Educational space missions of TUMnanoSat family

Ion Bostan, Nicolae Secrieru,
Valentin Ilco, Nicolae Levineț
National Center Space Technologies
Technical University of Moldova,
Chisinau, Rep. Moldova
Ion.bostan@cnts.utm.md, nicolae.secrieru@cnts.utm.md , nicolae.levinet@cnts.utm.md, valentin.ilco@cnts.utm.md,

Viorel Bostan, Sergiu Candraman Adrian Girscan, Andrei Margarint
National Center Space Technologies
Technical University of Moldova,
Chisinau, Rep. Moldova
Viorel.bostan@adm.utm.md, scandraman@gmail.com, adrian.girscan@gmail.com, andrei.margarint@cnts.utm.md

***Abstract* — This paper presents a brief overview of the basic features of CubeSat and their missions. It is described how to approach the various educational missions in the nanosatellites family designed at the TUM Space Technology Center, named TUMnanoSat, specifying the characteristics of the basic subsystems: electrical power supply, processing and data management and telemetry communications.**

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

I. Introduction

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

The primary responsibility of California Polytechnic State University, as the developer of the Poly Picosatellite Orbital Deployer (P-POD), is to ensure the safety of the CubeSat and protect the launch vehicle (LV), primary payload, and other CubeSats. CubeSat developers should play an active role in ensuring the safety and success of CubeSat missions by implementing good engineering practice, testing, and verification of their systems. Failures of CubeSats, the P-POD, or interface hardware can damage the LV or a primary payload and put the entire CubeSat Program in jeopardy. As part of the CubeSat Community, all participants have an obligation to ensure safe operation of their systems and to meet the design and minimum testing requirements outlined in this document [1, 2].

To facilitate access to space for university students the CubeSat was become as standard. Since then the standard has been adopted by hundreds of organizations worldwide. The CubeSat standard facilitates frequent and affordable access to space with launch opportunities available on most launch vehicles. Therefore, CubeSat developers include not only universities and educational institutions, but also private firms and government organizations.

From these guidelines, the TUM Space Center has aligned this standard with its goal of creating a nanoscale family that could deliver a variety of spatial education and research missions.

II. CubeSat's Educational Space Missions

The reason for the small mass of these satellites was mainly due to the limited payload capabilities of the launch vehicles. All satellites were simple satellites and once the launch vehicles became capable of launching larger satellites, satellites became larger and more advanced as well. It is plausible to think that in the decades to follow there was no apparent need for simple satellites like in the first years of space flight. Advanced satellite technology was too big to integrate in a very small satellite. However, in the late nineties this changed due to the availability of low power microelectronics, providing a potential for a high performance over mass ratio. More than half of the pico- and nanosatellites were built with an educational objective: university-class satellite projects. [5, 6].

This means that there is a strong correlation between pico- and nanosatellites and universities, but this is not predominant. Technology demonstration is the most common objective for pico- and nanosatellites, although only 14% of the missions are technology demonstration only. Operational use, like scientific measurements or radio communications, is also an objective of more than half of the pico- and nanosatellite missions. However, it has to be noted that the scientific measurements are often very limited compared to large scientific satellites. Of the satellites with radio communication as operational objective, this is always for radio amateur hobbies or experiments and the performance is not comparable to commercial communication satellites. The target mission duration of the satellites is unknown for more than half of the pico- and nanosatellites, especially for the educational satellites, but for the known pico- and nanosatellites they vary from a few days up to five years. The average intentional mission duration is about eight months, showing that most pico- and nanosatellites are build for a relatively short lifetime.

Regarding to pico- and nanosatellite subsystem technologies, it can be mentioned the following. For the electrical power supply there is about three-quarters of all pico- and nanosatellites are equipped with solar cells. From 1997 this is even 85%, thus there are still some pico- and nanosatellites which run on batteries as electrical power supply only. Gallium Arsenide (GaAs) solar cells are used the most since they provide a very high conversion efficiency up to 30% and are widely available. Silicon solar cells are also used, even in recent pico- and nanosatellites. Although they have lower efficiencies, the cost of such cells is very low compared to the GaAs cells. About 16% of the satellites have deployable solar panels, all others which do have solar panels have them body mounted. In this case the size of the structure is limiting the area of the solar array significantly.

The average power available ranges from ten of mW to seven Watts. For pico- and nanosatellites, the available bus power could be divided by the total mass of the satellite, which is presented in Fig. 6. What can be noticed is that the average specific power increases when the mass of the satellite become slower. This can be logically explained by the fact that the mass of the satellite is related to the volume (third power), while the effective area of body mounted solar cells is related to the area of the sides of the satellite (second power). This is one of the smallest satellites, but is very flat with a relatively large solar cell area combined with sun pointing. The conversion method of raw available power from the solar cells to power on the space craft bus is Direct Energy Transfer (DET) or Peak Power Tracking (PPT) for most pico- and nanosatellites. The DET method takes the power at a predetermined voltage point on the current– voltage (IV) characteristic of the solar cells and shunts excessive power. This is a very simple and reliable method, but because the IV-curve shifts with temperature and degradation of the solar cells, the point should always be taken with a margin from the maximum power point. The PPT method just follows the IV-curve from the open-circuit voltage with DC-DC convertors, but can lead to problems if there is a too large instantaneous current surge. The maximum power point tracking (MPPT) is the most elegant method, since it will retrieve the maximum power from the solar cells. Excessive power can be easily measured and either shunted or used advantageously. Due to the increased complexity of the MPPT method, only 7% of the pico- and nanosatellites are using this. The satellites with non-rechargeable batteries used Mercury batteries in the early pico- and nanosatellites and Lithium batteries for pico- and nanosatellites in the last decade. Most satellites with solar cells have rechargeable batteries of Lithium-ion or Lithium-polymer type, although some use Nickel–Cadmium or Lithium– Chloride batteries [5, 6].

For the attitude control there are almost 40% of the pico- and nanosatellites have active attitude control where as a same amount has passive control, mostly by means of magnetic material. A little more than 20% does not have any attitude control at all, leaving the satellites tumbling free in space. The function of most attitude control systems in pico- and nanosatellites is simple rotational damping to limit the rotation rate of the satellite. This is important fora reliable power generation and communications. About 15% of the pico- and nanosatellites use the attitude control to point in instrument. This is mainly nadir pointing of a camera or pointing of a radiation detector along the magnetic field lines. The used control for this is currently very simple compared to larger satellites and one should not expect more than just a rough pointing of the instrument. Very few pico- and nanosatellites have attitude control for pointing a solar array or to perform ground station tracking. These types of control are always more difficult to obtain than the ones stated above, since they require at least two axis active control.

III. The most common used sensors are sun sensors and magnetometers. Earth sensors and gyros are also used, but one should consider the few star trackers sensors not to be real high accuracy sensors so far. Magnetic control, either passive or active, is very popular in pico- and nanosatellites. Since almost all pico- and nanosatellites operate in LEO, magnetic control is a simple and effective means of attitude control. Spin-stabilization and a gravity gradient boom are also simple but effective means of attaining static attitude. Momentum wheels, reaction wheels and thrusters are actuators which are suitable for more precise and dynamic control, but still remain scarce among pico- and nanosatellites. It is difficult to obtain and compare accuracies and reliability figures of attitude control systems, but in general it can be stated that attitude control in pico- and nanosatellites is still in an early development phase and does not yet allow for precise remote sensing or ground station tracking. About 16% of the pico- and nanosatellites are equipped with a GPS receiver, there by having a direct means of onboard navigation. Only eight pico- and nanosatellites (9%) are equipped with means of orbit control, five of them with cold gas propulsion, one with electric propulsion, one with chemical propulsion and one with a solar sail [5,6]. For the Communication there are the most pico- and nanosatellites having a downlink frequency in the UHF band and transmit their data with a digital form of modulation. Typical data rates are between1200 and 9600 bps, but higher rates up to 80 kbps are seen as well. The VHF band and S-band are also used (some times as secondary downlink frequency). VHF limits practical data rates (9600 bps), while on the S-band high data rates up to 256kpbs are used. The uplink frequencies show a similar distribution, but S-band is scarce. Also data rates are limited, possibly due to the fact that up links are mostly used for short commands rather than large data packets. It can be stated that communication capabilities

TABLE 1. CUBESAT'S EDUCATIONAL SPACE MISSIONS EXAMPLES

Mission name	Organization	Mission objectives
KySat-1	Kentucky universities	The primary mission objective for KySat-1 is educational outreach. Can be commanded via mobile ground stations using HAM frequencies. These mobile ground stations will be taken to schools around the state for children to have their first direct interaction with a satellite. The goal is to stimulate young minds by bringing aerospace technology to them.
RinCon 1	University of Arizona	Low-power beacon system, which provides a redundant means of relaying sensor data in analog form if the primary (digital) transmitter fails.
SEEDS	Nihon University	Communication with the amateur ground stations, the sensing of the satellite housekeeping data, and the analysis of its orbit and attitude. Each mission has many sub-missions.
UCISat 1	University of California, Irvine	Primary mission of capturing imagines of the Earth and transmit them. IMU (Inertial Measurement Unit) used to determine how well the passive ACS performs.
Aramis-C1	Polytechnical University of Torino	Project developed that provides low cost and higher performance space missions with dimensions larger than CubeSats. The feature of AraMiS design approach is its modularity. These modules can be reused for multiple missions which helps in significant reduction of the overall budget, development and testing time. One has just to reassemble the required subsystems to achieve the targeted specific mission.
KatySat 1	Stanford University	Develop satellite bus and other educational purposes. Cubesat will host a web server that will be accessed by the ground station. An amateur radio operator will be able to ping the satellite and receive a confirmation from the satellite
ERPSat01	Sfax School of Engineering	Educational objectives: collaboration and contacts with industry, universities and other CubeSat groups; insight into the system engineering process and team dynamics; deeper understanding of subjects. Scientific and research objectives: technology demonstration and validation for space application; communication link for picosatellite; space discovering using pictures taken by the camera on board the satellite; attitude determination. Its main missions are to capture images of the earth in order to help protecting the environment from forest fires and also to be used for cartography and providing communication in non covered Tunisian areas.
KN-SAT1	University of Khartoum	To give students at Sudanese Universities a hands-on space project experience. To document the process and skills and forward it to more students and post graduated engineers. To promote space engineering and space science education at other Sudanese educational institutes. Building, testing and launching the cube satellite. Monitoring and tracking the cube satellite. Telecommunication of the cube satellite.
Quest-1	Valle Christian High School	Give students experience in satellite development tasks. Collect images from space taken by this satellite. Download environmental data from the satellite. Learn about satellite tracking technologies. Teach other schools about satellite development and tracking technologies.
Lucky-7	SkyFox Labs	Test the first space friendly electronic spacecraft subsystems and design considerations in combination with modern COTS electrical components leading to increased radiation tolerance within the harsh space environment as a precursor for the next generation of Deep Space CubeSat missions and serving in future also for the conquest of Mars by CubeSats/small satellites.

between pico- and nanosatellites and the ground are mostly limited due to the link budget rather than the radio technology, since micro-electronics for high data rates are widely available and are applied in the systems, but available power is scarce and the potential of ground station tracking with high gain antennas is limited by the performance of dynamic attitude control system [5, 6]. For the Command and data handling there are since the late nineties, low power microcontrollers have gradually become available. Their processing performance is similar or even better than most of the outdated but space qualified processors used in satellites and their power consumption is only in the order of mW. The down side of those processors is their high susceptibility to particle radiation in space. The risks are sometimes tackled by redundancy on different components and a distributed command and data handling architecture with multiple microprocessors spread across the satellite. Popular microprocessors are peripheral interface controllers (PICs) from Microchip and mixed signal processors (MSPs) from Texas Instruments. Advanced RISC machines (ARMs) from various suppliers are also becoming popular due to their higher processing power capabilities over the other microprocessors.

The satellites which use a distributed command and data handling system mostly use the I2C data protocol for communication between the microcontrollers. USB and CAN are also used a few times, but are less popular. Areas on could be the fact that these protocols require significant power with respect to the total available power and require extra electronics for most microcontrollers, while I2C support is already integrated in most microprocessors and consumes an insignificant amount of power [4, 5, 6].

For the structure there are almost half of all pico- and nanosatellites launched have been in the CubeSat form factor with the single unit (1U) CubeSat being the most popular one. Only considering pico- and nanosatellites since the introduction of CubeSats, even 76% of all pico- and nanosatellites have been CubeSats. The popularity of this form factor comes due to the fact that CubeSat structures, subsystems and launch adaptors are commercially available and relatively inexpensive, yielding a low threshold for starting a CubeSat project. All other pico- and nanosatellites have different non-standardized structural forms [1, 5, 6].

At this stage, there are a number of CubeSat projects, developed and developing, which carry out a variety of missions, mainly educational, but also research, verification of new technologies [7, 8]. Some examples are in the table 1. Is the question how it is possible to carry out such a wide range of missions, respecting all the CubeSat standard restrictions? The answer is positive, given that although the standard imposes a series of restrictions, there are thousands of space missions available.

A very representative example is the QB50 project [9]. One of the main purposes of the QB50 project is to achieve a sustained and affordable access to space for small scale research space missions and planetary exploration. Space agencies are not pursuing a multi-spacecraft network for in-situ measurements in the lower thermosphere because the cost of a network of 50 satellites built to industrial standards would be extremely high and not justifiable in view of the limited orbital lifetime. No atmospheric network mission for in-situ measurements has been carried out in the past or is planned for the future. A network of satellites for in-situ measurements in the lower thermosphere can only be realized by using very low-cost satellites, and CubeSats are the only realistic option.
Another objective of the QB50 project is to carry out atmospheric research within the lower thermosphere, between 200 - 380km altitude, which is the least explored layer of the atmosphere. To explore this region, atmospheric explorers were flown in the past in highly elliptical orbits (typically 200 km perigee, 3000 km apogee); they carried experiments for single-point, in-situ measurements but the time spent in the region of interest was only a few tens of minutes. By contrast, QB50 will provide multi-point, in-situ measurements for a time period on the order of months, instead of minutes.

Nowadays, sounding rocket flights provide the only in-situ measurements. While they do explore the whole lower thermosphere, the time spent in this region is rather short (a few minutes). There are only a few flights per year and they only provide measurements along a single column. Powerful remote-sensing instruments on board Earth observation satellites in higher orbits (600–800 km) receive the backscattered signals from atmospheric constituents at various altitudes. While this is an excellent tool for exploring the lower layers of the atmosphere up to about 100 km, it is not ideally suited for exploring the lower thermosphere because there the atmosphere is so rarefied that the return signal is

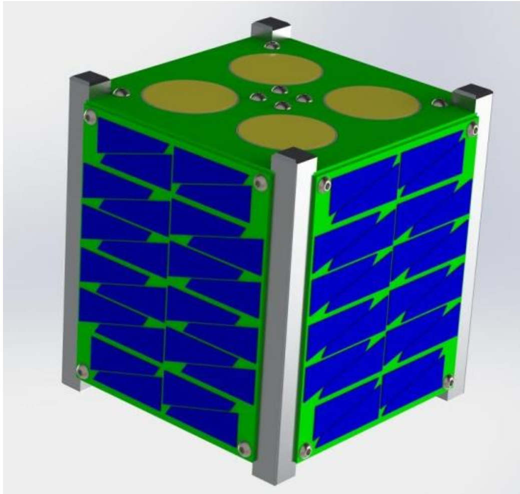
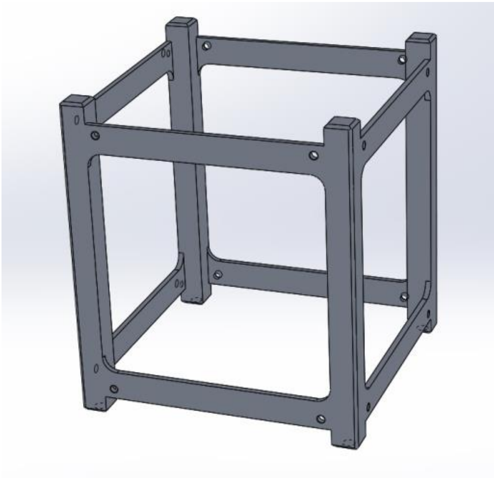
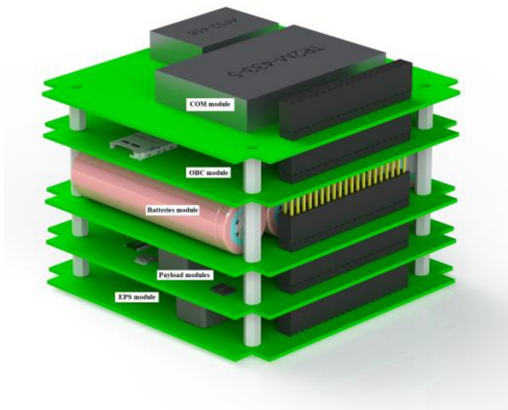


Figure 1. 3D view of the "TUMnanoSAT" family .



a)



b)

Figure 2. TUMnanoSAT structure.
a) primary structure, b) internal structure

weak. The same holds for remote-sensing observations from the ground with LIDAR's and radars.

The multi-point, in-situ measurements of QB50 will be complementary to the remote-sensing observations by the instruments on Earth observation satellites and the in-situ measurements by sounding rockets. All atmospheric models, and ultimately thousands of users of these models, will benefit from the measurements obtained by QB50 in the lower thermosphere.

IV. III. TUMNANOSAT FAMILIY

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

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

NCST began designing a family nanosatellite TUMnanoSAT for checking various concepts and test concrete solutions, involving more students. For **the structure** there are almost pico- and nanosatellites launched have been in the CubeSat form factor with the single unit (1U) CubeSat being the most popular one, therefore it is decided to provide a CubeSat standard for design of picosatellites to reduce cost and development time, increase accessibility to space. The "TUMnanoSAT" family are a typical 10 cm cube with a mass of up to 1.33 kg, that make possible to benefit from the sharing of information within the CubeSat community (http://cubesat.org) [9]. The 3D view of the "TUMnanoSAT" family is presented in the fig. 1 and reflects the main design choices and co-location of the components of the TUMnanoSAT. The primary structure of TUMnanoSat is carried out in accordance with the CubeSat Design Specification (CDS) [9] and it is shown in fig. 2. It is made of hard anodized aluminum after machining process. Design for primary structure, mechanisms such as deployment of solar panels and antenna, equipment layout plans, separation mechanism, and materials for primary structure. Already, at the current stage we have two samples nanosatellite "TUMnanoSAT I", under which it has accumulated experience in developing satellites subsystems. Recent versions "TUMnanoSAT II", promoted in current projects, are a previous version subsystems development: solar panels, subsystem management and distribution, communication subsystem telemetry, onboard computer, the structure of the satellite, the construction modules in the form stack, etc (fig. 2). To save time and money for engineering models of the TUMnanoSAT nanosatellite, it will be manufactured following a proto-flight approach for some parts or subsystems, but mainly will be developed in house with our forces, therefore, it will be developed for concept validation and testing. The test that can be realized are so limited (in time or entity) because the functionality of the CubeSat cannot be deteriorated.

The main purpose of **the power system** is to provide enough electrical power to the rest of the subsystems, such that the satellite is able to function during the entire length of the mission. Power subsystem includes the following components:

1) Four solar panels, which are placed on lateral side surfaces of nanosatellite.
2) MMPT for each photovoltaic panel.
3) The battery pack connected by 6S1P scheme to obtain the required voltage.

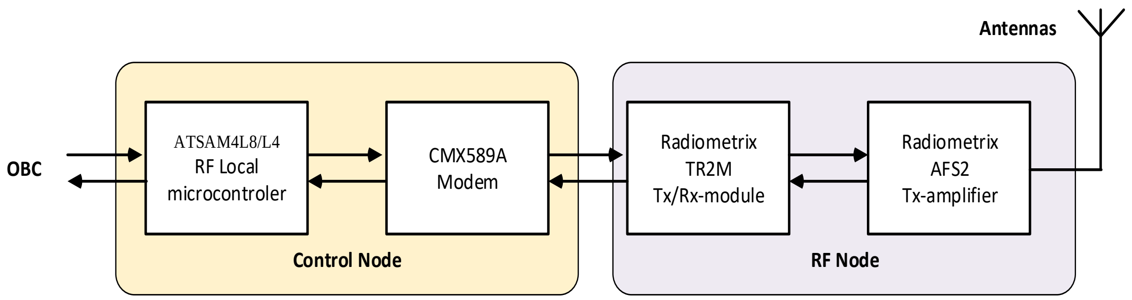


Figure 3. TUMnanoSAT communication subsystem.

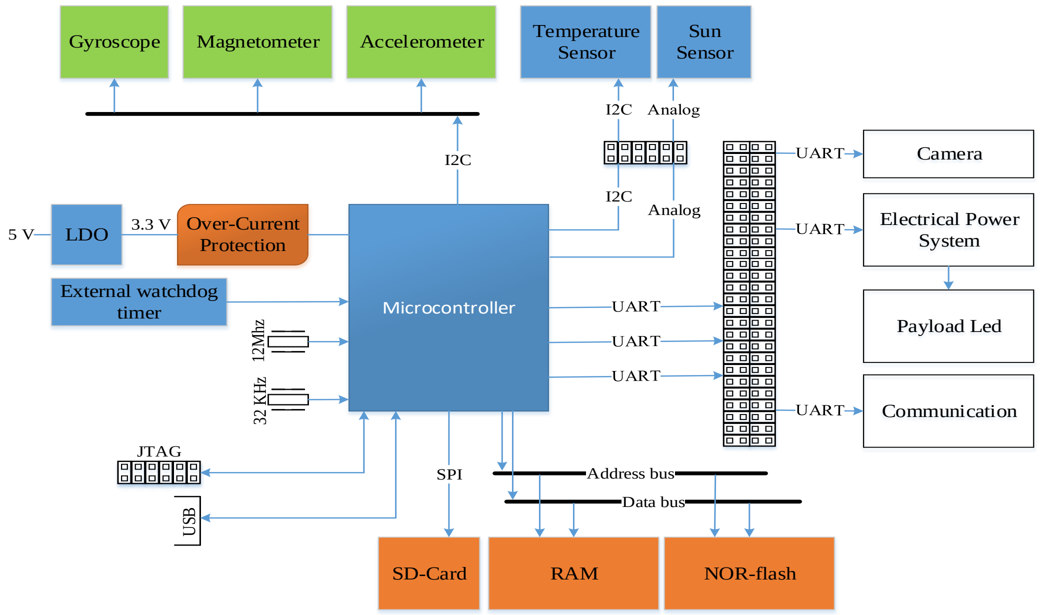


Figure 4. On Board Computer structure diagram.

4) DC/DC convertor with output voltage of 3V/5V.
5) LDO for OBC subsystems, payload sensors and low resolution cameras.
6) Other Power Key for switching the mission's loads.

Photovoltaic panel contains 20/24 improved triple-junction gallium arsenide triangular Advanced Solar cells , Max power ~1.5W per panel.

The **communication subsystem** of the TUMnanoSat

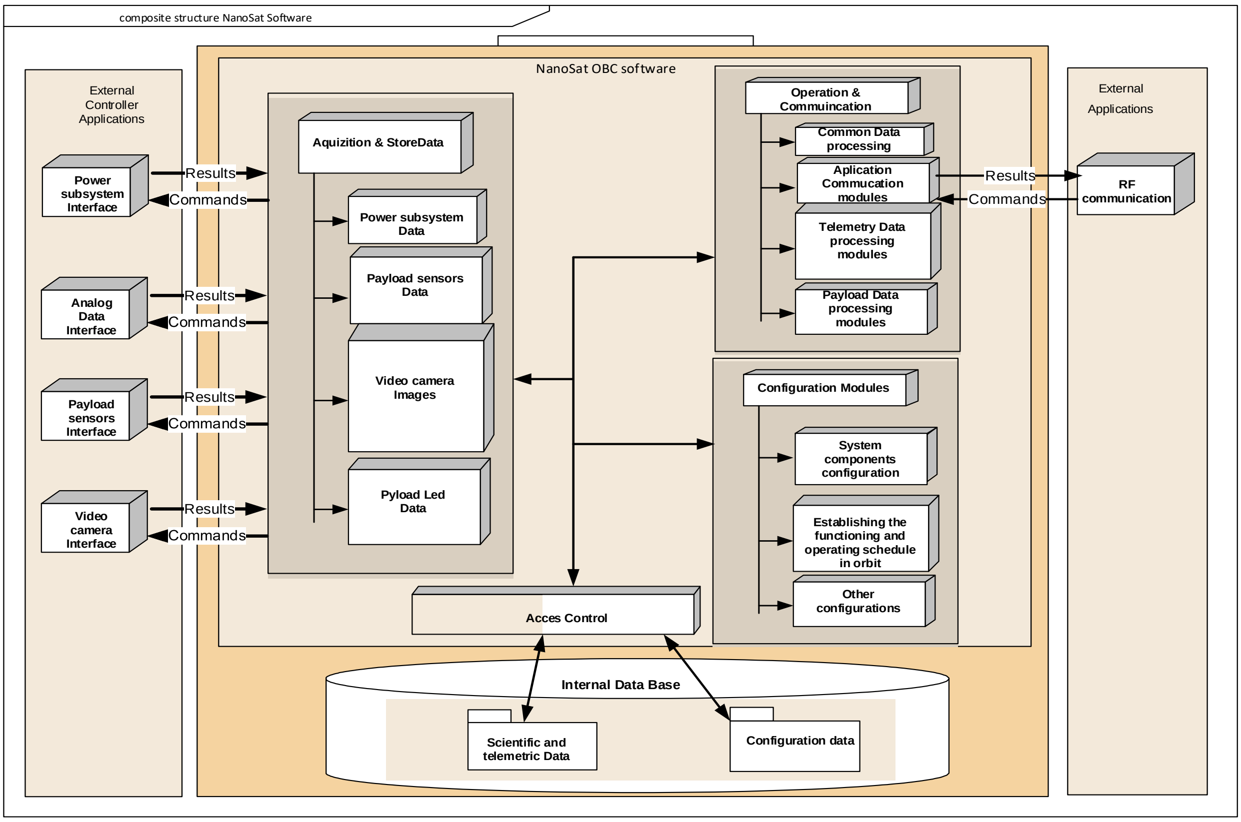


Figure 5. On Board Computer software structure diagram.

consists from two nodes: Radio Frequency node and Control node. The control node contain a CMX589A modem with local ATSAM4L microcontroller. CMX589A modem feature are: variable data rate from 4 to 200 kbps; full or half duplex Gaussian Filter and data recovery of min shift Keying (GMSK); low power: 3.0V, 20kbps, 1.5mA typ./5.0V,64kbps, 4.0mA typ. (see fig. 3). The ATSAM4L8/L4 embeds state-of-the-art pico-Power technology for ultra-low power consumption. It combined power control techniques that are used to bring active current consumption down to 90 µA/MHz. The device allows a wide range of options between functionality and power consumption, giving the user the ability to reach the lowest possible power consumption with the feature set required for the application. The Radio Frequency Node consist of TR2M transceiver module and AFS2 amplifier module. The TR2M transceiver module offers a low power, reliable data link in an industry-standard pin out and footprint. This makes the TR2M ideally suited to those low power applications where existing wideband modules have insufficient range, or where multi-channel operation is needed. Two versions are available, covering the 458.5-459.1MHz UK band (at 100mW) and the European 433.05-434.79MHz band (at 10mW). It has the following features:

a) 433MHz version conforms to EN 300 220-3 and EN 01 489-3 458MHz version to MPT 1329 (UK specs).

b) Any 5MHz band module from 420MHz to 480MHz available as factory tuned custom variant

c) High performance double superhot, 128 channel PLL Synthesizer with TCXO

d) Data rates up to 5 kbps for standard module

e) Feature-rich interface (RSSI, automatic noise squelch, analogue and digital baseband)

f) Incorporates a 1200baud dumb modem

g) User configurable via RS232 interface

h) Low power requirements

The AFS2 amplifier module is to increase the transmitted power of a Radiometrix multi channel TR2M transceiver module. It provides transmit and receive paths, and can be simply 'dropped into' the aerial connection. The AFS2 may be usable with other 100mW output devices, but no guarantees can be offered. It has the following features:

- Conforms to EN 300 220-3 and EN 301 489-3
- Custom variants from 420MHz to 470MHz on any 5MHz band
- TX and RX path with <1dB loss
- 500mW RF power output (for 100mW in)
- Operation at +5V (regulated)
  - Low current consumption: 250mA transmit, <2mA receive
  - Fully screened and Small Size: 33 x 23 x 9mm

The Data Processing subsystem/OBC is an own development, one of several made from previous it gained high experience. OBC is based on ATSAM4L8/L4 CPU. The ATSAM4L8/L4/L2 embeds state-of-the-art picoPower technology for ultra-low power consumption. It combined power control techniques that are used to bring active current consumption down to 90 µA/MHz. The device allows a wide range of options between functionality and power consumption, giving the user the ability to reach the lowest possible power consumption with the feature set required for the application. On-chip regulator improves power efficiency when used in switching mode with an external inductor or can be used in linear mode if application is noise sensitive. The ATSAM4L8/L4/L2 supports 4 power saving strategies. The *sleep* mode put the CPU in idle mode and offers different sub-modes which automatically switch off/on bus clocks, PLL, oscillators. The *wait* and *retention* modes provide full logic and RAM retention, associated with fast wake-up capability (<1.5µs) and a very low consumption of, respectively, 3 µA and 1.5 µA. In addition, WAIT mode supports SleepWalking features. In *backup* mode, CPU, peripherals and RAM are powered off and, while consuming less than 0.5 µA, the device is able to wake-up from external interrupts (see fig. 5). The core of Data Processing subsystem is designed as standard in accordance with the manufacturer's recommendations. For connection to peripheral units, they use different types of interfaces: I2C, UART, SPI, USB, JTAG. All sensors have ADCS (microgyroscope, magnetometer, accelerometer, other nanosensors) are integrated I2C interface and connection. Auxiliary sensors, the sun sensor will be connected directly to the 16-channel ADC 300Ksps (ADC) with up to 12 Bits resolution.

Nano-satellite software is organized and structured in a modular way. It consists of several components: Modules acquisition and data storage; Operational data processing modules and communication with ground stations; Configuration software modules; Internal database (see Fig. 5). All these modules are released as a set of tasks, which operates under the control of RTOS operating system. All the Data are stored in the Data Base on Flash memory with SPI interface. The OBC/OBDH subsystem, being as the 'brain' of the nanosatellite, is responsible for communicating with the rest of the subsystems and for relaying information between them. Below follows a brief description. The CubeSat will collect WOD and log telemetry every minute for the entire duration of the mission, where whole orbit data is defined as the following set of parameters: time, spacecraft mode, battery bus voltage, battery bus current, current on regulated bus, current on regulated buses, communication subsystem temperatures, EPS temperature and battery temperature. The WOD is stored in packet format in the OBC until they are successfully downlinked. This is so that the information could be used to determine the causes of any problems in the case of a CubeSat anomaly. The correctness of received WOD packages should be verified by teams on ground (e.g. using parameter range checks). The OBC have a real time clock information with an accuracy of 500ms during science operation. Relative times should be counted/stored according to the epoch 01.01.2000 00:00:00 UTC. This use the GPS data and/or an uplink clock synchronization command could provide such information. The OBSW will protect itself against *unintentional* infinite loops, computational errors and possible lock ups, using the watchdogs.

The **Satellite Control Software** (SCS) is a software package provided by the this project that could be implemented by the CubeSat teams on own ground stations and will provide:

- Ground station interface software
- TM/TC Front End
- CubeSat "TUMnanoSAT" Control System
- Operations User Interfaces software
- Communications handling with the modules for science and WOD data uploading.

A TUMnanoSAT OBS communication modules with ground stations have implemented for check of incoming commands, data and messages, consistency checks and rejection of illegal input. The OBSW TUMnanoSAT is programmed and developed by the NCST team and it will contain code that is for use on that CubeSat on ground and in orbit. Regarding to scientific data, it is implemented a command to be sent to the TUMnanoSAT which can delete any payload data held in Mass Memory originating prior to a date-time stamp given as a parameter of the command.

Attitude and Orbit Control Subsystem of TUMnanoSAT have the attitude determination equipment, including the MPU-9150 is a System in Package (SiP), that combines two chips: the MPU-6050, which contains a 3-axis gyroscope, 3-axis accelerometer, and an onboard Digital Motion Processor™ (DMP™) capable of processing complex MotionFusion algorithms; and the AK8975, a 3-axis digital compass. The part's integrated 6-axis MotionFusion algorithms access all internal sensors to gather a full set of sensor data. The MPU-9150 incorporates InvenSense's MotionFusion™ and run-time calibration firmware that enables manufacturers to eliminate the costly and complex selection. The control is realized with magnetotorquiers. The main goal of this subsystem is to accumulate the during orbit flying of satellite to simulate and optimize the attitude control of the next satellite missions.

V. Conclusion

The pico- and nanosatellites, especially CubeSats, have become popular in the past decade and the amount of developers and projects is increasing. They are not only built by universities but also larger space organizations like NASA, Boeing and the Aerospace Corporation. Technologies in the field of command and data handling and electrical power systems are quite advanced. The bottleneck for pico- and nanosatellites remains the attitude control performance, especially in terms of dynamic control and control accuracies. Communication is mostly limited by available power and antenna gain rather than the technical developments on that system itself, thus attitude control is indirectly limiting satellite-ground communication data rates. Besides educational objectives, which can easily be met if students are working on the projects, technology demonstration objectives are very attractive and successful.

The ultimate goal for TUMnanoSAT is to utilize CubeSat projects form factors as a framework for the pre-college community student-designed payloads and the creation of a national competition. TUMnanoSAT aims to promote increased student interest in STEM (Science, Technology, Engineering, and Math) careers via direct student involvement in every phase of a CubeSat space mission: mission management and operations, nanosatellite construction and testing, and spaceflight data processing and utilization. It would also become a clearinghouse for funding opportunities, resources, and supplies, and facilitate the creation and operation of nodes where collaborative pre-post flight activities can be developed and carried out. The CubeSat projects seeks to create pathways for Teacher Professional Development with the goal of developing Master STEM Teacher Leadership in the Rep. of Moldova, which translates into authentic STEM learning experiences for students in the classroom..

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