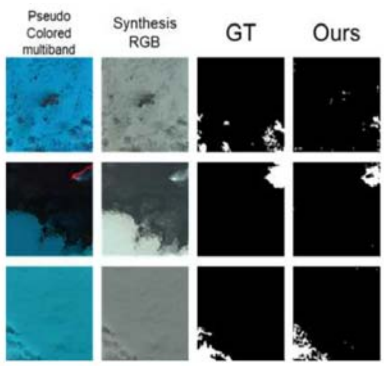

Figure 4: U-Net based On-board cloud coverage estimator result

SESSION 6

TELECOMMUNICATION AND GROUND SEGMENT

ESOC GROUND STATION ARCHITECTURE FOR CUBESATS

André Lofaldi

Solenix, European Space Agency, Germany

The SMILE Ground Station is located at the European Space Operations Centre (ESOC) in Darmstadt, Germany and is part of the Special Mission Infrastructure Laboratory Environment (SMILE). It currently comprises two terminals, ESOC-1, which is a commercial 3.7 meter S/X-Band antenna, and ESOC-1A, which supports the VHF, UHF and S-Band amateur radio frequency bands.

ESOC-1 is capable of transmitting and receiving in S-Band and receiving in X-Band. It is designed for tracking spacecraft in LEO and it features a 3 axis positioner which eliminates the "key hole" problem for high elevation passes. To protect the system from the environment, it is protected by a glass fibre radome. A fiber optic link connects the antenna to the back end and control room.

ESOC-1A features two crossed Yagi antennas, one for VHF and one for UHF, a 1.2 meter mesh dish for S-Band, all mounted on the same axis.

The back end consists of a CORTEX Command, Ranging and Telemetry Unit and a set of Software Defined Radios (SDR) for experimental modulation and communication protocols.

OPS-SAT is a ESA driven cubesat mission which is to launch in late 2019, it will utilize the UHF system of ESOC-1A with a dedicated GomSpace GS100 modem, as well as the S-Band system of ESOC-1 for TT&C. X-Band will be used for high bandwidth experimenter data. The MCS is based on SCOS-2000 and can operate interchangeably in UHF and S-Band.

The main mission of OPS-SAT is to allow external institutions to develop custom applications and take control of the spacecraft, including experiments with the communication systems. This flexibility is a perfect match for the SDR back end of ESOC-1.

AN OPEN SOURCE IMPLEMENTATION OF THE CCSDS SLE SERVICES IN PYTHON

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VisionSpace Technologies GmbH

LibreCube Initiative

The Open Source CubeSat community is currently lacking the capability to use existing radio amateur ground-station networks to transfer live data to the end users / mission control centres. SatNOGS, the biggest network of the kind, provides services for archiving and offline distribution of telemetry data. At the moment, an operator using the SatNOGS network is not able to receive telemetry in real-time and make use of the station uplink chain, when available, for direct commanding. We believe that the community could benefit considerably from services that provide real-time monitoring and control over a distributed ground-station network.

As a first step to address the current limitations we introduce in this contribution a new free and open source implementation of the CCSDS Space Link Extension (SLE) services in Python. The SLE standard, used by all major space agencies, is one of the most adopted CCSDS standards and is key to enable the inter-agency utilisation of ground-station networks like the Deep Space Network. Additionally, it is supported by most, if not all, private ground-station operators. SLE services have proven reliable, and can be used even for missions, like most CubeSats, that do not adhere to the CCSDS telemetry and telecommand frame and packet formats. SLE provides different types of telemetry return services, for real-time telemetry reception, a telecommand forward service and the capability to receive annotation information about the current status of the space link. We take the initiative to put forward a solution based on SLE because of its proven track record and out-of-the-box interoperability with existing commercial and agency ground-stations.

Our current SLE stack offers:

An **SLE provider**, offering the ground-station (provider) side services for delivery of telemetry and uplink of telecommands. In addition, it offers some level of ground-station configuration management services over a REST API (https://github.com/visionspacetec/sle-provider);

An **SLE management client**, allowing anyone to access the SLE management services on the provider using a Python API (https://github.com/visionspacetec/sle-management-client);

A set of **SLE common libraries** (e.g. ASN.1 mapping) for the development of provider and user services (https://github.com/visionspacetec/sle-common).

In the current implementation only the Return All Frames (RAF) service has been implemented. RAF is not only able to transfer CCSDS telemetry transfer frames but also any other frame format like AX.25, which is used by many amateur CubeSats. The event-loop based implementation in Python is lightweight, cross-platform and easy to deploy. Python was chosen because of its wide use in the Open Source community and the short development cycles it allows. It provides high data throughput, enough for amateur and most commercial satellites. A heartbeat mechanism ensures that the connection is always alive and ready to transfer mission critical data. The communication between user and provider can be encrypted, using the implemented protocol features and has been verified with up to date reference software from the European Space Agency (ESA). For the REST API, the use of HTTPS is prepared and can always be combined with an authentication scheme to ensure data integrity at any time.

The current stack does not offer an implementation of an SLE user since at the time of writing at least two free and open source implementations exist: LibreCube SLE and the NASA AMMOS framework. Our provider has been tested and proven to work with both. In addition, we have tested our implementation against the SCOS-2000 ground-station Network Interface System (NIS), showing that it holds against existing commercial implementations of the SLE user. In what concerns the interface of the SLE provider with the ground-station backend, the provider has been tested with the Cortex CRT at ESA's European Space Operations Centre (ESOC) development ground station ESOC-1.

Besides its use in a traditional ground-station setup, the SLE provider can also be used to relay telemetry and telecommand data from/to cloud ground-station service providers and satellite operators. Cloud based scheduling systems could be used to dynamically configure the ground-station network, using the SLE provider's REST API, ensuring highly efficient use of the ground-station time and minimizing the need for human interaction. Upcoming developments include not only the support for a wide range of commercial and amateur ground-station equipment and Software Defined Radios (SDR), but also extensive testing and further performance improvements. Implementation of the telecommand forwarding service is also planned.

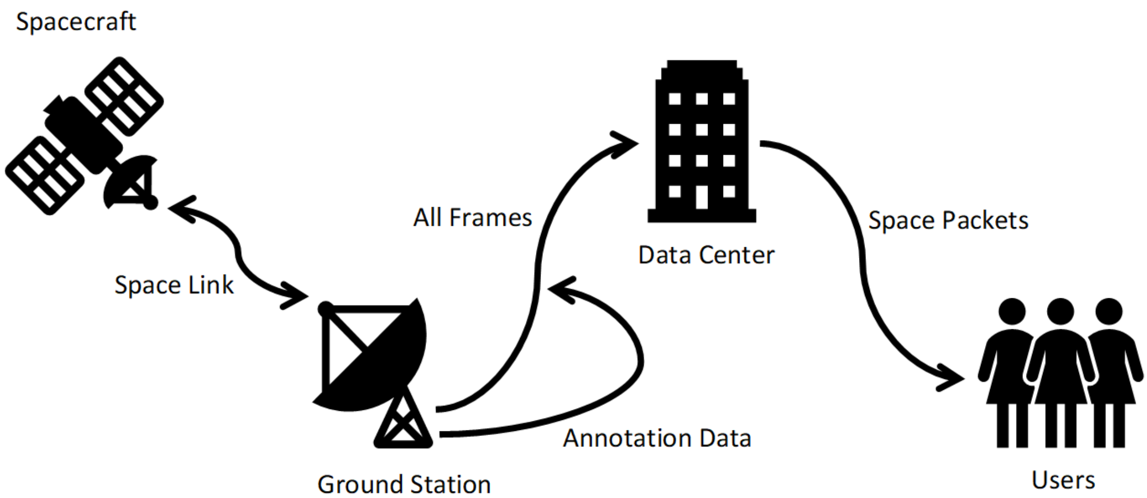

Figure 4: Example SLE RAF service configuration

IRIS CUBESAT COMMUNICATION SYSTEM, AN AD-HOC COMMUNICATION CONCEPT

Yun-Peng Tsai[1], Dian-Syuan Yang[1] and Jyh-Ching Juang[1]

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The development of The Internet of Things is at an ascending rate. The communication system of CubeSat is different from two places, compared to the "things" that are about to be connected in the IoT future. In the first place, the major method of LEO CubeSat to do data exchange is still through the mission-specific ground station. The number and the coverage of accessible ground stations would directly restrict the data exchange volume per day. In the second place, the current frequency allocation method for CubeSat operation would soon not be suitable to apply in a crowded spectrum. With an increasing number of CubeSat, it would increase the salience of spectrum scarcity issue. This phenomenon can be observed from the development process of the terrestrial mobile communication system. IRIS team recognize that the above issues would limit the potential use of CubeSats in support of the future mission. The IRIS-A mission goal is to assess the performance and potential limitations of the Ad-hoc communication concept using terrestrial communication technology.

Based on the Ad-hoc communication concept, CubeSat can be capable to connect and log out the Internet network provided by the ground station dynamically, via LTE protocol with the eSIM solution. The IoT payload monitors the displacement between its current position and target ground station. When CubeSat approaches the target ground station, a sync signal will be broadcast. Once the CubeSat signal is identified by the ground station, the data exchange process will automatically perform. The implementation of this function would need the following three devices to cooperate in IoT payload. Firstly, a custom-made software-defined radio module is used to perform two key functions. One is the eSIM solution which is used to identifies and authenticate the CubeSat to connect the Internet network. Another the estimation and compensation of Doppler effect experienced by the ground station. Secondly, a GPS receiver notifies CubeSat current position in orbit. The last one is a chip-scale atomic clock which provides accurate time information. The design of the selected concept and technical solutions will be mentioned in a presentation.

IRIS project funded by MoST in Taiwan is planned to launch two different CubeSat missions, named as IRIS-A and IRIS-B. IRIS-A is for IoT communication technology demonstration, and IRIS-B is for in-orbit intelligence that remotes sensing data processing technology demonstration. In addition, the communication module will be validated through these two missions, the pioneering IRIS-A, and the following IRIS-B.

KA-BAND ISL FOR SMALL SATELLITES

ESA Contracts No. 4000117148/16/UK/ND and 4000125853/19/UK/AB

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1. Abstract

In this paper we will elaborate over an inter orbital Inter-Satellite link.

Inter-Satellite links are communications subsystems acting as enablers or performance enhancers in satellite constellations. They reduce communications latency and decrease dependence on ground segments.

Antwerp Space has been very active and interested in the development of such technology since many years. With the intra orbit ISL project (LEO-LEO, in Ka band) almost near its completion, a new development has recently started on a data relay system using FSS frequency bands of Telecom Satellites (LEO-GEO).

The purpose of this project is to develop and test a flight model of an on-board Transceiver at Ka-Band, performing a function of Inter-Satellite Link from one cubesat in LEO orbit to a Telecom satellite in a GEO orbit. The project includes also a mandatory IOD where the capabilities of the system will be fully demonstrated.

Its distinguishing feature is that it targets small-sized units developed using so-called 'COTS' components, validated for use in Space by means of lighter procedures than for conventional Space units flown on larger satellites, yet dependable enough to support commercial missions for 5 to 7 years at least.

The project will thus deliver a pair of transmitter and receiver units very close in build standards and cost to the subsequent models of the Flight product. These units will be designed for integration aboard the small modular spacecraft known as Cubesats. During the project several potential users have been contacted, i.e. constellation promoters and satellite manufacturers, to evoke their interest in the use of ISLs in their application domains. These span communications, Science, AIS, VDES, ADS-B, Earth Observation and Machine-to-Machine (M2M) communications.

2. Market and Use cases

The global satellite industry is experiencing a shift of paradigm in both technologies and market applications, exhibited by the rapid expansion of the nano/micro satellite market segment being driven by emerging commercial applications such as low data rate communication (IoT/M2M) or low and medium resolution EO. This trend was caused by continuous miniaturization in electronics, cost saving, short timeframe from the development of nano/micro spacecraft to launch into the orbit and finally operations. It is estimated that during the time period of 2018-2022, 2680 nano/micro satellites will be launched of which approximatively 70% will represent commercial applications (22% communications and 50% EO and remote sensing).

Despite such technological and business advancements, one critical nanosatellite subsystem – ISL – making nanosatellite-based constellations technologically feasible for high value-added IoT/M2M applications, has not been introduced yet. This subsystem is required to downlink to end-customer's server real time or near real time data received by a satellite from IoT/M2M devices. Such requirement is critical for the following satellite communications applications:

- Space-Based ADS-B infrastructure to collect messages broadcasted by airplanes (1090 MHz via Extended Squitters).
- Space-Based AIS infrastructure to collect AIS messages broadcasted by vessels.
- Other IoT/M2M application such as high value asset monitoring where real time tracking is necessary.

The introduction of ISL will allow to match capabilities of constellations based on nano/micro satellites with those which are based on medium and large satellites.

3. Inter-Satellite Link frequency band selection.

3.1 Rationale and advantages of Ka-Band

During the project preparation phase preliminary contacts were established with the major operators offering global satellite network coverage: SES Global [L], Eutelsat [F], and Inmarsat [UK] in order to better design the system from both technical and economical point of view.

These discussion lead to the following conclusions:

- Consensus in all operator discussions is that C-Band should not be considered because of potential interference levels to adjacent GEO satellites due to limited LEO antenna size. This leaves Ku and Ka-Band.
- Ku band is available with adequate coverage from Intelsat (with future HTS to be covered [but] via LEOs), SES and Eutelsat. Ka is available world-wide with very good coverage in particular over the oceans from Inmarsat; SES also provide global Ka- service but via MEO satellites.

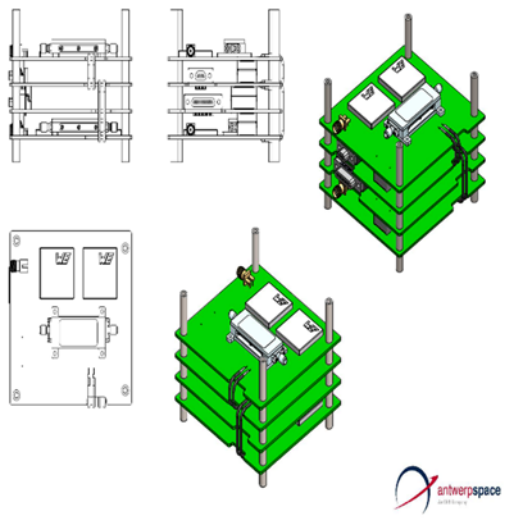
There is a similar a priori consensus opinion from Eutelsat and Inmarsat regarding the recommended use of spread-spectrum, in both directions, for both technical and economic reasons.

From a purely technical prospective, when speaking about ISL, Ka-band has several advantages compared to other frequency bands. One of the interesting facts about Ka band is that it carries double available bandwidth than in Ku band and five times more than C band. Due to the smaller wavelength this also means that Ka-band components are typically smaller, leading for example to smaller antennas. A common rule of thumb is that as frequency bands increase, antenna sizes go down. A Ka-band antenna is more or less half the cost of a Ku-band one, while occupying a much smaller footprint. Ka-band systems will, therefore, be smaller in size, less expensive, easier and quicker to install, resulting in a lower overall CAPEX than is the case with Ku-band systems. Ka band has also the advantage of being much more concentrated than the Ku band and can transmit more information with narrower beams, allowing the frequencies to be reused significantly, making subscription rates much more attractive. The available and larger amount of bandwidth supports higher transmission flow rates and therefore delivers higher speeds for subscribers. Having no vested interest in the spacecraft itself, be it a larger Cubesat or a diminutive smallsat, nor an exclusive link with a specific application, the system study leading to this development has been as comprehensive and open as possible. It also follows that the execution of the development work will be performed and focus for the In-Orbit Demonstration, and for the production of a professional Space product beyond the IOD. The configuration of the equipment in terms of technical solutions, component selection and testing philosophy provides a response to the triple constraint of performance, in-orbit dependability and budget. The technology developed focuses on the application of the Ka-ISL aboard CubeSats because it provides the most constraining environment in terms of technical budget. Larger satellites will easily accommodate a Ka-ISL sized for CubeSats. As part of the development, also an environmental validation programme will be developed, going beyond the usual proposal for experimental ventures, but still along the lines of a Cubesat-minded approach.

3.2 Mechanical design

In order to reduce mass, volume and cost, the system presents itself as a series of PCB boards stacked on top of each other, with local radiation shielding where required. To be able to mount this system in a CubeSat, the system has been designed to comply with the 6U structure. As for the CubeSat best practices, the PC-104 format has been taken as reference, which sets the maximum overall dimensions to 90.2 mm by 95.5 mm. The total height of the Ka-ISL system is of lesser importance, but in practice it is smaller than 1 unit.

The Ka-ISL system comprises a stack of four printed circuit boards, stacked-up on top of each other. The four boards (Rx, power, digital and Tx) are assembled as shown below.



The boards are oriented so that the connectors used for external data and power are oriented towards the inner structure of the spacecraft. The 6U structure is particularly well-suited for this purpose, as there is some space within the chassis for the passage of the cables. The Ka-ISL payload is interfaced with the satellite structure. Foreseeing a large heat dissipation, the payload is put in direct contact with the external surface of the satellite, on the (expected) coldest side of the spacecraft .

The electronics is arranged together as a stack. This is not only an advantage in terms of volume optimization, but also simplifies the harnessing, allowing shorter cables and even board-to-board direct connection if necessary. In addition, the boards have similar operational temperature requirements and arranging them together will simplify the thermal control of that part of the satellite.

An exception to the above rationale, is done for the UHF radio board, placed closer to the antenna set, in order to shorten the RF cabling.

COMPACT 3D PRINTED ANTENNA TECHNOLOGY FOR CUBESAT APPLICATIONS

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This paper presents a new technology enabling the design of high performance miniature antennas for CubeSats by using additive manufacturing of ceramic materials. Based on a patented technology [1], the dielectric material is structured in 3D to obtain the desired effective permittivity. High values of permittivity can be achieved in order to obtain miniature antennas. As an example, a patch antenna with a 3D printed substrate has been designed.

The above mentioned antenna should be a linearly polarized patch antenna that works at the GNSS L1 central frequency *(f=1.575 GHz).* The electromagnetic tool that has been chosen to simulate the antenna is Ansys HFSS. The size of the substrate is 50x50 mm^2 and the one of the ground plane is 65x65 mm^2. Thus, this antenna easily fits on a 1U CubeSat panel, however, we want to remark that the antenna has not been optimized in terms of size, since this was not the main goal of this work.

First, the patch antenna with a full substrate (ε_r = 7.6) has been designed. To find the 3D structure of the substrate with the same permittivity than the full-substrate, the effective permittivity can be calculated by combining full wave simulation and analytical models, hence, with the aim of the calculated S-parameters and using the theory of homogenization [2]-[3]. The full-substrate with the dielectric constant ε_r has then been replaced by the 3D-substrate with the effective permittivity $\varepsilon_{eff} = \varepsilon_r$. The simulated antenna with this 3D substrate presents a reflection coefficient below -30dB and a radiation pattern with a maximum boresight gain of 4.71 dB at the frequency *f=1.575 GHz*.

With these very encouraging results and to further show the feasibility of the 3D printed antenna technology, the patch antenna has been manufactured and measured. The manufactured 3D patch antenna is illustrated on Figure 1. The pieces (ground plane, 3D-substrate and patch) are hold together by a M3 screw. The antenna is fed by a SMA connector. The measured reflection coefficient is represented on Figure 2. As to compare this result with the simulated one, the S_{11} obtained in HFSS has been added to the diagram.

The simulated and measured reflection coefficients are very similar, however, there is a slight difference regarding the resonance frequency. The measured resonance frequency is at *1.655 GHz*, i.e. *5%* higher in frequency than the expected one. We consider that the difference arises by means of a tiny error in the effective permittivity of the manufactured 3D-substrate.

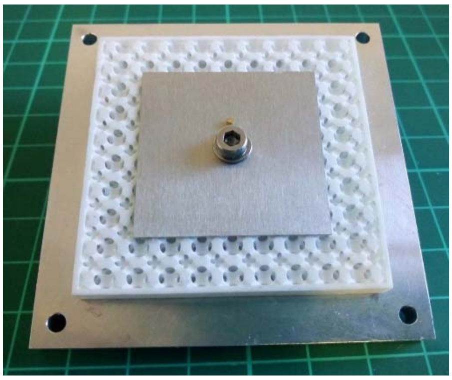

Figure 1: Manufactured 3D printed patch antenna.

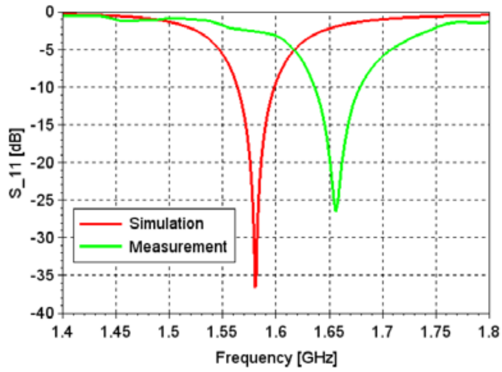

Figure 2: Simulated and measured reflection coefficient of the 3D printed patch antenna.

Thus, the feasibility and design principle is hereby demonstrated. The simulated and measured results of the antenna prove that this technology works very well. Except a tiny shift on the resonance frequency, the results are identical while using a full-substrate with a relative permittivity or a 3D-substrate with an effective permittivity**.** Simulated and measured results of the radiation pattern will be presented. The manufacturing of other compact 3D printed antennas, such as Dielectric Resonator Antennas (DRA), with the aim of this technology is planned.

References

N. Capet, "Method for manufacturing a dielectric part with meshes forming a three-dimensional solid lattice and dielectric part thus manufacture," WO2016092191A1, 16 June 2016.

Z. Hafdi, S. Zemouli and A. Chaabi, "Retrieval of effective parameters of left handed materials by using different approaches," 2013 8TH INTERNATIONAL CONFERENCE ON ELECTRICAL AND ELECTRONICS ENGINEERING (ELECO), Bursa, 2013, pp. 427-430.

D. R. Smith, S. Schulz, P. Markos and C. M. Soukoulis" Determination of effective permittivity and permeability of metamaterials," *PHYSICAL REVIEW B*, Vol. 65, 2002.

FLIGHT PLAN, CONTINGENCY OPERATION AND REDUNDANCY PROVISION FOR THE COMMUNICATION SYSTEM OF A 3U CUBESAT WITH HYPERSPECTRAL IMAGING PAYLOAD

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This paper details the modes of operation and various contingency provisions of the onboard communication system during the flight of a 3U CubeSat featuring a hyperspectral camera as its payload.

The satellite follows a combination of centralized and distributed architecture, with the On-Board Computing (OBC) system responsible for the execution of flight plan and payload operations, while other tasks are off-loaded to dedicated microcontrollers of the Electrical Power System (EPS) and Telemetry, Tracking and Command system (TTC). The OBC controls the sequence of operations, called modes, and communicates relevant sets of parameters to the EPS and TTC over SPI interface, whereas the individual microcontrollers perform specific operations in these modes. Control over the communication architecture, particularly downlink, is carried out by the TTC microcontroller. A hyperspectral imaging payload introduces unique constraints on power, on throughput as well as in terms of pointing. Hyperspectral cameras and associated image compression require very high amounts of power. This, coupled with the limited power generation capabilities of a CubeSat (due to their small size) presents a two-fold problem for the communication system - limited power availability, and at the same time, significant amounts of data to be downlinked. In addition to this, the communication system has to operate in limited amateur radio frequency bands due to regulations which further reduce the downlink speed and errors in downlink data increases.

Another problem is raised due to harsh space environment which presents a major challenge to the system, and the conceptualization of the system must therefore ensure reliability and robustness. These requirements significantly influence design decisions, not only for the hardware of the communication system, but also the software implementation of the modes and contingency operation for the telemetry subsystem. The satellite implements a full-duplex UHF-VHF architecture using Gaussian Minimum Shift Keying (GMSK) modulation scheme for data downlink and uplink, while a Morse coded, simplex, On-Off Keying (OOK) scheme for transmitting the beacon. The uplink is done via a monopole, while a turnstile is used for downlink.

While the OBC runs different processes in different modes, the TTC microcontroller also carries out mode-specific operations. The presentation elaborates the flight plan of communication system operations and how the TTC microcontroller switches between the modes therein. Entry conditions to and exit conditions from each mode are also described. The modes have to be designed to ensure that the system works even in case of emergencies, such as antenna deployment or system faults. Hence, interrupt-based emergency modes are included as part of the flight plan and elucidated subsequently. It also elaborates the following provisions to minimize emergencies and tackle system failures:

An initialization mode for the Telemetry system that determines antenna configuration full/semi-duplex settings dynamically in-flight on the basis of antenna deployment feedback and functional transceivers in circuit.

Sharing of beacon control between the TTC and the Electrical Power System, so that the beacon starts transmission as soon as antennas are deployed, regardless of a functioning TTC system.

Variable control over downlink/uplink among the TTC and OBC processing elements - The TTC microcontroller is programmed to control downlink (where uplink is handled by OBC) or both uplink and downlink (in case the initialization mode is semi-duplex)

Hardware duplication of critical-path resources to ensure a nominally functional system.

Study on configuring downlink turnstile as two independently operable dipoles in order to reduce the dependence of telemetry on the success of antenna deployment

Introducing contingency operations for hardware as well as software is crucial to achieve reliability and to ensure mission success in spite of component failure. The emergency modes have an operating communication system that is fueled by the redundancies proposed herein. In the end, a review is presented for various events of exigency, what input conditions trigger an entry into corresponding contingency modes and what processes are executed by the microcontroller.

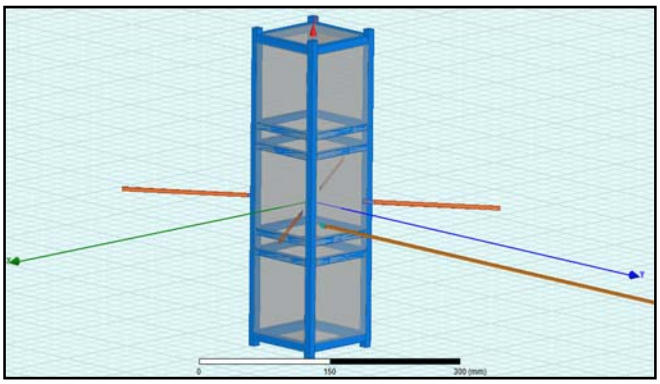

Fig. 1 Placements of Antennas (Monopole for VHF and Turnstile for UHF) with redundancy provisions

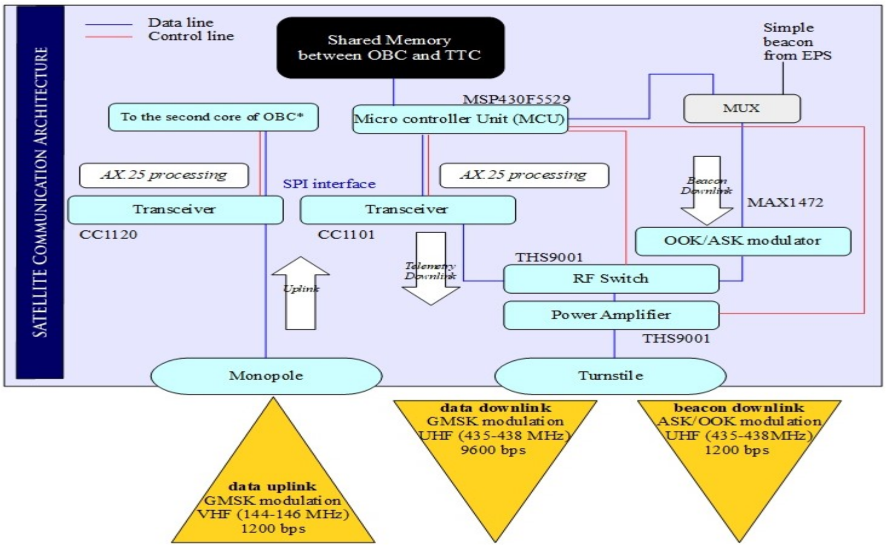

Fig. 2 Block diagram of on-board communication architecture

REFERENCES:

Modes of Operation for a 3U CubeSat with Hyperspectral Imaging Payload, Shubham Sharma, Rutwik Jain et. al. International Astronautical Congress (IAC) 2018, October 2, 2018, Bremen (Germany).

Swiss Cube,"SwissCube Mission and System Overview - Phase C," 2008.

Johan L. Tresvig, "Design of a Prototype Communication System for the CubeSTAR Nano-satellite", Department of Physics, University of Oslo, July 2010.

SESSION 7
CUBESAT CONSTELLATIONS

SPACE UNION – A LEO CONSTELLATION FOR SMALL SATELLITE DATA RELAY

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[1] Vilnius Gediminas Technical University

Low Earth Orbit is getting busier than ever due to the growth of small satellite market and emergence of new satellite mega constellations such as OneWeb, SpaceX, LeoSat and others. New space players, especially nano and microsatellite owners, are faced with huge challenges in getting frequency licenses as spectrum is getting very scarce and bandwidth requirements are increasing. Furthermore, small satellite constellations for IOT and Earth observation require expensive worldwide ground station network to downlink large amounts of data.

Space Union is a new satellite constellation concept for LEO data relay that tackles this challenge. We propose a new frequency sharing scheme whereby small satellites would use inter-satellite radio links to transmit their data to a distributed network of gateway satellites instead of directly communicating with ground stations. These LEO gateway satellites would serve as high bandwidth in-orbit "hot-spots" by relaying network data via high speed optical links either directly to optical ground stations or by using another GEO relay satellites, such as EDRS.

Since intersatellite radio links would be utilized only inside local in-orbit networks within limited range, the risk of radio interference to other already existing or future satellite systems is limited. This would allow nearly the whole spectrum of intersatellite frequencies to be utilized within a local in-orbit network and then re-used inside other spatially segregated satellite networks. The re-use factor of intersatellite spectrum only depends on the number and location of gateway satellites. We foresee that efficient frequency sharing schemes similar to those used in ground based cellular wireless networks, e.g. coded orthogonal frequency-division multiplexing (COFDM) could be used within local satellite clusters. High speed laser terminals used by gateway satellites could leverage virtually unlimited bandwidth of free space optical communication without the need of frequency coordination.

We will present the technical feasibility of such a concept, preliminary design of gateway satellite constellation and propose future steps for implementation.

INTELLIGENT NANOSATELLITE CONSTELLATION SYSTEM USING A.I. AND BIG DATA

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Korea Aerospace Research Institute

Launched cubesats are over than 1000 since 2000, and recently there are many kinds of new nanosatellite missions with constellation and formation flying. For example, Planet which is the nanosatellite company is operating many nanosatellites over than 100 for earth image gathering. As such, the cost-effective nanosatellite has already become a big flow.

Generally, compared to mid-to large satellites, the nanosatellite has relatively low performance. However, due to its low development cost, it complements this disadvantage by operating a number of nanosatellites. For this reason, there are some attempts to apply the constellation or formation flying technology to nanosatellites. From this point of view, in KARI, the Intelligent nanosatellite project is initiated. There are many kinds of required technologies for multi-nanosatellite operation. Among them, this project aims to demonstrate some of the technologies required for global imaging through multiple nanosatellites such as automatic on-board scheduling, on-board cloud detecting and big data management. In this paper, we will introduce these technologies and the nanosat platform.

In general, all operations of satellites take place at ground station. (Figure 1) Thus, as the number of satellites increases, the works of ground station also increase. (Figure 2) However, the main object of multiple nanosatellite operation is gathering big data. Therefore, the operation is relatively simple compared to mid-to large satellite. (Figure 3) Theses characteristics also suggest the possibility of performing the satellite's operational schedule on-board. Thus, in this project, we will make a simple on-board scheduling algorithm for multiple-nanosatellites and test it on orbit. This suggested algorithm is consisted on three parts: on-board event predictor, on-board scheduler and autonomous targeting controller. For the on-board event predictor, the two-step approach is applied. By using GPS measurement, the LL(Latitude-Longitude) estimator will be updated and calculate coarse event time. Then the self-updatable OOP(On-board Orbit Propagator) find out the fine event time. Based on these results, the on-board scheduler will assign the operation mode for future such as Figure 4. And, finally, the attitude controller will accomplish the mission.

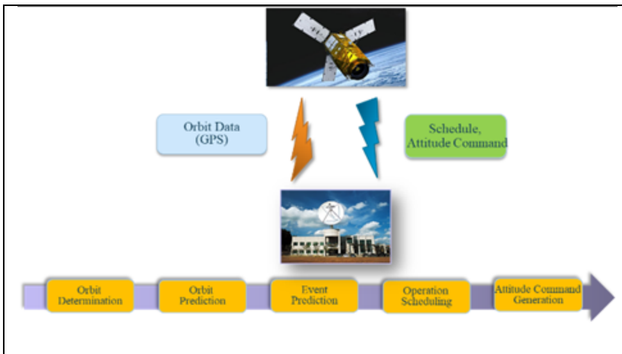

Figure 5: General satellite operation process

Figure 6: Multiple nanosatellites operation

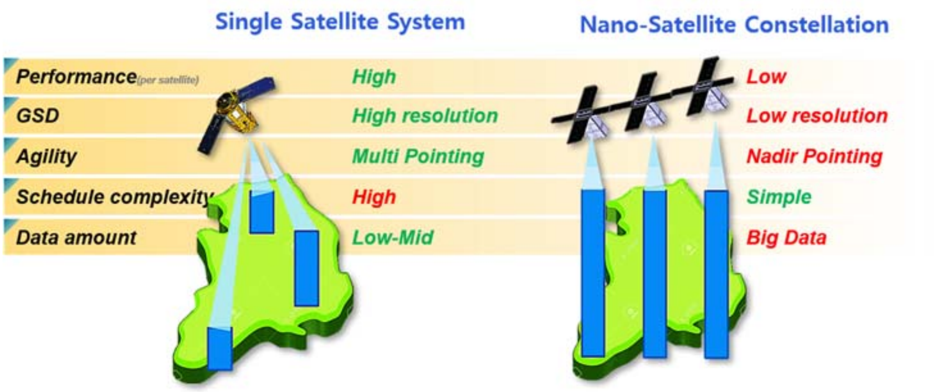

Figure 7 : Operational difference

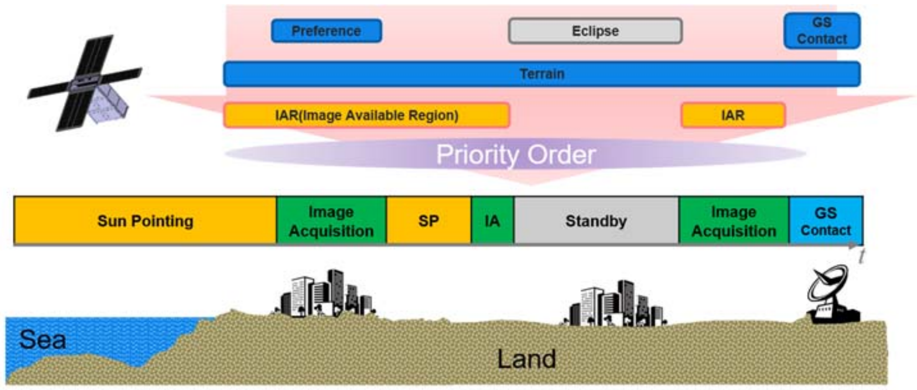

Figure 8 : Conceptual design for on-board scheduler

After taking the earth images, on-board cloud detector estimates the cloud coverage rate in image. Actually, it is difficult to find out the high-speed downlink module for nanosatellite. Among the nanosatellite market, the S-band transceiver is the only candidate, and it has 1~4 Mbps downlink speed. If the nanosatellite takes very high-resolution image, the downlink speed is not sufficient to download mission imagery. Thus, we need to take an efficient downlink strategy, such as setting priority of download. Generally, the surface of the earth is covered by 67% of the cloud, and sometimes it can occlude mission target area. For example, 75% of downloaded mission imagery from KOMPSAT-1 was not used since imagery contaminated by the cloud. It means that there was some waste in the downlink data budget. For this reason, we are developing the on-board cloud detecting algorithm based on machine learning technique. More details will be introduced the other paper on this symposium.

If the nanosatellite sends their images to ground station, the ground station must manage these data. As increasing the number of nanosatellites, the image data will be dramatically increased. For this reason, the big data management system also suggested in this project. For this system, we tested two kinds of big data management techniques: SPARK and SciDB. For the ROI (Region Of Interesting) size, we compared the searching time and the SciDB has more suitable performance for earth images. Base on this database management technique, the earth image data visualization system is developed such as Figure 6.

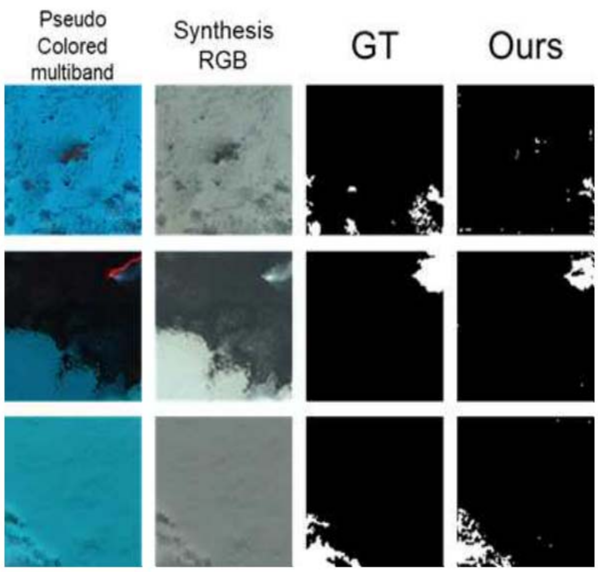

Figure 9 : On-board cloud detector result

Table 1: Search time result for SciDB and Spark

	Q1	Q2	Q3	Q4	Q5
SciDB	57.7	24.17	11.8	6.1	2.1
Spark	22.2	19.4	16.6	14.8	11.2
# of data	193,267,575	90,216,212	35,692,650	15,284,808	4,126,720

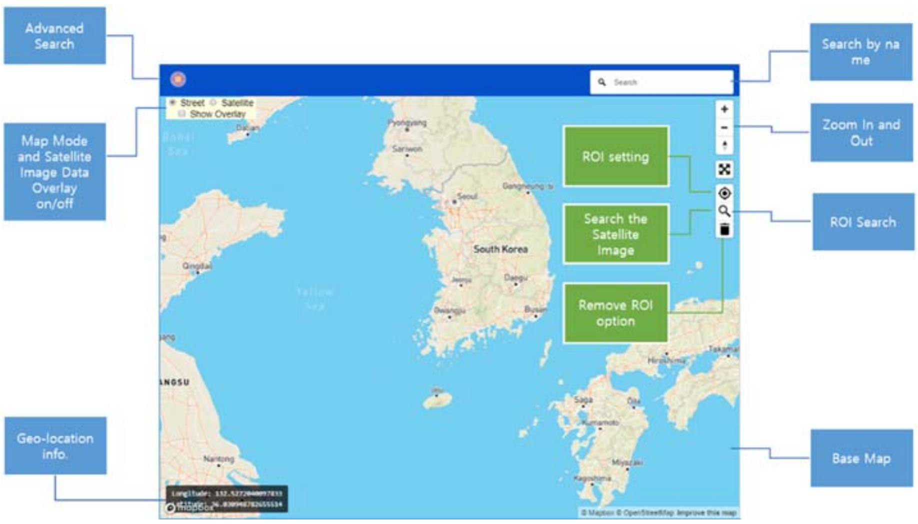

Figure 10 : Visualization of big data management system

Finally, we are also developing the target test platform of these algorithms. For this target platform, we designed the 6U cubesat called A-HiREV (Advanced High REsolution image and Videio) nanosatellite. This nanosatellite is based on the HiREV nanosatellite which was designed for making the standard nanosatellite platform for future space missions since 2015 such as Figure 7. Actually, this is the first attempt to develop the 6U nanosatellite in Korea. Thus, it is required to grow the domestic nanosatellite infra before full-fledged development. For this reason, in the last year, the EQM was developed and tested. Therefore, for this project, we decide to use the same design of HiREV to reduce the cost and development period. We will develop the A-HiREV until next year.

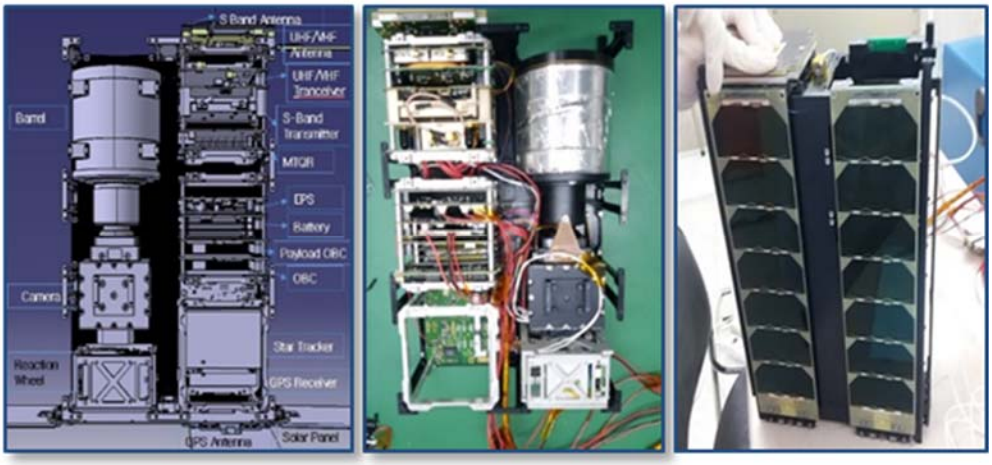

Figure 11 : HiREV nanosatellite

BUILDING A GLOBAL SATELLITE CONSTELLATION FOR IOT DEVICES

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OQ Technology is building a global low earth orbit (LEO) satellite constellation to provide Internet of Things (IoT) connectivity to remote and sparsely populated areas that would otherwise remain unconnected to the internet.

The Internet-of-Things will be the next great technological revolution and will have a considerable economic and societal impact, with the number of IoT connected sensors and devices expected to exceed 27 billion by 2025. However, this can't be achieved if a worldwide coverage is not enabled as 75% of potential devices will not be connected to the internet due to limited infrastructure. Also, 3G coverage in remote and rural areas is limited to only 29% and there are 3.4 billion people living in these areas.

One of the main requirements of IoT applications is the cost which must be very low, and the lack of low-cost global connectivity providers is the reason why IoT over existing satellite infrastructure is not attractive [1]. We believe in OQ Technology that CubeSat with their lower cost; their smaller size and their standardized structure can fill that gap. The potential applications using a true global low-cost connectivity are versatile and can cover geolocation services, oil and gas asset monitoring, smart agriculture, supply chain monitoring, etc.

In term of telecommunication link, providing a connectivity using LEO satellites presents many advantages like a true global coverage and avoids the negative aspects of current geostationary earth orbiting satellites (GEO). The lower altitude leads to a low propagation delay and a low signal loss due to propagation enabling the possibility to build small and low power IOT user terminals [2]. However, the velocity relative to the user terminal located on Earth is very high and is almost inexistent in GEO and terrestrial networks. Managing the typical high doppler shift and doppler rate of a LEO satellite is a big challenge to be solved in order to enable an efficient telecommunication link between the payload and the IoT device.

Deploying a constellation of nanosatellites is a challenging journey. Indeed, the philosophy behind nanosatellites compliant with the CubeSat standard is to use commercial-off-the shelf products in order to increase reliability and many companies are now providing COTS components. Nevertheless, this market is quite young, and each COTS product doesn't have the same maturity and many previous missions failed for unclear reasons during their first phase of operations. A suggested way to avoid such failures is to dedicate more time on functional test rather than increasing the complexity of traditional acceptance and qualification tests of each COTS product [3].

Another challenge consists of the launch of these constellation. Up to now, approximately 90% of the nanosatellites are launched as secondary payloads on medium or big launchers [4]. However, launching 40-60 satellites as secondary payload is not acceptable as the constellation must respect strict requirements in term of orbit selection and schedule. Several companies are developing micro launchers in order to launch several nanosatellites as primary payload while keeping a competitive price. This will permit to deploy the full constellation in one or two launch on a dedicated orbit and timeline.

After a brief presentation of the context, the technical challenges to build our nanosatellite constellation will be addressed following by a description of the status of the project.

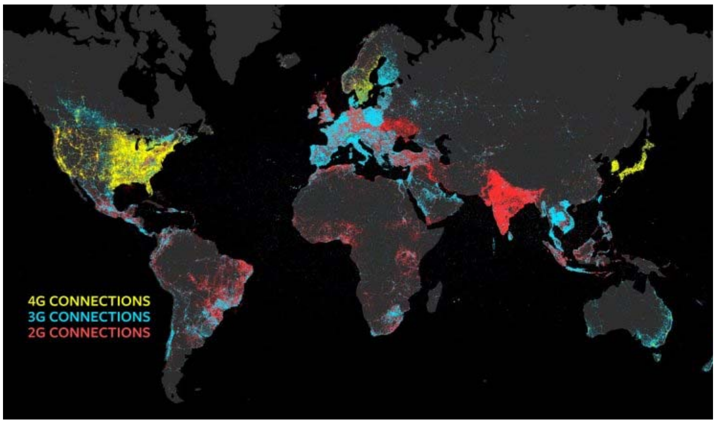

Figure 1: Map describing the connectivity on Earth (Facebook)

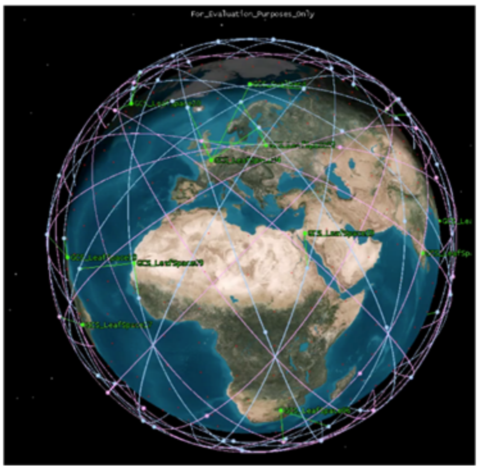

Figure 2: Example of a global coverage using a constellation of LEO satellites

References

[1] V. Almonacid and L. Franck, “Extending the coverage of the internetof things with low-cost nanosatellite networks,”Acta Astronautica, vol.138, pp. 95–101, Sep. 2017.

[2] Z. Qu, G. Zhang, H. Cao, and J. Xie, “LEO satellite constellation for Internet of Things,”IEEE Access, vol. 5, pp. 18391-18401, 2017.

[3] M. Langer and J. Bouwmeester, “Reliability of cubesats-statistical data, developers’beliefs and the way forward,” inAIAA SmallSat, 2016.

[4] Wekerle, T.; Bezerra Pessoa Filho, J.; Eduardo Vergueiro Loures da Costa, L.; Gonzaga Trabasso, L. Status and Trends of Smallsats and Their Launch Vehicles—An Up-to-Date Review. J. Aerosp. Technol. Manag. 2017, 9, 269–286.

SMALL SATELLITE CONSTELLATION FOR TGF AND TLE OBSERVATIONS

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Small satellite constellation can be used effectively for study Atmosphere transient phenomena, such as Terrestrial Gamma-ray Flashes (TGFs) and Transient Luminous Events (TLEs). Study of TGFs and TLEs still remains very important despite a lot of data obtained about such phenomena in recent time. The crucial point in understanding of TGFs physical nature is confirming or refuting their direct connection with the given thunderstorm or lightning. For this goal, besides of the event fine timing, a good localization of the TGF source is also necessary. The typical angular resolution of instruments usually used for TGF observations is not better than ~10^{o} that scales to the space accuracy of TGF source localization of ~100 kilo-meters for the instruments flying at 500 km orbit. It is enough for TGF source identification with thunderstorm area, but it is insufficient to guarantee the identification with a given thunderstorm cloud. This latter task will demand an improvement of the angular resolution of suggested instruments by at least a factor of 10. The solution for the localization problem can be achieved by applying the triangulation method for observations of the selected area with different satellites.

For this purpose the Universat-SOCRAT multi-satellite mission is elaborated now at Lomonosov Moscow State University. The small satellite constellation should be consisted from three basic small spacecraft, added by complementary satellites of Cubesat type. It is planned that one of them will be a joint development of Lomonosov Moscow State University and Aserbaijshan National Aviation Academy. The most of constellation satellites should be launched together with main spacecraft on similar solar-synchronous low altitude orbits (400-600 km) that provides the favourable conditions for the study of TGFs and TLEs from different areas of the Earth Atmosphere including near Equatorial and Polar regions. Such satellite constellation provides joint observations of a given area. Sufficiently light X-ray and gamma-ray detectors aimed for the TGF detection only, without spectrometer capabilities on-board the CubeSats will realize the triangulation technique. By this the necessity of maintaining of given distance between satellites is a separate technical problem. It can be solved using thrusters on nano-satellites.

EARTH OBSERVATION BY UTILIZING NANOSATELLITE CONSTELLATION

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Keywords: nanosatellites, telescope, constellation, Earth observation, high-resolution

Nowadays, Earth Observation (EO) satellites with huge telescopes onboard provide high-resolution images and allow to distinguish two objects located on Earth at a distance of fewer than 0.5 m from each other [1]. Such high-quality image requirements result in huge volume and mass of the instruments, notably increasing the costs of their launch and fabrication. Will be presented the conceptual design of a synthetic aperture telescope [2], which may meet similar resolutions as current state-of-the-art Earth observation systems, but simultaneously, having a significantly smaller launch volume.

The main application of the presented concept of satellite telescope is to monitor Earth phenomena, e.g. natural disasters, land survey, insurance and precision farming. Therefore, the key criterions during the design process were to achieve a sufficient resolution and possibly the widest field of view. Additionally, it was attempted to obtain the smallest possible volume of the structure and dimensions corresponding with the CubeSat standard, in which the basic unit is 1 U = 100x100x100 [mm]. It is assumed that the overall dimensions of the stowed telescope module in the nanosatellite structure should not exceed 7 U. The 4 U are reserved for the CubeSat bus which contains modules, such as: On Board Computer (OBC), Communication Module (CM), Electrical Power System (EPS), Attitude Determination and Control System (ADCS) – necessary for proper device operation on the orbit. The next 2 U or 3 U are intended for the telescope instrument topology. It is allowed to place part of the telescopic system in the nanosatellite bus structure.

The SatRevolution company establish your goal to create a constellation of small, light and inexpensive Earth-observing nanosatellites, utilizing the proposed CubeSat telescope solution. The greater number of devices results in a shorter time of revisit above a specific place, which may lead to the precise imaging of a chosen area in real-time. This conception was named REC - Real-time Earth-observation Constellation. The final goal is to reach 30 minutes refresh rate by placing more than a thousand of CubeSats on 300-350 km Low Earth Orbit by simultaneously less than a 1m resolution! In the presentation will explain technical assumption and restriction for optics, mechanics and electronics part of the nanosatellite telescope and sequence of planning the mission will be presented.

GIOBAL IOT SUPPORT INFRASTRUCTURE. PROJECT GLOT

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NanoAvionics, Lithuania

The recently funded GIoT (Global Internet of Things) project is the first pilot and commercialization project of global Nano-satellite-powered “constellation as a service" solution to offer network operators easy and low-cost access to space-to-ground communications. The GIoT system architecture will serve Internet of the Things (IoT) and Machine to Machine (M2M) network operators of both terrestrial and satellite-based; the architecture will expand network coverage over oceans and remote areas where cellular networks are not presently available, and will provide a lower-cost access solution to regions where cellular networks already exist.

The GIoT infrastructure combines constellations of interconnected Nano-satellites and traditional satellites with a worldwide network of ground receiving stations and communications processing systems to permit constant data exchange between ground and space segments critically important for IoT/M2M applications.

The GIoT brings three critical key partners and their unique expertise together to create the combined offer of novel service.

1) NanoAvionics – for Nano-satellite technologies, NanoAvionics will provide its upgraded and improved 6U size Nano-satellite bus (M6P) with green chemical propulsion with constellation synchronization capabilities;
2) Antwerp Space – for communication between Nano-satellites and Geo-stationary satellites, Antwerp Space will provide the Inter-Satellite Link (ISL) module, which will be designed for M6P bus, permitting real time connectivity through conventional Geo-stationary satellites;
3) KSAT – for space-to-ground communication, KSAT will provide ground station services tailored M6P bus for global connectivity with the ground segment.

This project, by integrating the system capabilities listed above, will provide a solution for global IoT/M2M services. The direct advantages of this solution are: Approximately 10 times lower prices for global IoT/M2M communication; Provision of real time data exchange capability to IoT/M2M systems; Significantly reduce the number of barriers to entry for new IoT/M2M operators; Global coverage not dependent on geographical area.

SESSION 8

LAUNCHERS AND DEPLOYERS, PROPULSION AND RENDEZ-VOUS

SECONDARY PAYLOAD STRUCTURE (SPS)

QUALIFICATION OF THE EUROPEAN SOLUTION FOR A 'PLUG-IN' SMALL SATELLITES CARRIER FOR PIGGY-BACK ON LIGHT LAUNCH VEHICLES

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The paper will present the accomplishments of the development of the Secondary Payload System (SPS) by Airbus Defence and Space Netherlands and ISIS - Innovative Solutions in Space as part of a joint undertaking to establish a European capability for cost-effective piggy-back launches of nano- and microsat on a frequent basis. The paper presents the results of the SPS Equipped Qualification Model dynamics test that have been completed March 2019. Further it describes the foreseen evolutions of the SPS dubbed SPS-XL and SPS-FF. The first being an enlarged version with double auxiliary payload capability, the second being a controlled free-flyer mainly for the purpose of providing a platform for cost-effective and regular In-Orbit Demonstration (IOD) missions.

The basic version of SPS is a modular and standardized platform on which nanosatellite, microsatellites and IOD payloads can be manifested for launch underneath the main payload. The SPS is equipped with a sequencer unit and six QuadpacksTM and enhances the launcher capability by providing attachment ports and an in-orbit (radial) deployment capability for 24 3U nano-satellites or 6 micro-satellites (mass up to 30 kg), or a mixture thereof. The SPS is also equipped with a tailored clampband separation system for release of the main payload. A first flight is anticipated in 2020 on the VEGA launcher.

While in its basic version the auxiliary payloads are deployed from the SPS that remains on the launcher upper stage, the free-flyer version (SPS-FF) is the answer to the need for a uniquely low cost access to space for in-orbit technology and service demonstration missions. By simply activating the lower interface clampband system after release of the primary payload, the SPS-FF can be separated from the upper stage in certain orbit for longer duration in space. In addition, its functionality is extended though a Service Module (SM) concept that can support a variety of in-orbit demonstration payloads.

The main launcher envisaged for SPS application is VEGA and its upcoming upgrades. Other launcher candidates are PSLV and Soyuz. SPS will be manifested on an opportunity basis when excess mass for additional payload is available on the launcher. The business model of SPS is based on delivering a full launch service to satellite customers on a piggy-back launch rideshare basis. For the launcher operator, the SPS provides an excellent opportunity to achieve a high 'fill-factor' for each launch.

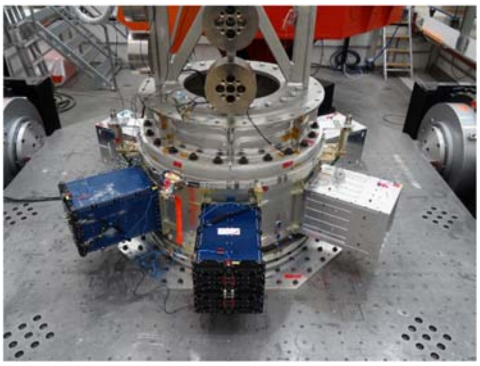

Figure 1: SPS Qualification Model during test

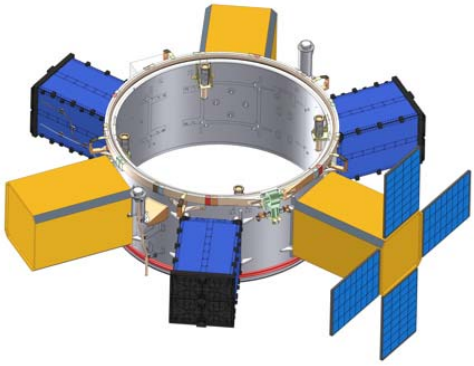

Figure 2: SPS Free-flyer

DEPLOYMENT AND SEPARATION DEVELOPMENTS AT COSMOS INTERNATIONAL

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COSMOS International Launch Services GmbH was founded in 1995 as a launch service provider for the rapidly growing small satellite manufacturer OHB System based in Bremen. The most important launch vehicle used by COSMOS International at that time was the Russian COSMOS-3M. A total of nine German institutional and governmental satellites, one Korean science mission and one commercial US-customer mission were conducted. The most important program was the German SAR-Lupe reconnaissance system with a total of five satellite launches on the COSMOS-3M, which was modified especially for the requirements of the OHB satellites. From the launch sites in Plesetsk and Kapustin Yar, Russia, a total of 21 spacecraft were launched.

COSMOS International has also launched smaller missions with the Russian launch vehicle, DNEPR, from Baikonur and in 2007, it led the first non-Indian customer dedicated launch with the Indian PSLV-C8 launcher. Since then, COSMOS International in cooperation with Antrix, India, has successfully launched six more spacecrafts for customers in Germany, Luxembourg, Italy, Latvia and the USA.

The small satellite market has been experiencing a huge increase in number of satellites to be launched in the last years and it shows a large demand on rideshare and dedicated launch options. COSMOS International address this demand not only with rideshare options on launches that OHB booked with its own satellites as primary payload but also with competitive options for a dedicated launch or dedicated rideshare options in the near future.

Optimizing the accommodation of small satellites as rideshare passengers on the payload of a launcher is the key factor to economic cost-effective launch prices for the main passenger but also the small rideshare passengers.

COSMOS International developed a new COSMOS-12U-Deloyer which is designed highly modular. Multiple deployers can be stacked without interacting each other due to the doorless design. Hence, the number of cubesats can be increased easily depending on the performance of the launcher. Moreover, the holding of the CubesSat is improved inside the deployer by clamping the Cubesat on all rails simultaneously. This provides optimal load application and reduces the possibility of gaping significantly. Furthermore, this type of constraint guarantees a perfectly aligned deployment.

Additional sensors, cameras and radio modules are state of the art in many technical areas. Therefore the COSMOS-12U Cubesat Deployer will have these type of hardware as integrated parts. The possibility of machine to machine communication via satellite network will provide additional data of the deployer status as well as the status of the Cubesat. Integrated cameras will transmit videos and pictures of the cubesat deployment.

The deployer has increased space between deployer side structure and the Cubesat itself. As already mentioned the deployer has no opening door. Due to this tow advantages the assembly of the Cubesat is much easier and late access to the satellite is possible. The COSMOS-12U-Deployer is planned to be tested in Q1 2020 and the first mission is planned to take place in 2020.

This paper will give an overview on COSMOS International and the development of the COSMOS 12 deployer.

CONCEPTUAL DESIGN AND GUIDELINES OF ELECTROMAGNETIC DOCKING DEVICES FOR RENDEZVOUS DOCKING MISSION

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[2] University of Science and Technology

Many research institutes are developing rendezvous docking demonstration projects, such as OAAN[1], CPOD[2] by NASA, AAReST[3] by Caltech, SSC, and IIST. Korea Aerospace Research Institute also has the plan to perform on orbit test of rendezvous docking by two cubesats, called KARDSAT(*KA*RI *R*endezvous *D*ocking demonstration *SATe*llite), that the one is 6U sized chaser and another is 3U sized target.

All current ongoing missions have electromagnet or permanent magnet as the role of docking. OAAN uses permanent magnet, and the others utilizes electromagnet. KARDSAT adopts both two kind of magnet - target has permanent magnet, while chaser has electromagnet. Taget of KARDSAT is smaller and has lower power capability than chaser, so permanent magnet is more proper than electromagnet. Electromanet in chaser is capable of changing the direction of magnectic dipole to attach(docking) and detach(undocking) the chaser to or from target.

The first conceptual design of docking system of KARDSAT, shown in figure 1, at SDR held at 20/12/18 was three probe-drogue structures with electromagnetic bars, both of target and chaser. Reviewers commented general design guidelines of magnetic docking devices in satellites. First, magnetic fields of the magnetic dipoles influence internal subsystems around the magnet, especilly reaction wheel. Thus magnetic flux leakage into the satellite body should be minimized. Second, magnetic fields of simple magnetic bar associated with attraction or repulsive force are only in the one side of docking plane, while magnetic fields behind opposite side are not. In other words, approximately only half of magnetic fluxes are engaged in docking. Finally, magnetic dipole moments of docking devices generate unwanted disturbance torque by interacting Earth magnetic fields. OAAN considers parallel docking direction to Earth magnetic fields for the torque not to emerge.

To overcome these, horseshoe or similar topological shape of magnet is appropriate for magnetic docking system. For horseshoe magnet, most magnetic fluxes pass through the magnetic core material and less fluxes leak into the satellite bus than those of simple magnetic bar. And magnetic dipoles of horseshoe are on the same plane of docking, so most magnetic fluxes are in the one side of docking plane and larger attraction force is expected. Finally, a pair of horseshoe magnet with opposite direction of magnetic dipoles each other, should be placed to the same docking plane to remove the disturbance torque. Figure 2 represents the conceptual design of docking system with twin electromagnet in chaser satellite.

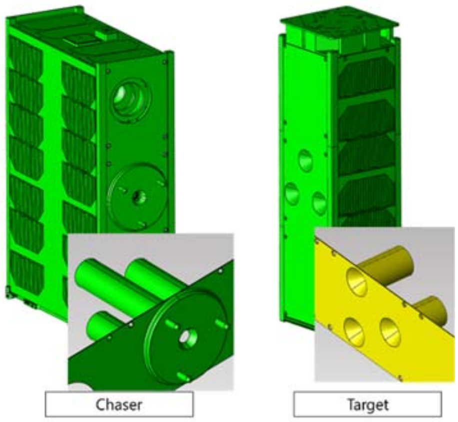

Figure 1: Conceptual Design of Docking System of KARDSAT at SDR(20/12/18)

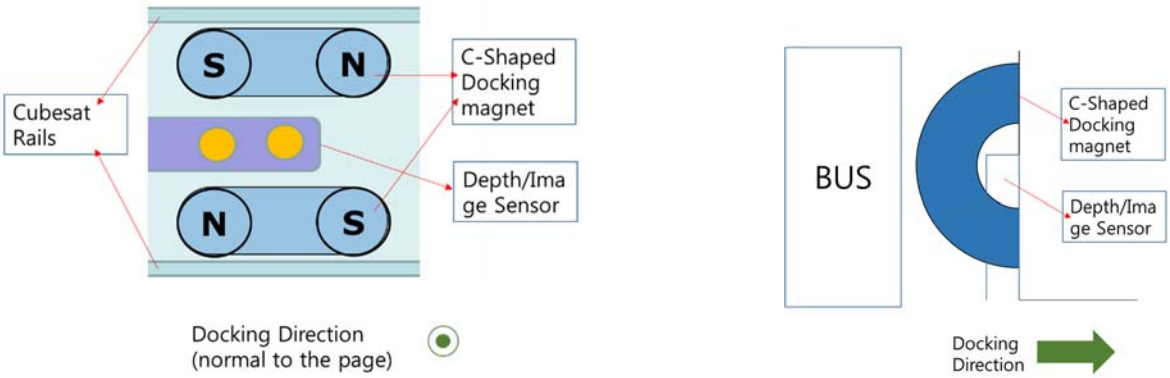

Figure 2: Present Conceptual Design of Docking System of KARDSAT(Left: normal view, Right: cross sectional view)

References

1. PRELIMINARY GN&C DESIGN FOR THE ON-ORBIT AUTONOMOUS ASSEMBLY OF NANOSATELLITE DEMONSTRATION MISSION, 54th AIAA Aerospace Science Meeting, 2016
2. Cubesat Proximity Operations Demonstration, Fact Sheet, NASA, FS-2018-07-04-ARC, 2018
3. https://directory.eoportal.org/web/eoportal/satellite-missions/a/aarest

IONSAT: A 6U STUDENT SATELLITE WITH IODINE PLASMA PROPULSION

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Propulsion is a natural next step for small satellites, as shown in the Starlink constellation from SpaceX. The complexity of electric propulsion subsystems, of the processes to integrate and test them within small satellites and even CubeSats is not yet well known in the community. Could a university CubeSat built by a group of students embark a electric thruster, pass all reviews milestones, and perform an interesting mission?

Here we show the preliminary design of a 6U nanosatellite from École polytechnique. The student space centre of Polytechnique is reinvesting its QB50 experience in a new mission partnering with the Laboratoire de Physique des Plasmas of Polytechnique for technical support, ThrustMe for the propulsion subsystem, VKI for a science payload, CSU Toulouse for a ground segment and CNES for project supervision.

Following a feasibility study in 2017-2018, the preliminary design phase led to a 3U*2U CubeSat with deployable solar arrays with a total of 32 standard cells, 144Wh of batteries and a SCAO based on 3 reaction wheels and magnetotorquers. The mission will lead the CubeSat to orbit lower than 300km where the thruster will be used to balance atmospheric drag. The attitude control strategy is established to maximize solar exposition while minimizing atmospheric drag, basically freezing two rotationnal degrees of freedom. The orbit raising strategy is thought to set a lower limit on the perigea altitude while keeping a low orbital excentricity.

It has been proven that a group of student can perform a preliminary design of a mission involving an electric thruster in a 6U CubeSat. It has been found that no technical hurdles would oppose the CubeSat to be ready for launch in 2021-2022, providing appropriate funding.

INTERPLANETARY CUBESAT MISSION USING ELECTROSPRAY ASSISTED TETHERING (PORCUSAT)

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The proposed PORCUPROP system consists of an integrated Electrospray thruster array and Electrodynamic tethers, with each component having its designated function. The paper charts out an entire Jovian mission using the integrated subsystems. In this combined system, the electrospray thruster array will be the main propulsive contributor in the first stage, while the tether array plays a major role in the presence of considerable magnetic field.

Electrospray propulsion is based on the electrostatic extraction and acceleration of positive and negative ions from an ionic liquid, a zero-vapor pressure conductive salt that remains in the liquid phase at room temperature. Intense electric fields of the order of 1V/m achieved at the tip of electrically stressed menisci called Taylor cones, formed at the ends of sharp emitter structures. Emitter structures are electrochemically etched on a substrate using micromachining processes with tip diameters of 200 micron. Emission is achieved from here where ions are accelerated and passed through a downstream extractor thus generating thrust. Electrospray thrusters provide the much-needed accuracy in maneuvering for interplanetary missions along with conservative propellant consumption rates. It has already been tested on board the LISA Pathfinder (ST-7) mission. The drawbacks of the system include high power requirement especially during planetary descent and limited life due propellant storage.

Electrodynamic tethers utilize crossed electric and magnetic fields to induce a perpendicular force. The magnetic field comes from solar flare activity or high magnetic fields in gaseous giants and the electric field comes from a flowing current though a tether (conductive wire), completely independent of propellant.

PORCUSAT once in the interplanetary orbit, will utilize the Electrospray arrays to generate thrust for acceleration, utilizing just the liquid phase propellant and solar cells thus requiring no pressuring, valves, or complex feeding systems because the fuel is driven by capillary forces induced by the ion evaporation process.

The aim of this research is to construct a feasible system for CubeSats which efficiently controls the previously mentioned systems over different legs of the mission and pave the way for interplanetary cubesat missions, while fulfilling the clause of low weight, low power and economy in the system. This will consequently overcome the disadvantages of the aforementioned propulsion systems when used individually. The use of tethers to maintain minute orbital corrections instead of the sole electrospray will save a lot of propellant and avoid the dangers of orbital deviation, satellites like the Voyager was subjected to. It can also be used for descent into planetary orbits and power generation. Preliminary design will involve a system which successfully identifies the end of the mission based on the amount of ionic fluid left in the electrospray thruster reservoir. On fulfilling the requirement, it will then proceed to deploy the electrodynamic tethers through a series of mechanical systems. Evaluation has been done based on the following performance parameters: -Specific impulse (Isp), thrust, mass, power consumption, delta V, ease of fabrication and cost. Computational analysis of bare tether electron collection in and out of the orbital motion regime is also employed in the paper for ideal dimensions and material selection of tethers.

References:

P. D. Pavarin, “Universit a Master Degree in Aerospace Engineering PRELIMINARY SIZING OF AN Internal thesis advisor :,” 2017.

E. Propulsion, “Session : Electrospray Propulsion,” pp. 1–9, 1975.

Grustan-gutierrez, Enric, “Microfabricated Electrospray Thruster Array with High Hydraulic”, 2017.

Sanjurjo-Rivo, M., Sánchez-Arriaga, G., & Peláez, J. (2015). Efficient Computation of Current Collection in Bare Electrodynamic Tethers in and beyond OML Regime. Journal of Aerospace Engineering, 28(6)

Juan R. Sanmartin and M. Charro, Universidad Politecnica de Madrid, Electrodynamic Tether Microsats at the Giant Planets, 2006

SESSION 9
CUBESAT FLIGHT EXPERIENCE AND LESSONS LEARNED

PREPARING FOR THE NEW CYCLE: LESSONS LEARNED FROM ESA'S FLY YOUR SATELLITE! 2

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'Fly Your Satellite!' (FYS) is a recurring hands-on programme conducted by the ESA Academy Unit of ESA's Education Office. The programme was established to support university student teams in the development of their own CubeSat by enabling a transfer of knowledge and experience from ESA specialists to the students. Selected teams are guided through project reviews and supervision of their verification process, conducted according to ESA professional practice and standards tailored to fit the scope of university CubeSat projects[1].

By participating in their CubeSat project, the students gain significant practical experience in the full lifecycle of a real satellite programme. ESA provides support in the form of reviewing documentation and ad-hoc support from ESA specialists to resolve and follow-up issues in a wide range of disciplines. Workshops and lectures on space activities are offered in a dedicated Training and Learning Facility to provide students with a broad background knowledge in the different aspects of a space mission. The subjects range from specific engineering lectures to courses on product assurance, project management, space law and telecommunication regulations. CubeSat teams which achieve test readiness have access to a dedicated CubeSat Support Facility and other state-of-the-art ESA test facilities. Eventually the launch opportunity is offered when the flight readiness of the CubeSat is demonstrated.

The second edition of the "Fly Your Satellite!" programme started with the acceptance of six CubeSat teams in May 2017. This edition is structured in five phases that closely resemble the development phases of a professional satellite projects: Design, Build, Test, Launch, and Operate Your Satellite! As part of the design phase, student teams prepared data packages containing detailed information on their CubeSats' design, project management, and the assembly integration and verification plan. A panel of ESA specialists, covering different disciplines of the space domain, reviewed the data packages and agreed with the teams on a set of clarifications to be prepared and corrective actions to be undertaken by each team to improve their spacecraft design, in order to achieve the objectives of the Critical Design Review.

During this process, a number of issues were identified and were recognised to be common amongst several teams, underlining the importance to create and disseminate the outputs of the reviews which may have value as lessons learned. Similarly, a need to establish common good practices was observed in order to facilitate the work of the reviewers and to make the students acquainted with the relevant ESA standards. The lessons learned have been categorised into different areas including 'design', 'preparation for testing' and 'space project management'.

The presentation furthermore addresses the next call for proposals of 'Fly Your Satellite' and how these lessons learned may support student teams aiming to participate in the third programme cycle (FYS-3).

Figure 12: CubeSat team discussing their CubeSat design with an ESA specialist

[1] https://www.esa.int/Education/CubeSats_-_Fly_Your_Satellite/Fly_Your_Satellite!_programme, 13 May 2019

THE EVOLUTION OF VALUE FROM A QB50 SURVIVOR

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nSight-1 (QB50 AZ02) is one of two 2U size satellite developed in South Africa as part of the international EU-funded QB50 project [Wiid2017]. The satellite carries two main payloads: an atmospheric science instrument, and an RGB Bayer-matrix imager for Earth observation. Mission-specific challenges included integrating our imaging hardware into the severely space-and-power constrained 2U form factor enforced by the QB50 mission. Additionally, the available UHF data link needs to simultaneously serve the atmospheric science payload as well as the intended imaging mission.

In many ways, nSight-1 represents a "first". It was the first privately funded, commercially developed, South African satellite. It was developed to demonstrate capability and to obtain flight heritage on subsystems that include a novel multispectral imager.

Deployment into orbit from the International Space Station was achieved on 25 May 2017. At the time of presenting our work, two and a half years have passed. nSight-1 has exceeded its design life (expected 12-18 months), by an impressive factor of two. Not only has nSight-1 succeeded admirably, it has also succeeded where many other of its peers have failed. In this work we explore specific risk mitigation strategies that have contributed to its unique success, and from which other CubeSat missions may benefit.

A specific goal that nSight-1 served was to provide the first flight heritage to the indigenously developed Gecko imager. The flight heritage obtained by including the Gecko payload aboard nSight-1 has proven invaluable, and has led to a family of derivative and evolutionary improved Earth Observation payloads that have now found a place in the global commercial CubeSat market.

Current CubeSat research constellations that are plucking the fruits of the pioneering role nSight-1 and QB50 played include the Telematics International Mission (TIM). By using a constellation of CubeSats, each equipped with a Gecko imager, TIM will be able to compute 3D tomographic maps of large-scale opaque structures, and specifically of clouds. An application of this technology is foreseen to be 3D or 4D (temporally dynamic) imaging of volcanic ash clouds. [Zaksek2018]

In this work we describe the road that led to the first flight of the Gecko Earth Observation payload aboard nSight-1, the flight heritage and results that were obtained during nSight-1's more than two year long mission, as well as the road to technological maturity and commercialization that flowed from this – primarily scientific – mission.

Not only Earth Observation, but general data processing and data storage functions may be performed by the modular design that was chosen as underlying architecture in the Gecko imager. A proof of this concept is the adaptation of the Gecko imager's control unit (CU) to the Netherlands China Low-Frequency Explorer (NCLE) science payload. NCLE needed a highly capable compact processor with flight heritage that could be repurposed for radio astronomy. Using a design that is itself an evolution of a core component of nSight-1, removing the image sensor and reprogramming the field programmable gate array, a capable low-power radio astronomy processing unit was realised [Chen2018]. This payload, which in itself is a shining example of international collaboration, NCLE now orbits the Earth-Lunar L2 point aboard the Chinese Queqiao satellite. At the time of writing the NCLE payload was entering its commissioning phase and has started to return radio astronomical science data.

We conclude by reflecting on the role that governments and scientific missions can play in developing new technology, with a specific focus on the developing world.

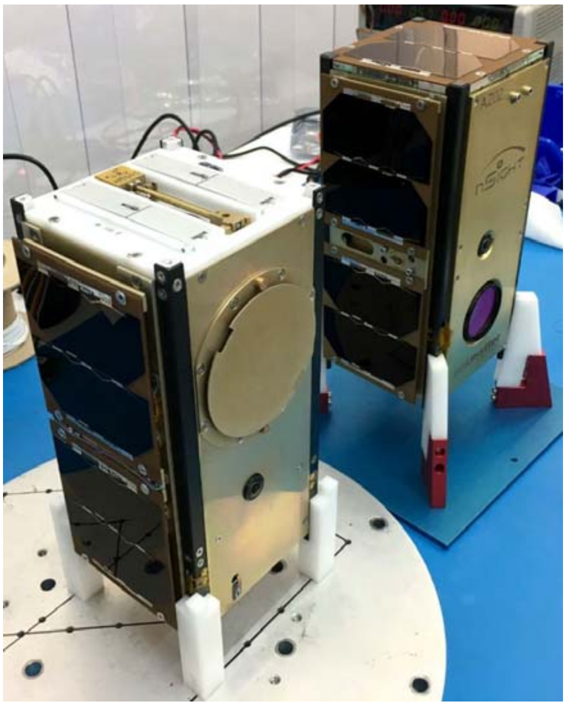

Figure 1: ZA-AeroSat and nSight-1,
two members of the QB50 constellation

References:

[Wiid2017] Wiid, K., Visagie, L., Burger, H., Malan, D. F., & Steyn, W. H. (2017). The Development of" nSight-1"-Earth Observation and Science in 2U.

[Zaksek2018] Zakšek, Klemen, et al. "Using picosatellites for 4-D imaging of volcanic clouds: Proof of concept using ISS photography of the 2009 Sarychev Peak eruption." *Remote Sensing of Environment* 210 (2018): 519-530.

[Chen2018] Chen, Linjie, et al. "Development of the Netherlands-China Low Frequency Explorer (NCLE)." *42nd COSPAR Scientific Assembly*. Vol. 42. 2018.

PW-SAT2 SATELLITE LESSONS LEARNED

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PW-Sat2 is the project held by Warsaw University of Technology in Students' Space Association at Faculty of Power and Aeronautical Engineering. The project had started in Q1 2013, one year after the launch of the first Polish satellite PW-Sat. As a continuation of the space debris mitigation subject, the second satellite main payload is a deorbit sail fully designed and developed by students. Several additional payloads had been proposed and chosen as a secondary mission goals. The satellite had been successfully launched on board of Falcon 9 at SSO-A mission on 3rd December 2018. The satellite completed its mission by testing all primary and secondary payloads. Deorbit sail deployment was executed on 29th December. On-board cameras sent dozens of valuable images confirming the full deployment. Four days after sail deployment the team noticed some damages on the sail material. The investigation showed some probable scenarios. Nevertheless PW-Sat2 stays still operational while decreasing its orbit. For 6 years of the project the team has been evolving in the mean of project organization, management, development methods and experience. More than 100 members have been involved in the project in total. The team tried to tailor and apply ECSS project phasing standards, since the project was financed through ESA.

Various technics and applications for the project management had been tested in order to find the best solution. The development of the technical solutions and trade-offs made from the beginning of the project to the integrated satellite gives a very clear lessons learnt and recommendations for the future missions of similar scale. Several critical situations during the project development made it close to be aborted, both technical, financial and organizational. Fortunately, it only influenced the project duration and bring the worthful experience. The economic situation in the country, namely the full membership of ESA in 2012, initiated the space industry growth. This situation brings a number of partners and sponsors to the project. Part of the companies were focused on gaining the experience required to start the space activity. Partners from non-space industry joined the project bringing their experience in commercial software development in on-board software development and testing methods.

CURRENT STATUS OF PICO TELESCOPE CUBESAT “STARS-AO” ON ORBIT

Masahiro Nohmi

Shizuoka University

Stars-AO was launched on October 29th, 2018 by the H-IIA rocket. It has been developed by Shizuoka University and amateur technologists, and named “AOI” as Japanese nickname. The author presented its development and the initial result in a few days after the launch in the last 10th European CubeSat Symposium at Toulouse, France, and audiences were interested.

However, Stars-AO stopped CW beacon by the command for waking up the main CPU. The reason was considered as follows. The main CPU was designed to stop CW beacon before separation from the rocket due to the requirement from the rocket interface, because no signals are permitted before the separation. The software should be that the main CPU does not stop CW beacon after separation from the rocket by detection from the separation switch. But, the software has a mistake, that is, CW beacon is stopped when the main CPU turns on. Then, the ground commanding needed for re-starting CW beacon transmission. The command for starting CW beacon was sent several times, and several responses from Stars-AO were received, but cannot be decoding except once. This is, the ground station was not sufficient condition to receive (decode) satellite FM packet. At last, Stars-AO was shut down because of energy consumption (by sending many FM packet). After the ground experiment evaluation for commanding sequence, and also the ground station was checked and refurbished, the reboot operation has been tried. Then, Stars-AO was rebooted on March 6th, 2019.

The rebooting process, current status, and also next operation are to be presented at the 11th European CubeSat Symposium. Also, Stars-AO was applied to the scientific program (contest) for senior and junior high school students, it is also to be introduced.

Stars-AO is a 1U CubeSat, and its objectives are to take a picture of stars, that is, astronomical bodies, and to transmit data by high speed communication of amateur radio frequency around 437MHz. Taking a picture of stars with less than 1 second shutter speed is possible by the newest super high-sensitivity pico-camera WAT910-BD, developed by WATEC CO., LTD. This high-sensitivity pico-camera makes it possible to take a pictures of stars under low accuracy attitude control of CubeSat. Then the next subject is to transmit image data to the ground station with high speed communication. Here, considering that general people can enjoy with CubeSat, high-speed communication by amateur radio frequency 437MHz is expected. 115.2kbps transmitter has been developed. Transmission packet protocol format is being developed by amateur software developer, including error detection and correction for compensating errors due to high speed communication. Also, Software Defined Radio (SDR) has been developed because no commercial radio can receive data with 115.2kbps by 435MHz.

Stars-AO is one of STARS project satellites. STARS (Space Tethered Autonomous Robotic Satellite) project purposes to evaluate and to verify a space mechanical control system by a university satellite. Five satellites: STARS (KUKAI), STARS-II (GENNAI), STARS-C (HAGOROMO), Stars-AO (AOI), and STARS-Me (TENRYU) were already launched. STARS was launched by the H-IIA rocket in 2009, and it is still alive. It is a mother-daughter satellite, a tethered satellite, and also a robotic satellite. STARS-II was launched by the H-IIA in 2014, and it was already decayed. The 300m tether deployment was evaluated by orbital altitude change. STARS-C was released from the ISS (International Space Station) in 2016. It consists of 2U CubeSats connected by 100m long Kevlar tether. STARS-Me will be experimented for demonstration of space elevator. It consists 2U CubeSats connected by hard tape tether, and a climber robot stowed in a CubeSat translates on tether. Stars-AO is not a mechanical control system, but it will verify and confirm challenging technologies related to high resolution camera pictures and high-speed communication those are expected future STARS satellites.

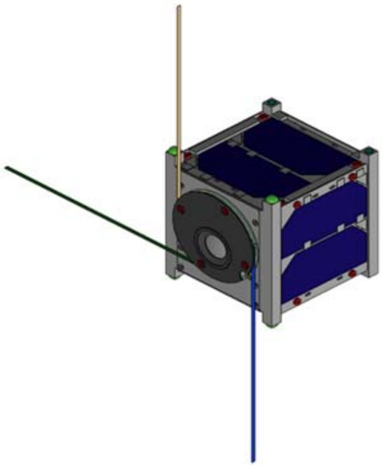

Figure 1: Stars-AO image

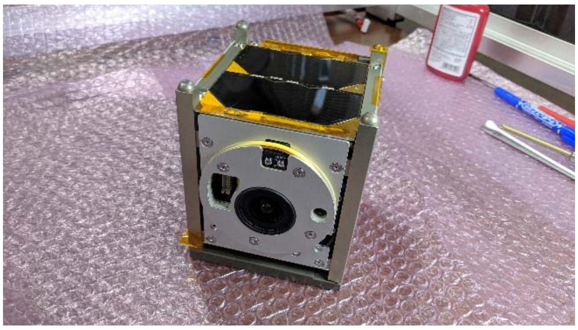

Figure 2: Stars-AO Flight Model

POSTER SESSION

ANALYSIS OF AUTONOMOUS PROPELLENT-LESS FORMATION FLIGHT

by Jan Thoemel

Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg

The advent of low-cost satellites produced an unprecedented number of new mission concepts. First, cubesats were used for educational and technology demonstration purposes. Then, their potential to establish global constellations has been recognized and implemented. Currently, effort is made to investigate the potential of formations, i.e. a small number of satellites flying relatively closely to each other steered by a common and relative control law.

As cubesats dominantly occupy low Earth orbit where a residual atmosphere is present and they have severe mass and volume restriction, it appears advantageous to use aerodynamic effects instead of a propulsion system to control the orbit of the satellites. Solar pressure provides an additional force that can be exploited to this end. Because commanding the satellites manually and independently is challenging, due to rare and overlapping ground station to satellite contacts, and costly, the formation maintenance is ideally accomplished autonomously on-board the space craft.

We recently developed an algorithm called COSMOS employing central and distributed LQR-based control laws and in contrast to the majority of research codes full 3-axis Euler-angle based aerodynamics. After being validated against data from literature, we use it to analyze physically possible formation configurations and the dynamics of their deployment, maintenance and reconfiguration.

We assess a new mission concept consequent to our findings based on a three 1-unit cubesats formation. Each satellite has solar panels acting as solar-aero-dynamic surfaces.

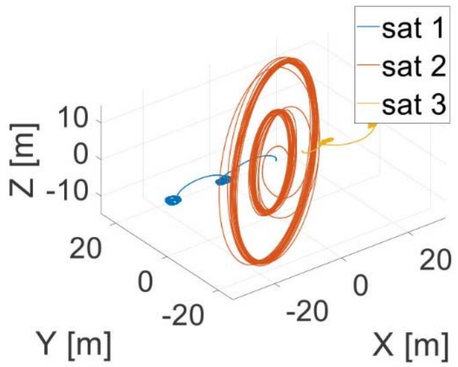

Fig. 1 Flight paths of the members of a 3-satellite formation in local coordinates. Observe the deployment in a formation with two coplanar members, and reconfiguration.

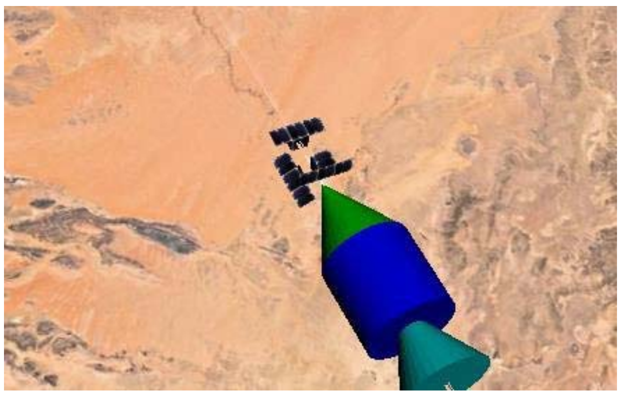

Fig. 2 View of the formation in Earth coordinates after release from upper stage. Formation deployment start with one satellite slowing down and another veering off-plane.

ECLIPSE – A STANDARD PM TOOLSET FOR ACADEMIA LED CUBESAT PROJECTS

Dennis Roshal[1], Sapienza Consulting[2]

Academia led CubeSat programmes often take risks in the product realisation and business areas of their space project, paying limited attention to important aspects such as Project Management, Product Assurance, Configuration Management, Quality Assurance and Data Management. This is usually due to the small scale of the operation and the drive for cost minimization, which often precludes the purchase and use of dedicated professional software tools. It is common for Academic projects to use non-specialist freemium software solutions that, besides falling short of the industry professional standards, involve the risk of service interruption and loss of data control. In some cases, project data stored online can even be claimed by such freemium software providers as their own property.

With ECLIPSE for academia, Sapienza aims to collaborate with CubeSat programmes and offer an integrated, modular and scalable suite of applications that can be used during their projects end-to-end. The value lies in eliminating the need for several detached tools, which are not tailored for space project management processes, require constant maintenance and tend to become knowledge silos that significantly hinder efficiency. Moreover, the introduction of ECLIPSE within a CubeSat programme gives the students a unique opportunity to work with industry standard software in a learning/live environment.

ECLIPSE is widely used throughout the space sector by organisations ranging from international agencies (ESA), industry primes (OHB, Airbus, Thales) and SMEs (QinetiQ, IberEspacio). In fact, ECLIPSE is the only space-oriented web-based toolset providing an answer to the multifaceted needs of the PA-QA-DM and PM office in space projects. The suite was built on the back of the success of applications employed by all ESA projects and originally designed by Sapienza.

Through collaboration with academia-led CubeSat projects, Sapienza strives to learn more about CubeSat businesses and anticipate their market needs. Evaluating structured feedback received from students and academic staff will provide us with invaluable input for future improvements and evolution of the tools. In return, the academia will be able to use ECLIPSE in their CubeSat programmes free of charge with an educational license. We believe in this form of mutual value creation, based on initial contact and positive feedback from several universities around the world that were facing the challenges described above.

Adherence to common standards and effective management throughout a distributed project team in a small-scale space operation is difficult to achieve without the appropriate tools. With ECLIPSE, Sapienza makes this a possibility and wishes to build a CubeSat community using the tool that can benefit from it and influence its evolution through feedback. With this initiative we also aim to empower the new generation of engineers to face the professional challenges of tomorrow.

ADVANCED POSITION-SENSITIVE GAMMA DETECTOR FOR CUBESATS

V.V. Bogomolov[1], A.F. Iyudin[1], I.A. Maximov[1], A.V. Minaev[1], A.A. Novikov[1], M.I. Panasyuk[1], S.I. Svertilov[1], I.V.Yashin[1]

[1] M.V.Lomonosov Moscow State University

Despite the evident limitations on size, mass, power consumption and other board resources CubeSats give good opportunity for observations needing use of several spacecraft, so-called constellation. As example of such observations study of Terrestrial Gamma-ray Flashes (TGFs) with the use of several nano-satellites can be discussed. In the case of constellation of CubeSats placed in the orbits in such a way that mean distance between them will be about thousand kilometres the triangulation technique for TGF source location can be realized. For such observations we present advanced position–sensitive gamma detector adapted for CubeSat format

This instrument should be consisted from a set of minimum 16x16 scintillating crystals of Ce:GAGG type, with size of 1.0x1.0x3.0 cm^3 each, that should be placed along one CubeSat side. As it is well-known Ce:GAGG crystals have quite high light output (~57 000 phot/MeV) and density (~6.7 g/cm^3) with sufficiently small decay time of ~80 ns, that ensures a high throughput of the unit. The fast crystals help to realize the high accuracy of the time measurements and high throughput of the measuring channel. Relatively high density of Ce:GAGG crystals provides the high efficiency of gamma quantum detection in wide energy range. Due to the high light output Ce:GAGG scintillators also give good energy resolution. For example, we have tried Ce:GAGG pixels with thickness of 3.0 cm, and found the high detection efficiency of gamma quanta with energies up to a several MeV, and an energy resolution of ~4% at 1 MeV.

The Si-PM light sensors, or small vacuum photomultipliers could be used for viewing of Ce:GAGG crystals. For example, Hamamatsu R1463 is quite compact photomultiplier with an input window of Ø13 mm. R1463 photo cathode is sensitive at the wavelengths of 300 – 650 nm, with maximum cathode sensitivity at about 420 nm, that is in good correspondence with the emission spectrum of Ce:GAGG.

The tracking gamma spectrometer has its own read-out unit of analogous and digital electronics.

MIURA 5: THE EUROPEAN AND REUSABLE MICROLAUNCHER FOR CUBESATS AND SMALL SATELLITES

Maximilian Nürmberger, PLD Space

MIURA 5 is a European reusable microlauncher developed by PLD Space. Founded in 2011 in Elche (Spain), PLD Space aims to serve the emerging small satellites (up to 200kg) and CubeSats market with a dedicated, flexible and affordable launch service. For this, PLD Space is currently developing a family of reusable launch vehicles: MIURA 1 and MIURA 5. MIURA 1, a suborbital rocket for microgravity research will serve as technology demonstrator for its successor MIURA 5. Thus, MIURA 5 will provide commercial access to space.

Market assessments carried out by PLD Space have confirmed a significant growth in the small satellites demand. Actually, more than 4100 small satellites are forecasted up to 2028. This market is widely dominated by CubeSats (71%). This substantial evolution of the nanosatellites market has been enabled by lower-cost hardware, the components miniaturization and the development of COTS for space applications. Thus, these factors have enabled to reduce the size and the cost of satellites. In addition, market analysis has shown that majority of small satellites intend to reach a Sun Synchronous Orbit (SSO) and that many nanosatellites are constellations. Moreover, Europe represents a relevant market, just after North America.

The two-staged MIURA 5 launch vehicle can deliver a payload mass of 300 kg to a 500 km sun-synchronous orbit, an optional kick-stage enables the deployment of satellites in different orbits. Flexible launch configurations are available to meet the needs of a broad spectrum of CubeSat missions. Possible options are a dedicated launch, a piggy back flight as primary payload or as passenger, and a rideshare of similar sized satellites. With the last two options being the most appropriate ones for CubeSat missions. All flight configurations also come along with the increased flexibility, shorter lead times and reduced costs that are achieved with every MIURA 5 mission.

During the Symposium, PLD Space intends to present MIURA 5, the first microlauncher designed and operated by a private company in Europe.

Figure 1: MIURA 5 Launch Services

Figure 2: MIURA 5 Flight

CHARGED PARTICLES DETECTOR FOR CUBESAT SPACE MISSIONS

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Using CubeSats as a space platform is very appropriate for measurements with compact detectors. Such instruments can be used successfully for radiation monitoring in the Earth radiation belts and precipitation areas because of a sufficiently small geometry factor, which is enough for the task. We present a multi-purpose spectrometer of protons with energies 2…160 MeV and electrons with energies 0.15…10 MeV for installation in CubeSat format. The main element of the spectrometer is a telescope assembly, including semiconductor (silicon) detectors with different thickness and (optional) scintillator detector, which are placed coaxially one under the other. To measure the pitch-angle distribution and omnidirectional fluxes, several telescopes with differently directed axes can be used. Direct measurement of omnidirectional particle fluxes can be realized using spacecraft rotation. The axis of rotation should be perpendicular to the Equatorial plane. The required rotation period is ~6 seconds with a measurement frame of 300 milliseconds. An active orientation system of the spacecraft is not critical for mission success, but the availability to point exact directions with accuracy ~ 5° can significantly expand mission objectives.

Different instrument arrangements are considered depending on the mission parameters. In one case the axis of the main telescope and the 1st axis of the satellite are perpendicular to the plane of the magnetic meridian. The axes of another 2…4 telescopes lie in the plane of the magnetic meridian. The 2nd axis of the satellite is directed to the center of the displaced magnetic dipole (close to the nadir direction), which leads axes of four telescopes to lay in the magnetic meridian plane and the axis of another telescope to be normal to this plane. In the case of polar orbit, the axis of 2…4 telescopes should lie in the orbital plane.

In another case, the first axis of the satellite is normal to the plane of the magnetic meridian. The second axis of the satellite is directed along the magnetic field induction vector B, calculated from the model of the displaced dipole. The axes of 2…4 other detectors lie in the plane of the magnetic meridian.

The main operational mode is when all detectors are switched-on and operate continuously. Instrument switching between operational modes is carried out by commands from the ground station or by the internal scheduler of the control unit. To optimize the payload energy consumption, several energy-saving modes to be implemented (different sampling rates from full-speed operating up to partial switching-off).

INORBIT NOW LAUNCH SERVICES FOR PRECISE CUBESAT DEPLOYMENT

Matteo Andreas Lorenzoni[1], Eleonora Luraschi[1]

[1] D-Orbit S.p.A.

D-Orbit is a service provider for the Traditional Space and NewSpace sectors, with capabilities in satellite manufacturing, launch, deployment, satellite operations, end-of-life strategies and solutions, space propulsion and related critical software. D-Orbit's products and services cover the entire lifecycle of a space mission, including mission analysis and design, engineering, manufacturing, integration, testing, launch, as well as end-of-life decommissioning.

The objective of the service here proposed is to provide an affordable, reliable and repeating transportation service to Earth orbits to spacecraft, experiments and payloads in a CubeSat format.

D-Orbit provides launch services in rideshare launches using dispensers able to host CubeSats from 1U up to 16U. The deployers are designed and manufactured in the D-Orbit HQ in Italy.

Moreover D-Orbit has developed, manufactured and launched ION, which is the only free flying carrier available on the market that can provide a full phasing of all the satellites onboard in less than three (3) months. It is able to carry a total capacity of 48 unit-CubeSat, configurable in different format size, from 1U up to 12U. Its release strategy significantly reduces the deployment time of constellations of up to 85% compared to traditional differential drag method. By releasing each Nano satellite into a precise orbital slot, we guarantee a wide separation between spacecraft and dispenser, a faster signal acquisition, and a stable collision-free formation. This brings several advantages such as:

- Reduced time to profitable operations, this means longer operational time of each satellite
- by reducing the time when the satellite is in orbit, aging, without being profitable;
- no need to operate the satellites to perform the drag maneuver;
- each spacecraft, intended as a financial asset, is immobilized for a shorter time.

ION maiden flight was in August 2019 on board the VEGA POC rocket and it is equipped with propulsive capabilities since its first flight.

In December 2018 D-Orbit was awarded by ESA of a contract for the development of an enhanced version of the In-Orbit CubeSat Deployer (called "ION mk02" in the frame of the Platform CubeSat Deployer Sat Project). The activity consists in the study, specification, design, production and qualification of a small satellite dedicated to the precise in-orbit deployment of a number of CubeSats. The satellite will have traditional bus subsystems, i.e. redundant avionics, electrical and power, attitude control and thermal control, propulsion subsystems. Each CubeSat is able to receive power and possibly communicate with the satellite bus allowing CubeSat checkout during the pre-launch phases and before their release into orbit. The satellite is in charge of releasing the various hosted CubeSat precisely at the required orbital position and with a reduced tumbling rate. The overall benefit of such configuration is to provide a single interface towards the launcher authorities and to allow the CubeSat to be precisely inserted reducing satellite dispersion time, enabling new mission and deployment scenarios for CubeSat operators, especially in support to large constellation of nanosatellites. The PCD Sat Project is schedule to end in April 2020.

The presentation will include the status of the ION mk01 maiden mission after its launch and the lesson learnt. We'll present as well how the results will be integrated in the development of the future and enhanced versions of ION.

STATUS OF EDUCATIONAL OUFTI-2 1U CUBESAT AS OF MAY 2019

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We describe the current status of the educational OUFTI-2 1U CubeSat. This satellite is a successor to the OUFTI-1 satellite, which became silent after 12 days in orbit, in May 2016. A thorough analysis of the possible reasons of failure of OUFTI-2 led to a significant re-design.

The primary mission of both satellites is identical, namely a home-made space repeater for D-STAR amateur radiocommunications. The freeing-up of some space on-board, in major part due to a new design philosophy for the on-board processor (OBC), allowed us to embark new secondary payloads: one for testing the performance of a new type of electronics-shielding, multilayer material with small size & weight, and the other – designed by high-school students – to perform inertial measurements.

The radiocommunication (COMM) system of OUFTI-2 continues to provides (1) D-STAR voice & data user communication, (2) AX.25 telecommand & telemetry, and (3) automatic, periodic beacon (BCN) Morse-code transmissions. However, now, the D-STAR system also provides a beacon mode, and the BCN a higher power efficiency and, in addition to the transmission capability at 12 words/min, a high-speed data transmission capability at 2400 bits/sec. The discovery of a previously-unnoticed "sync word" in the D-STAR frames received by the COMM led to a huge reduction of the number of interruptions to the OBC. The new Electrical Power System (EPS) uses a semi-regulated bus, rather than an unregulated one, leading to a better control of the charge of the two batteries, thus improving their life duration. For OUFTI-2, we switched to a structure and solar panels from ClydeSpace.

The major difference between OUFTI-2 and its predecessor resides in its OBC. OUFTI-1 featured a pair of redundant MSP430-based electronic boards, one commercial and one homemade. A very likely reason for the failure of OUFTI-1 lies in the use of these redundant processors/boards and a possible continuous handover from one to the other. Therefore, significant attention was devoted to make the OBC more robust. At one point, in October 2017, the opportunity arose to use the Digital Programmable Controller (DPC) from Thales Alenia Space, Belgium. A main feature of the DPC is the fact that it is very highly resistant to space radiation. It also features 3 separate core processors, each with a distinct function.

The current status of the satellite is as follows. The design of the BCN, COMM, and OBC is complete. The same holds for the EPS, except for the circuitry between the solar panels and batteries, which is being finalized. The four electronic boards are at various stage of completion, and prototypes have been built. For the OBC board, we use a temporary, test piggy-back system so that we could easily change the DPC if this proved necessary. The architecture of the OBC software is essentially complete. The on-ground BCN decoding software is operational. We are also designing and constructing a solar lighting system and the electrical ground support equipment (EGSE). A first test of the on-bench assembled system should take place during the summer of 2019.

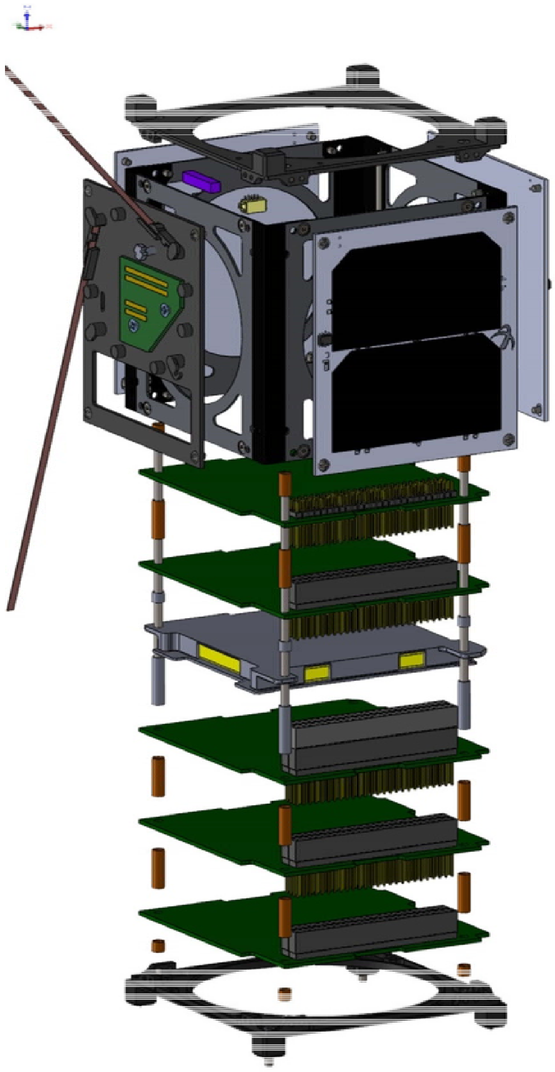

Figure 1: CAD model of OUFTI-2.

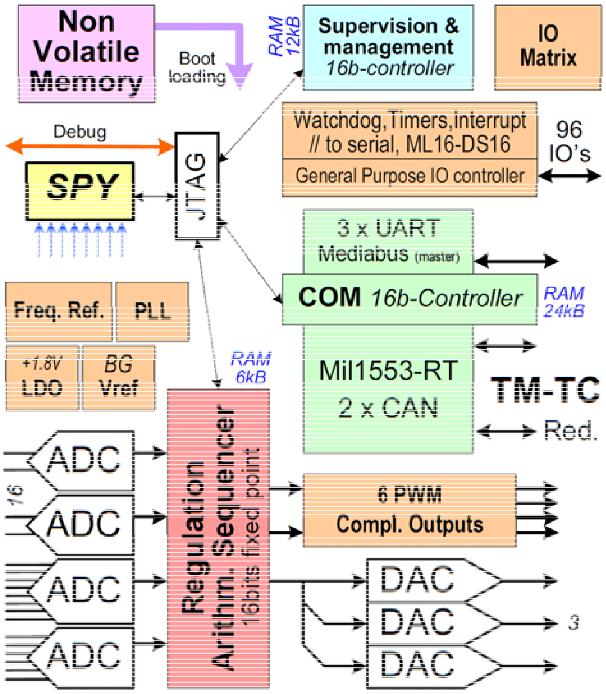

Figure 2: High-level architecture of DPC.

DE-ORBITING SIMULATIONS FOR LEO CUBESATS

H. Sert[1,3], B. Van Hove[2], Ö. Karatekin[2], V. Dehant[1,2], O. Chazot[3]

[1] Université Catholique de Louvain

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In Low Earth orbit (LEO) where the altitudes are below 2000 km, natural orbital decay of nanosat can be very slow and most satellites achieve a re-entry within years to decades due to mainly the atmosphere of the Earth. Recent progresses on access to space allowed small satellites (i.e Cubesats) at LEO, to gather science data or to make technological demonstrations. However, the growing population of LEO objects are carrying a risk of collisions. According to European Space Agency (ESA), any European satellite within the LEO has to de-orbit in 25 years after the end of its mission for the clearance of the space. De-orbiting should be considered as part of LEO satellite missions and it is an important topic within the scientific community due to mitigation of the growing space-junk problem and space debris researches.

In this study, Royal Observatory of Belgium (ROB) in-house trajectory simulation code is adapted for de-orbiting satellites with suitable force models to investigate de-orbiting time of Cubesats with different specifications. Accelerations on a satellite are calculated independently and summed according to Cowell's formulation [1] and numerically integrated to obtain state vectors of the satellite during de-orbiting flight.

3-Degree of Freedom (DoF) simulations for de-orbit times of Cubesats with different sizes and geometries are performed and the results are compared with other numerical models as well as flight data. In particular, we considered Inflatesail Cubesat (QB50-UK06) simulations which was part of the European QB50 program and the first European demonstration of drag sail de-orbiting Cubesat [2]. Influence of different Cubesats and environmental parameters on de-orbiting times are discussed.

References

[1] D.A. Vallado. Fundamentals of Astrodynamics and Applications. Microcosm Press/Springer, 2007.

[2] C. Underwood, A. Viquerat, M. Schenk, S. Fellowes, B. Taylor, C. Massimiani, R. Duke, B. Stewart, C. Bridges, D. Masutti, and A. Denis. The InflateSail CubeSat Mission –The First European Demonstration of Drag-Sail De-Orbiting. 2017.

X-CUBESAT RESULTS AND POST MISSION ANALYSIS

Lilla Solovyeva

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X-CubeSat is a nanosatellite designed by student of École Polytechnique, developed between 2011 and 2016, participated in QB50 program. Our satellite has been launched into orbit (415 km) on May 17th 2017 from the International Space Station and X-CubeSat finished your mission on February 4th 2019.

We would like to present the X-CubeSat results, post mission analysis, our experience feedback and last date of X-CubeSat obtained by amateur radio operators.

Thanks to more than one and a half worth of housekeeping data collected by our ground station and le collection of two-line elements across the satellite lifespan, we may put the physical measurements of the CubeSat, such as solar cells temperature, voltage and current, battery charge and temperature other subsystems states, regarding the satellite position at the time of their emission.

This analysis will provide validation or refinement for the models developed by the students during the development of the CubeSat, for use in our future projects.

SPACECRAFT THREE-AXIS STABILIZATION METHOD USING INTERNAL MOVABLE MASSES

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Smallsats including mini, micro, nano, pico and femto satellites has attracted increasing interests within the past few years. The statistic shows that from 2012 to 2017, over 1000 smallsats were launched and 87% were CubeSats[1]. Among these CubeSats, over 80% are used for remote sensing, which means that they all need special orientation, thus an attitude control system is essential for these spacecrafts. While designing these tiny satellites, two most tense parts are power consumption and volume which makes them hard to put into practical application. From this point of view, how to design a control system which is reliable and less power consumption is of great importance.

This work is to design a novel attitude control system using four internal movable masses (as shown in Figure 1). Internal mass moving has three effects, one is mass motion can change the relative position between the center of mass (COM) and center of pressure (COP), which can generate aerodynamic torque. And this can be done by moving the opposite masses in the same direction. The second effect is that mass-shifting can change the distribution of angular momentum in body frame, and this can be done by moving the opposite masses in the opposite direction. While the third effect is moving mass can change the inertia tensor, which is an inevitable effect accompanied by the movement of masses. Here, we want to actively use the first two effects to realize the three-axis stabilization.

A three-step control strategy is proposed to complete the three-axis stabilization. In the first step, move the masses properly to generate aerodynamic torque to decrease the angular momentum of the spacecraft until the angular momentum coincides with the direction of the orbital Y axis. Then, use the masses as a damper to change the spacecraft rotating in its' body Y axis (Here, we assume the maximum of principal moments of inertia of spacecraft lies in the Y-axis, which matches with the shape of the CubeSat). The last step is to slow down the rotation about its Y-axis and at the same time realizing three-axis stabilization. Through these cascade steps, the required attitude can be obtained.

The novelty of this work is that the control system is very simple of which the mass movement can be realized through stepper motors. Compared with reaction wheels, it does not need to rotate very fast and does not have a dead zone. And it has an obvious advantage over thrusters which need a propellant. The control system can also be a method to eliminate the error between the center of mass and center of pressure if an error exists during the manufacturing process and the method can refer to [2]. Moreover, if the masses are set to the position which can make the position of COM before the COP in the direction of the X axis, then it is robust to the disturbances for low earth orbit since aerodynamic drag is the main environment forces acted on the spacecraft. In this way, the spacecraft is no need to provide energy to eliminate the attitude error from time to time which is the original intention of this design: save energy. The total mass of the four masses could be less than 10% of a 6U CubeSat so that the spacecraft can realize three-axis stabilization within two days from an initial rotation rate at about 5deg/s.

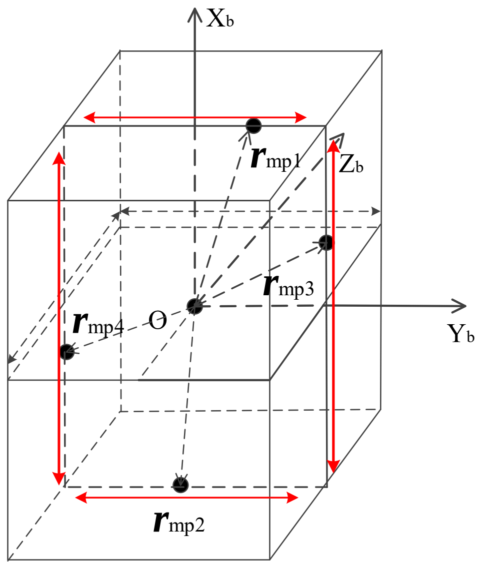

Figure 1: Illustration of the mass control system

Reference

[1] BOK C B, COMEAU A, DOLGOPOLOV A, et al. 2018. Smallsats by the Number 2018 [M]. Bryce Space and Technology.

[2] CHESI S, GONG Q, PELLEGRINI V, et al. 2014. Automatic Mass Balancing of a Spacecraft Three-Axis Simulator: Analysis and Experimentation. Journal of Guidance, Control, and Dynamics [J], 37: 197-206.

CALIBRATION METHOD OF MAGNETOMETER BASED ON BP NEURAL NETWORK

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In this paper, the BP neural network is used to calibrate the magnetometer. The traditional calibration method usually needs to establish the error model of the magnetometer. The calibration method based on BP neural network does not need to establish complex models, so it reduces the influence of uncertainty in modeling.

Firstly, the error model of traditional magnetometer calibration is analyzed. There are four main reasons for magnetometer errors: The three axes of the magnetometer are not strictly orthogonal. The sensitivities of the three axes are not consistent. Constant drift and random error.

Secondly, the structure of BP neural network is designed. The structure of BP neural network is one of the main factors affecting its performance. According to the Kolmogorov theorem, we designed the number of layers. Since the three-layer BP neural network can approximate any continuous function, the network structure selected in this paper adopts a three-layer BP neural network with only one hidden layer.

The number of hidden nodes is also important. Too many hidden nodes will lead to long training time, low generalization performance and overfitting. If the number of hidden nodes is too small, the accuracy of the network will be reduced and the error will be larger, which will affect the prediction ability of the network. The selection of the number of hidden nodes in the network should be as few as possible under the condition that the accuracy requirement is satisfied. In this paper, the subtractive method is used to design the number of nodes, and the influence of the different number of hidden nodes on network convergence is tested. The results show that the number of hidden nodes is at least three to ensure the stability of the network. Therefore, this paper adopts a three-layer network structure with three hidden nodes.

In addition, an improved BP algorithm is used to improve the training speed of the network. The basic BP algorithm has many problems, such as long training time, difficult to determine the network structure, easy to fall into local optimal solution, etc. The Levenberg-Marquardt method has the characteristics of fast network training speed and large memory demand. Therefore, the Levenberg-Marquardt method is adopted in this paper to train the network and improve its training speed. And the Levenberg-Marquardt method is derived.

Next, the simulation test is carried out. Firstly, BP neural network is used to calibrate the magnetometer. The simulation results show that the BP neural network can effectively reduce the error of magnetometer(as shown in Figure 1). Then the error of BP neural network is analyzed. The main factor that causes the error of BP neural network calibration is the random error of measurement.

Finally, on-orbit calibration is realized through simulation. After the satellite is in orbit, the sensor is affected by launch vibration, temperature change, space radiation, attitude maneuver, and other factors. The actual performance of the sensor is usually inconsistent with the result of ground calibration.BP network can be trained by accurate magnetic field intensity data and magnetometer measurement data. The realization of in-orbit calibration requires that the satellite can acquire data for on-orbit training. During the operation of the satellite, a large amount of magnetometer data and attitude data will be recorded. The accurate magnetic field data corresponding to the magnetometer coordinates can be calculated by using the high-precision geomagnetic field model and combining with the satellite attitude. In this paper, the training cycle is designed, and BP neural network is trained once per cycle to adapt to changes in magnetometer performance. The simulation results of on-orbit calibration show that BP neural network can effectively reduce errors within one cycle after changes in magnetometer performance(as shown in Figure 2).

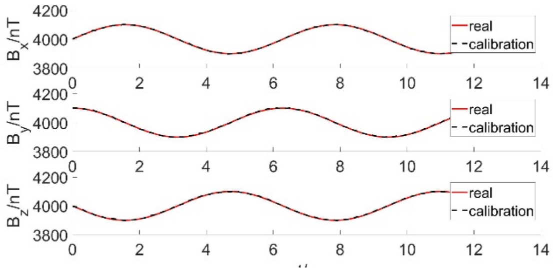

Figure 1: Calibration results of magnetometer

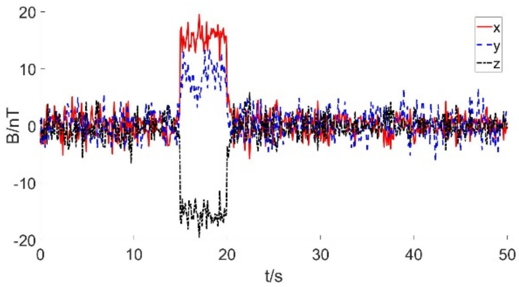

Figure 2: Error of on-orbit calibration

OPTIMAL TRAJECTORY PLANNING METHOD FOR LARGE ANGLE ATTITUDE MANEUVER OF CUBE-SATELLITE USING VSCMGS

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With the development of the space industry and the diversification of space missions, the rapid attitude maneuverability and precise steady-state pointing accuracy are required for the next-generation spacecraft, particularly for high-resolution earth imaging cube-satellites[1]. Variable speed control moment gyro (VSCMG) is a kind of control moment gyro (CMG) with variable wheel speed (as shown in Figure 1). Due to the torque amplification ability and non-singularity of VSCMG, equipped with VSCMG as the satellite actuator can effectively solve the contradiction between large angle attitude maneuver of satellite and high attitude stability near steady state[2].

In the process of rapid maneuvering, a large control torque is mainly provided by the change of gimbal angle, but the wheel speed is also changing in the process of rapid maneuvering, and it provides compensation to the control torque, which is called CMG working mode. When the system is near the steady state, the gimbal is locked, and the high-precision control torque is provided through the change of wheel speed, which is called reaction wheel (RW) working mode. Therefore, CMG working mode can be used for large angle attitude maneuver, and RW working mode can be used for attitude stabilization.

The application background of this paper is the large angle attitude maneuver of the satellite, it presents an optimal attitude trajectory planning method for the spacecraft equipped with VSCMG as the actuators. Firstly, a mathematical model of large angle attitude maneuver for satellite equipped with VSCMGs is established. Secondly, based on the research results of trajectory optimization, a large angle attitude maneuver method of satellite-based on hp-adaptive Radau pseudo-spectral method is proposed. Both the fixed time energy optimal and synthesis performance optimal cost functions are considered. This method takes the large-angle maneuver problem as an optimization problem which meets the boundary condition and a series of path constraints including gimbal angle constraint, wheel speed constraint, gimbal rates constraint, wheel acceleration constraint, singularity index constraint, angular rate constraint, and simultaneously minimize some performance criterion. And then, taking combination with adaptive Radau pseudo-spectral method and nonlinear programming technique to solve the optimization problem, the optimal VSCMG system trajectory is obtained. Finally, the example is simulated and verified from two aspects: (1) single attitude maneuver mission, CMG working mode is adopted for the satellite to complete a large angle attitude maneuver mission. (2) multiple attitude maneuver mission, since VSCMG is divided into two working modes: CMG working mode and RW working mode. CMG working mode can meet the requirements of agility, while RW working mode can meet the requirements of high attitude stability. when the satellite is engaged in continuous multiple attitude maneuver tasks, and when large-angle attitude maneuver is required, CMG working mode is invoked to output large control torque; When the satellite is in the attitude stability stage, RW working mode is invoked to accurately output a small control torque to overcome external interference torque. Numerical simulation shows that the smooth optimization trajectory satisfied with all constraints within the specified time, and the approximate accuracy is better than 10-6 precision smooth trajectory.

In addition, compared with the traditional trajectory optimization methods, the method proposed in this paper does not need to provide the information of the desired torque trajectory in the process of large angle attitude maneuver, it only needs to provide the starting and ending state of the satellite and various constraints.

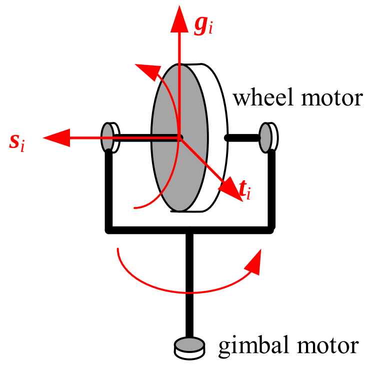

Figure 1: The structure principle of VSCMG

Reference

[1] Zhang L, Yu C, Zhang S, Cai H. Optimal attitude trajectory planning method for CMG actuated spacecraft. Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering 2017;232:131-42.

[2] Prabhakaran VS, Sanyal A. Adaptive Singularity-Free Control Moment Gyroscopes. Journal of Guidance, Control, and Dynamics 2018;41:2416-24.

ANALYSIS OF VARIOUS DECODING ALGORITHMS FOR A CCSDS BASED IMPLEMENTATION OF TURBO CODING

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The end of the proof of concept stage has ushered in the commercialisation stage for CubeSats, with an increasing need for space to ground links with higher reliability than before. Turbo codes providing more substantial coding gains and performance astonishingly close to the Shannon limit were previously used only for deep space missions, but are now being considered for CubeSats to tackle this need.

Various decoding algorithms (Bahl, Cocke, Jelinek and Raviv or Maximum a posteriori algorithm, log-MAP algorithm, max-log-MAP algorithm) have been explored in this paper. An implementation of turbo coding by CCSDS standards is then provided, and an attempt to study these decoding algorithms in terms of complexity, performance and ease of implementation is made. An early termination method has also been proposed using the CRC from the CCSDS recommendation itself, after removing phase ambiguities using the ASM. Finally, simulation results and BER plots for the complete system for various configurations at different code-rates (1/2 and 1/3) have been provided verifying the correct implementation of these algorithms.

DESIGN AND ON-ORBIT PERFORMANCE OF LOW-COST, COTS-BASED TOTAL IONIZING DOSE SENSOR FOR CUBESAT APPLICATIONS

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Destructive ionising radiation influence on electronics is a major concern in most of the space missions, especially in the days of increasing role of commercial off-the-shelf (COTS) parts. [1] In this work, we describe the design and on-orbit evaluation of the total ionising dose radiation (TID) sensor, suitable for small sats LEO missions. Real-life TID measurement data would significantly help the future missions in radiation-related risk mitigation as well as they provide valuable scientific data about radiation environment.

The total ionising dose sensor is based on radiation-sensitive field-effect transistors (RadFETs) which radiation-induced threshold voltage (Vth) shift can be measured in order to determine an actual TID value. Wide measurement range up to 10 kRad (100 Gy) with effective resolution better than 2 Rad (20 mGy) fits the needs for medium-long LEO missions. The sensor operates in unbiased mode, i.e. no power supply is required apart from short-time readouts, yielding extremely low average power consumption. It incorporates power supply, constant current biasing and low-noise analog to digital Vth readout circuitry allowing for easy measurement and data handling in a digital form via CubeSat standard-compatible I2C bus. All crucial components are space-proven or radiation-resistant widely available COTS.

As a sensing element, a Texas Instruments CD4007 integrated circuit comprising three MOSFET complementary pairs was selected - due to its proven TID sensitivity, initial threshold voltage value of P-MOSFETs suitable for low-voltage systems, small TSSOP14 package and wide in-market availability. [2] Thanks to numerous studies, CD4007’s electrical characteristics were initially well-known [2][3][4]; however, long-term Vth stability was tested along with thermal calibrations of the CD4007 as well as entire TID sensor.

Three P-MOSFET transistors available in single CD4007 IC improve statistical confidence of total dose measurements and introduce triple redundancy of the sensing element. Body diode of CD4007’s N-MOSFET transistor is utilized as a temperature sensor for threshold voltage thermal compensation. The solution allows for direct probing of silicon die temperature, simplifies mechanical sensor construction and resolves problems with temperature unbalance between P-MOSFET silicon structures and external thermometer.

The TID sensor is powered from 5 V satellite bus, with integrated latch-up current limiter and on/off switch. Thanks to the use of high-performance linear voltage regulator, it is immune to noise on power rail and can be powered directly from switching regulator. MOSFET, in diode configuration, is biased by high-stability 100 µA current source. Readout of the threshold voltage of selected channel is done by 24-bit sigma-delta analog to digital converter, providing high resolution of the readout. All internal electronics are powered only during readout and whole sensor can be disconnected from power bus. This tailors radiation requirements for the components and allows to minimize power consumption.

Flight model of the TID sensor was integrated with the PW-Sat2 2U CubeSat as one of the secondary scientific payloads. The satellite was successfully launched into 580 km SSO orbit on 3rd Dec 2018. Soon after the commissioning phase, total ionising dose readouts have begun to be carried out periodically. To date, over 12 readouts were taken, the last one indicating over 600 mGy of absorbed dose. Experimental data from TID sensor were compared to SPENVIS SHIELDOSE simulation results. All results exhibit nominal in-orbit operation, including effective temperature compensation which has significant impact on the sensor performance.

The sensor hardware design (schematics, PCBs, simulations), software (including source code) and detailed documentation including all calibrations and in-orbit results are freely available under AGPL 3.0 license.

[1] D. Sinclair and J. Dyer, "Radiation Effects and COTS Parts in SmallSats," AIAA/USU Conference on Small Satellites, 2013.

[2] P. Milic, “P-channel MOSFET as a sensor and dosimeter of ionizing radiation”, Facta universitatis - series: Electronics and Energetics 29, pp. 509-541, 2013.

[3] M. Martínez-García, et al., “Response to ionizing radiation of different biased and stacked pMOS structures”, Sensors and Actuators A: Physical, pp. 252, 2016.

[4] G. M. Mitev, S. Sarieva-Jordanova, M. G. Mitev, “Enhanced readout system for RADFET dosimeters research,” Annu. J. Electron., pp. 250–253, 2015.

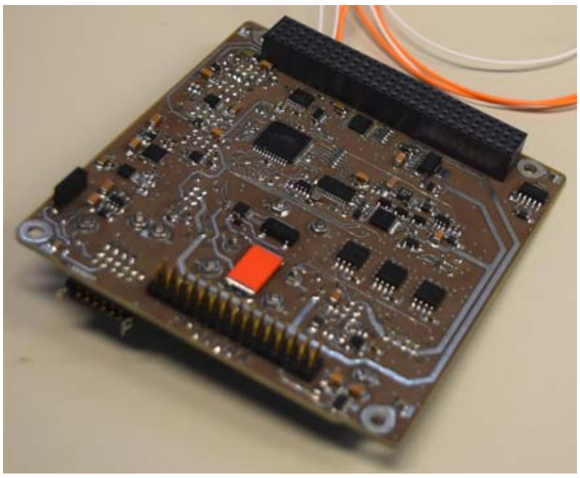

Figure 1: Flight model of PCB with RadFET sensor.

Figure 2: PW-Sat2 satellite hosting the sensor.

CLEAN PROPULSION SYSTEM FOR CUBESAT PLATFORMS CONTROL

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In the context of the increased interest in the development of micropropulsion, as well as in the research regarding cleaner propulsion solutions, a series of activities conducted at COMOTI, Romania, involve an experimental thruster system capable to perform extensive testing on H_2/O_2 gaseous mixtures, assuming the two components are obtained through electrolysis.

The activities, performed under ESA and ROSA (Romanian Space Agency) research contracts, are complementary and focus, on one hand, on the evaluation of the feasibility of an electro-chemical technology as application for an attitude control system for CubeSat sized platforms, aiming to demonstrate, by experimental means, the capability of the H_2/O_2 mixtures to be pulsed and ignited in a vacuum environment, and, on the other hand, on proving the potential of water propulsion for utilization on small scale platforms through water electrolysis technology, adapted and optimized, able to provide the H_2/O_2 necessary for executing the mission required manoeuvres.

The experimental setup and program have been developed based on the defined main technical requirements related to both the propulsion system and the laboratory model dimensioning, in terms of operating conditions and targeted performance level.

The system allows the measurement of multiple parameters along the flow path, starting from the gas sources and up to the expansion nozzle, at different acquisition rates, in order to track the gas-dynamic parameters of the process. Following a detailed experimental plan that included preliminary testing of the laboratory system architecture concept, as well as preliminary pulse mode and steady-state tests for instrumentation functionality and accuracy demonstration, a test matrix has been elaborated in order to cover the desired ranges.

The paper focuses on the tests performed in atmospheric conditions, at propellant pressure of up to 18 bars, mixture ratios of (0.6 - 1.4) relative to stoichiometric, targeting mass flows able to deliver up to 1 N of thrust in vacuum conditions. Moreover, pulse train operation is achieved, for the lowest possible on and off times, with respect to the proposed requirements, demonstrating the process repeatability.

In parallel, a small-scale electrolysis system, a PEM laboratory model, has been designed, developed and tested, in order to demonstrate the capability of the technology to be applied on small scale platforms, based on the imposed propulsion system requirements.

Integration aspects of the propulsion and electrolysis systems are taken into consideration, relative to known, similar models and based on the results obtained within the mentioned COMOTI and its partners' research activities. The method of connection and integration of the two main components assumes the design of compatible cases, with respect to CubeSat typical dimensions. The current development phase allows an easier adaptation for the case of the electrolysis system, due to its compact architecture, while the propulsion system is still in the process of downsizing, from laboratory model to flight hardware.

The conclusions are related to the demonstrated performance level of the propulsion and electrolysis systems, as well as on the steps of a development plan up to the certification stage.

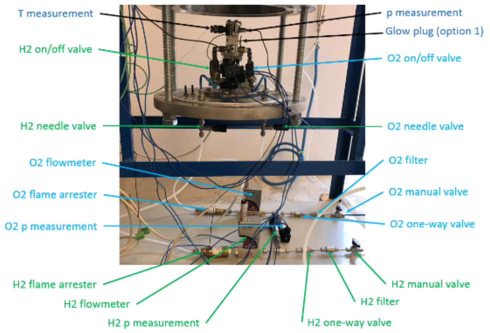

Figure 1: Experimental setup

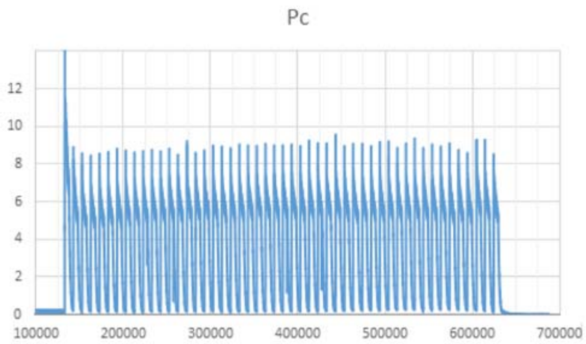

Figure 2: Combustion pressure in pulse operation

References:

Zeledon, R.A.: Electrolysis propulsion for small-scale spacecraft, Ph. D. Thesis, Cornell University, Ithaca, NY (2015)

Tethers Unlimited, Inc.: http://www.tethers.com/HYDROS.html

Popescu, J.A., Vilag, V.A., Porumbel, I., Cuciumita, C.F., Macrişoiu, N.: Experimental approach regarding the ignition of H2/O2 mixtures in vacuum environment, Transportation Research Procedia, vol. 29, pp. 330-338 (2018)

ON THE HIGH DENSITY COLD GAS THRUSTER -AFFORDABLE AND THE HIGHEST SPECIFIC VOLUME IMPULSE PROPULSION SYSTEM FOR CUBE SATELLITES TO MICRO SATELLITES

Junichiro Kawaguchi[1], Kaoru Ohahsi[1] and Yuki Kubo[1]

[1] Patchedconics, LLC, Japan

Contemporary cube to micro satellites demands seek affordable propulsion systems. The Patchedconics, LLC started development of the High Density Cold Gas Thrusters and will have the inaugural launch very soon aboard a 70kg Japanese micro-satellite. It carries propellant in liquid state and produces gas onboard. Total impulse carried is enormous in comparison with the conventional cold gas thrusters.

The company has devised a new propulsion system with much more, revolutionary volume effective propulsion system and mad a module proto-type. It was already applied for patent. At the same time, the company also developed innovative gas-liquid separation device for the thruster. It was also applied for patent. Those enable the propulsion system to be built in complete modular way and can be applied not only for cube satellites but for micro satellites up to a few hundred kilograms satellites. The presentation provides the contents of it.

MISSION OBJECTIVES AND CURRENT STATE OF THE FIRST LUXEMBOURGISH CUBESAT MISSION: LUXCUBE

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LuxCube is the first CubeSat student nanosatellite being developed at the University of Luxembourg (UL). The three goals of the LuxCube project are: educational training, technology demonstration and Earth observation. LuxCube complies with 1U CubeSat design specifications and is being developed by students during their course studies and final thesis as well as voluntary work. This paper describes the technology demonstration mission, fabrication of the scientific payload and its integration into the satellite structure and the current state of development of the satellite. It also provides insights into the methodology of a project-based learning approach used to connect the abstract concepts to practical results as a part of an educational program aimed to develop an institutional platform for space technology demonstration.

The primary mission of LuxCube is to give students at the UL the skills needed to design, build, test, and operate space hardware. Next to theoretical lectures as well as lab work in the domains of Mechanical and Electronic & Electrical Engineering, LuxCube project provides an excellent opportunity for students to gain hands-on experience in all the phases needed, from development until mission operations. Thus students will take part in the processes of hardware development, selection of applicable COTS systems, software development and the meticulous testing of the subsystems, as well as the entire satellite system. As a complete CubeSat program LuxCube also includes the development of an amateur radio frequency ground station for its spacecraft operations. Therefore, most ground operation is intended to be mainly conducted by students. With this primary mission objective LuxCube intends to pave the way for subsequent CubeSat missions developed at the UL.

Lux Cube's second main mission objective is a technology demonstration mission intended to test the suitability of thin film solar cells for space applications. The thin-film solar cells are developed at the UL Laboratory for Photovoltaics. The absorber of the thin film solar cells is Cu(In,Ga)Se2 (CIGS) with a thickness of roughly 2 µm. The complete solar cell is grown on a soda lime glass substrate and consists of a Mo/CIGS/CdS/ZnO/grid stack with an additional encapsulation. During the mission in space the current-voltage characteristics will be recorded during the sunlight period and transmitted to the ground station. These curves will be evaluated to obtain insights into degradation mechanisms caused by high-energy radiation present in the orbit. Based on these results the applicability of CIGS based solar cells for space application can be judged and how degradation process can be mitigated for future experiments. CIGS experimental solar cells are not used to power the satellite subsystems. As part of a third mission objective LuxCube will also include a scientific payload in form of a camera. This camera can then be used to provide daily imaging of the territory of Luxembourg to identify potential changes on the surface due to natural disasters such as flooding or wildfires.