OnionSAT

Critical Design Review

Berzsenyi Dániel Secondary School, Budapest

17 February 2024

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You can watch the video about our CanSat at the following URL:
https://youtu.be/-ymA6_CNtHA

1.1 Introduction

Tamás Pécsi: Programming the microcontroller of the satellite, developing and maintaining the IT infrastructure of the OnionSAT project, including our website, ground station application, and the „cloud station” application. The person responsible for CanSat's IT infrastructure.

Máté Barnabás Dernovics: Designing the landing mechanisms of the CanSat, designing the electrical circuit of the satellite, responsible for the production of the parachute and the physical security of the satellite.

Róbert Mihályffy: Designing the 3D model of the CanSat, responsible for the physical implementation of the satellite, and supervisor of the production.

Áron Kolláth: Managing outreach and sponsoration related tasks, responsible for the financial management of the OnionSAT project.

Miklós Gergely Virág (mentor): Verification of satellite related calculations, technical issues, answering technical questions.

We use Atlassian's Trello to distribute tasks within the team to optimise the speed of work. We also use GitHub to help us solve software-related issues quicker, because GitHub gives us insights into our code, and allows us to view the previous versions of our code.

1.2 Mission objectives

Our primary mission is to monitor the current status of the Cansat and its surroundings, from the aspects of the temperature, humidity, and pressure while it’s lowering altitude.

The presence of low-level jet streams in the atmosphere is measured using a three-axis accelerometer sensor that can determine the direction in which the CanSat is accelerating.

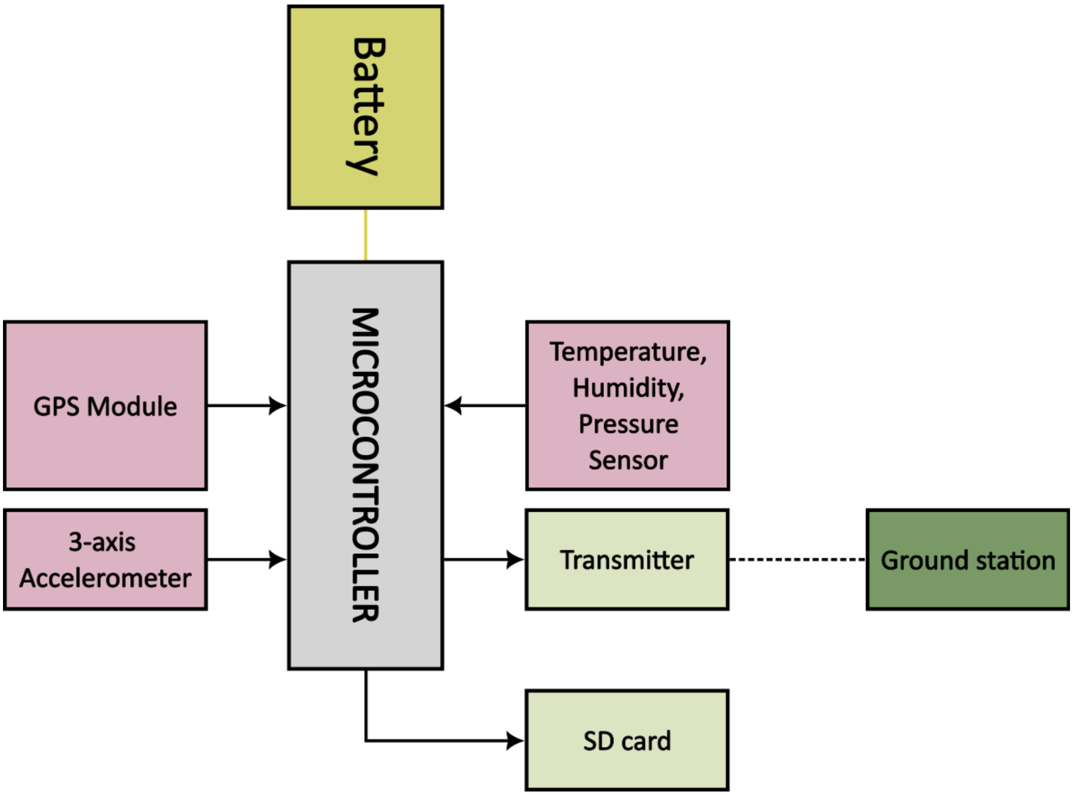
From the acceleration values obtained, we can infer the direction and magnitude of the runners, and we also measure thermals in the vertical acceleration direction.

We expect to encounter predominantly unidirectional currents during the CanSat expedition.

2.1 Overview of the mission

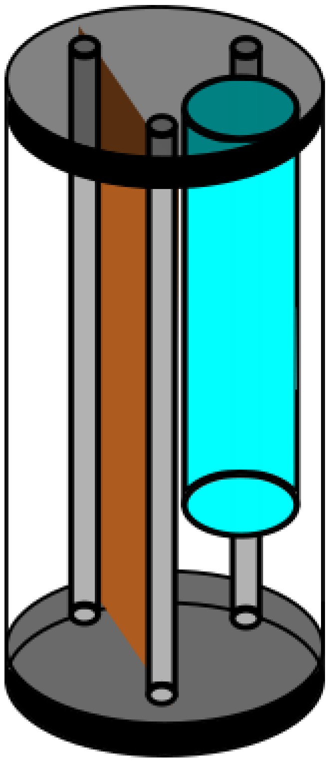
The CanSat satellite built by our team will be launched in a rocket to an altitude of about 1 km, where it will be ejected by a parachute system at a speed of up to 8 m/s and land. As it descends, it will take measurements with the primary (temperature, humidity and pressure sensor) and secondary (methane and carbon dioxide sensor) mission sensors and transmit the data to the ground station, as well as store the data on board to an SD card. To make it easy to find the CanSat, we have also installed a 3-axis accelerometer and a GPS module in the satellite.

The diagram below shows the basic operation of CanSat. The arrows indicate communication in the direction of the arrow, the dotted line indicates radio communication, and the green line represents an electrical input.



2.2 Mechanical/structural design

The CanSat can be separated into two main parts. A case which looks like a cup and a system of printed circuit boards which are strengthened by three zinc rods, the rods are going through the "cup" case and will be fixed by three nuts at the bottom. We placed our battery at the top, which goes into the printed circuit boards. At the top level it has a roof with a switch. The rods are going through the roof and at the end of the thread there will be three threaded hooks for the parachute.



CanSat's frame is 3D printed from ABS (acrylonitrile butadiene styrene), one of the most durable thermoplastics available. The worst-case yield strength of the material is 13 MPa according to information from the manufacturer's website. The worst case tensile strength of the material is 22.1 MPa.

$$p = \frac{F}{A}$$

According to the above formula, the pressure on the body is equal to the magnitude of the force divided by the surface area of the force on the body.

The surface area of the CanSat cylindrical housing can be calculated using the following formula:

$$A = (2 \cdot r^2 \cdot \pi) + (2 \cdot r \cdot \pi \cdot m)$$

Where "r" is the diameter of the circle on which the cylinder is based. And "m" is the height of the cylinder. When substituted, the equation looks like this:

$$A = (2 \cdot 0.066^2 \cdot \pi) + (2 \cdot 0.066 \cdot \pi \cdot 0.115) = 0{,}075m^2$$

The velocity formula can be used to determine the terminal velocity after parachute deceleration:

$$v = \sqrt{2gh}$$

Where v is the terminal velocity, g is the velocity acceleration (9.81 m/s^2) and h is the altitude from which the CanSat starts its descent.

$$v = \sqrt{2 \cdot 9.81\ \frac{m}{s^2} \cdot 1000\ m} \approx 140.071 \frac{m}{s}$$

The force acting on the cylinder can be calculated from the change in impulse (law of impulse):

$$F = \frac{\Delta p}{\Delta t}$$

Where $\Delta \boldsymbol{p}$ is the change in forces acting on the body, and $\Delta \boldsymbol{t}$ is the change in time.

$$\Delta p = m \cdot \Delta v$$

In this case, the $\Delta \boldsymbol{p}$ can be expressed by the formula:

$$\Delta p = 0.35\ kg \ \cdot 140.071 \frac{m}{s} \approx 49.025\ kg \frac{m}{s}$$

Substituting it back into the original equation gives the force that will act on the body during the moment of impact (which will happen in about 0.1s).

$$F = \frac{49.025\ kg \frac{m}{s}}{0.1\ s} \approx 490.25\ N$$

According to the equation $p = \frac{F}{A}$, the pressure on the body at the moment of the impact will be 6536 $\frac{N}{m^2}$, which is equal to 6536 Pascal (which is 0.006536 MPa). Which is well below the two specified thresholds, thus ensuring that the satellite's frame will not break up on arrival on the ground.

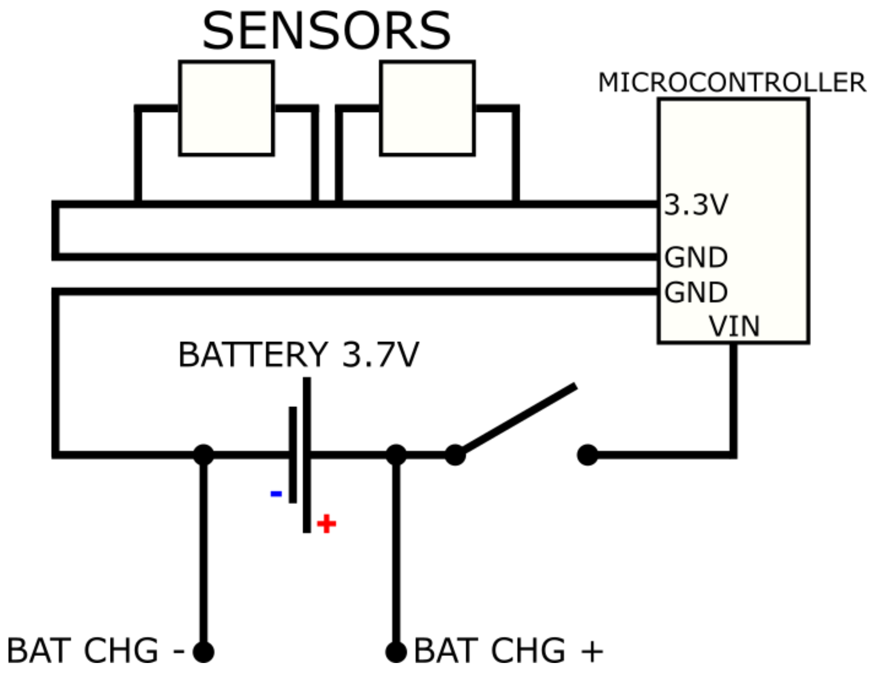
2.3 Electrical design

The CanSat will be powered by a single 18650 size Lithium-Ion battery, which provides the satellite 3.7V-4.2V DC (depending on the battery's charge level). Normal operation of the CanSat requires 3.3V DC, which is stepped down by a voltage regulator built into our microcontroller.

The satellite consumes approximately 160 mA of power during operation (please refer to section 5.1 for exact values), which the 3400 mAh battery can power for up to around 16 hours.

The battery can be charged with the CanSat's built-in charge controller through a micro usb connector, which requires a standard 5V input.

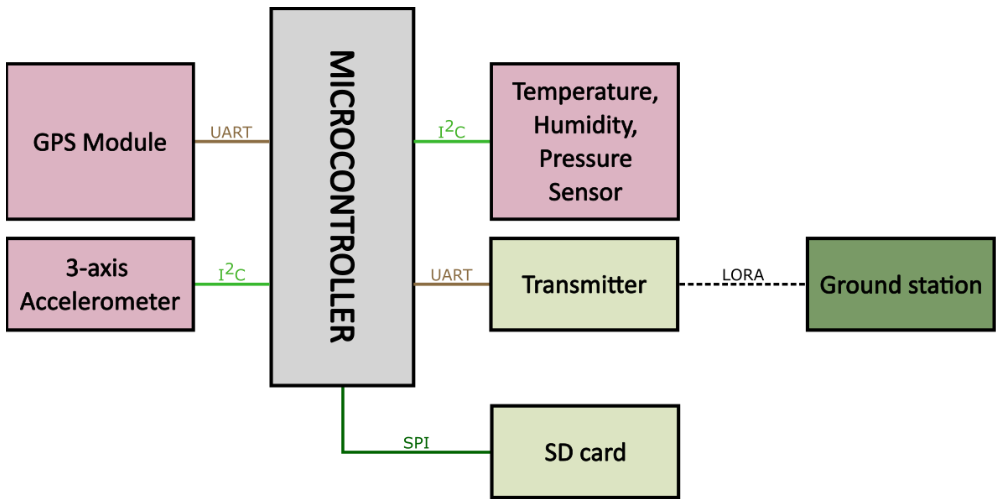
The diagram below details the CanSat circuitry. The *"BAT CHG +"* and *"BAT CHG -"* outputs refer to the positive and negative battery charge outputs, where the charge controller will be connected. The *"3.3V"* label on the microcontroller indicates the 3.3V voltage output of the microcontroller, the *"GND"* label indicates the grounding, and the *"VIN"* label indicates the microcontroller's power in point.



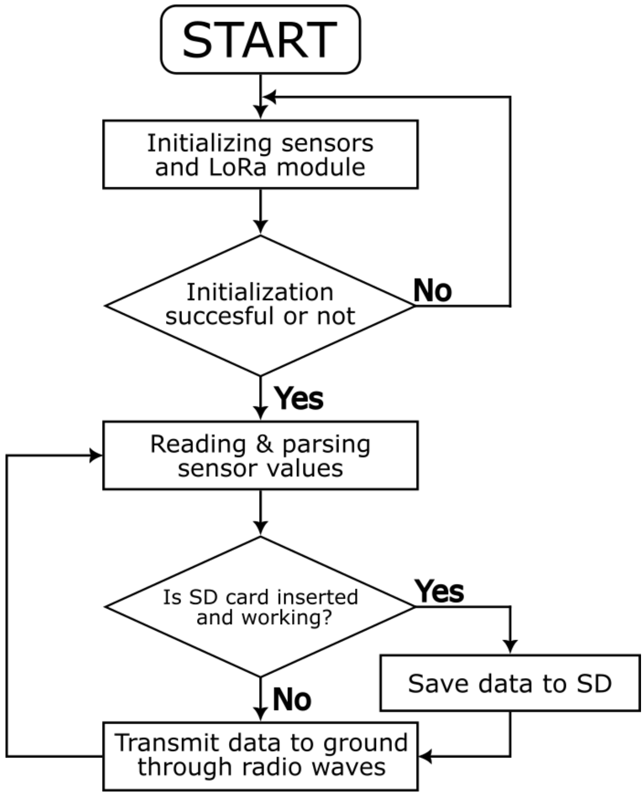
Various protocols are used for communication between the components of the satellite. The figure below details the type of the connection between the points.

UART stands for **Universal Asynchronous Receiver-Transmitter**.
I²C stands for **Inter-Integrated Circuit**.
SPI stands for **Serial Peripheral Interface**.
The **analog** designation refers to native voltage-based communication.
LoRa refers to **Long Range Radio Communication** technology, which we use to communicate with the CanSat from the ground.

UART, **I²C** and **SPI** are complex communication technologies between two devices (in most of the cases between a microcontroller and a sensor), mostly used in microelectronics.



2.4 Software design



The following diagram shows the program flow of the satellite microcontroller.

In the initialization phase, the microcontroller starts the sensors and sets the LoRa module to the values defined in the CanSat configuration file (the configuration file can be placed on the microcontroller using an SD card or Arduino IDE).

The microcontroller reads and processes the data from the sensors approximately every 50 milliseconds. During the processing, if there is an SD card available in the satellite, the data is saved in raw format (which can be opened later by our ground software, see section 2.6 for more information) and at the same time the data is sent to the ground station via the LoRa module.

Frequent data transmissions are necessary because, although LoRa technology is very reliable, the data packets can arrive corrupted (as with any other radio communication technology which can be affected by any external factor (e.g. weather)).

The microcontroller code is written in C++ using the Arduino IDE development environment. The source code can be viewed on our Github page (www.github.com/akameleon/onionsat).

2.5 Recovery system

The falling speed of the CanSat should be between 8-11 $\frac{m}{s}$. Our CanSat uses a parachute to reduce its speed while falling. Newton's first law states that an object's speed is always constant if the sum of forces affecting the object is zero. In our case, there are two forces applied to the satellite: the gravitational and the drag force. When the CanSat reaches its maximum speed these forces should be equal (Newton's first law).

Using the formula of air resistance:

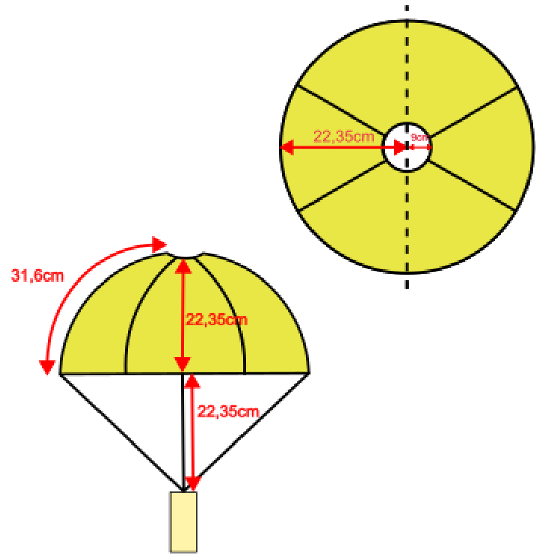
$$F_{airdrag} = \frac{1}{2} C \cdot \rho \cdot v^2 \cdot A$$

Where **C** is the object's drag coefficient, $\boldsymbol{\rho}$ is the density of the fluid in which the object goes, v is the speed of the object and A is the cross-sectional area. Our parachute is hemispherical, so it has a drag coefficient of 0.62, the parachute goes in air which has a density of 1.2 $\frac{kg}{m^3}$, the speed of the CanSat should be around $8 \; to \; 11 \frac{m}{s}$ (we did our calculations with $8.4 \; \frac{m}{s}$) and the cross-sectional area is the parameter that we want to calculate. The gravitational force equals to m*g, where m is the object's mass and g is the gravitational acceleration on earth (9.81 $\frac{m}{s^2}$). The mass of the CanSat and the parachute is 0.35 kg.

The equation in our case is:

$$0.35 \; kg \cdot 9.81 \; \frac{m}{s^2} \; = \frac{1}{2} 0.62 \cdot 1.2 \frac{kg}{m^3} \cdot \left(8.4 \frac{m}{s}\right)^2 \cdot A$$

$$A = 0.1308 \; m^2 = 1308 \; cm^2$$



We designed the parachute as shown in the picture, this way the parachute has a cross-sectional area of: $[(22.35 \; cm)^2 - (9 \; cm)^2] \cdot n = \mathbf{1308 \; cm^2} \sim \mathbf{1300 \; cm^2}$

The completed parachute's sizes are close to the sizes on the picture.

We made the parachute yellow, so it will be easier to find after landing, and we installed a GPS module in the CanSat which also helps us find the CanSat after landing.

2.6 Ground station

Our radio communication module can operate in any frequency band from 863 MHz to 928 MHz. For radio communication we would like to use a bandwidth of 250 kHz.

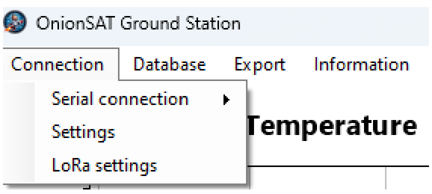
The 868 MHz frequency band licensed for ISM purposes is intended to be used in accordance with **European Commission Decisions 2006/771/EC** and **2008/432/EC** and **National Media and Communications Authority Decree 7/2015** for satellite-to-ground transmission using LoRa modulation.

The ground station will run a complex self-developed application using the Windows 11 operating system. The program is written in C# programming language with Visual Studio 2022 Community Edition programming environment.

The ground station displays the incoming sensor data on a graph in real time, and the incoming GPS data is displayed on a map in real time.

The incoming data is saved to the ground station's own hard disk, in the same format that CanSat uses to save to its own SD card. These saved files (regardless of their origin) can be loaded, so that, for example, in the event of a technical failure in radio communication, flight data saved on board the satellite can be loaded with a few clicks and plotted on a graph.

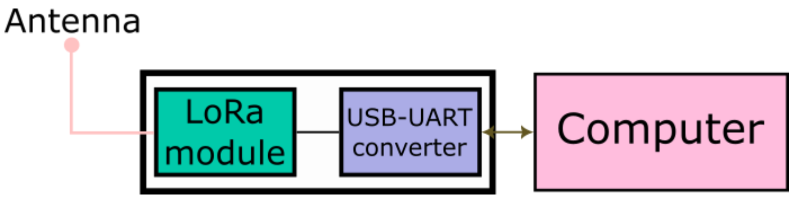
If there is a reliable broadband internet connection (LTE cellular network is preferred) in the launch area, the ground station transmits the data to a so-called "cloud station". Through the OnionSAT cloud station, anyone can view the data sent by the satellite in real time using their own browser. The cloud station can be accessed via the app.onionsat.com URL.



The LoRa settings are easily editable (such as the frequency or bandwidth of radio communication) through the ground station application.

In the dialog box that pops up, you can configure the settings of the ground LoRa module or generate a configuration file that can be uploaded to the satellite using an SD card.

The ground station consists of three parts, a computer, a PCB with a LoRa (radio communication) module and an USB-UART converter in a 3D printed housing, and an antenna connected to the LoRa module through an SMA (SubMiniature version A, semi-precision coaxial RF connector) cable.



One low-performance computer running the Windows operating system is sufficient for the ground station application to operate normally. We plan to supply this with 1 (and 3 spare) low-power laptops provided by the Central Pest School District.

3.1 Time schedule of CanSat preparation

Below is an outline of our planned implementation schedule, with the approximate working time in hours. The time intervals are planned periods as they stand, considering possible procurement periods, holidays and other school holidays.

There may be overlaps between different workflows, due to external factors. The table below is for informative purposes only. The hours shown are in man-hours per person. So, 1 hour worked by 1 person means 1 hour at the table and 1 hour of work by 2 people counts as 2 hours of work.

Time span	Approximated working hours	Description
October 2023	cca. 50 hours (finished)	At this stage of development, we prepared the sensors and the microcontroller to be built into the CanSat in the physics laboratories of the Berzsenyi Dániel

		Secondary School.
November 2023 - December 2023	cca. 100 hours (finished)	At this stage of development, we prepared the radio communication module of the CanSat, and we developed the ground and the cloud station application.
January 2024	cca. 40 hours (finished)	In this phase of development, we designed, built and tested the satellite's 3D-printed housing and circuitry.
February 2024	cca. 95 hours	In the penultimate phase of development, we are implementing the technologies needed to ensure a safe landing and are working on the final assembly of the complete satellite.

3.2 Resource estimation

3.2.1 Budget

The table below shows the budget for our CanSat satellite. The greyed out lines show the sponsored items given to us.

Name of asset/object	Article No	Price per piece	Quantity	Gross price in EUR
Adafruit ADXL345 Triple-Axis Accelerometer	1231	22,82 €	1 pcs	22.82 €
Adafruit PA1616S Ultimate GPS Breakout	746	41,00 €	1 pcs	41.00 €
Adafruit BME280	2652	19,21 €	1 pcs	19.21 €

Temperature, Humidity, Pressure Sensor				
Panasonic NCR18650BL Li-ion Battery 3,7V 3400 mAh	NCR18650BL	13,31 €	1 pcs	13.31 €
Arduino ESP32 WITH HEADERS	ABX00083	25,62 €	1 pcs	25.62 €
Voltcraft VC-13083780	VC13083780	1,47 €	1 pcs	1.47 €
PCB HR PR 100 (100x100mm)	10031788	1,65 €	1 pcs	1.65 €
Arduino MICROSD-MODULE	10042087	0,93 €	1 pcs	0.93 €
LoRa modules sponsored by ChipCad Ltd.	–	40,00 €	1	40.00 €
Hikvision 8GB microSD CL10	10040913	6,34 €	1 pcs	6.34 €
Ripstop nylon	–	7,44 €	0,14 m^2	1.05 €
Hemmer	–	0,64 €	2 m	1.28 €
Zn rod	–	8,04 €	1000 mm	8.04 €
Acrylonitrile-butadiene-styrene (3D printing material)	–	14,84 € (per kg)	26.53 g	1.17 €
Sum	–	–	–	183.89 €

3.2.2 External support

We would like to thank **Rackforest Ltd.** for providing us with the IT environment in their data centre to run our website and the Cloud Station application.

We would like to thank **Major Bt.** for supporting our project with 20 square metres of Ripstop nylon.

We would like to thank **PNL-Systems Ltd.** for providing us with some of our sensors.

We would like to thank **ChipCad Ltd.** for providing us with LoRa radio communication modules.

We would like to thank **Dr. Gyula Honyek**, an ex-professor of Eötvös Loránd University for helping us professionally assemble the electrical circuit of the satellite.

We would like to thank **Zsuzsa Szabó**, for her help in sewing the parachute.

3.2.3 Test plan

The testing of CanSat will be divided into 3 parts. The first test will be to test the minimum acceleration force of 20 g required by the regulations. The second test will test the parachute connection point's ability to withstand a 50 N load. The third test will test the satellite's rate of descent.

1. Figure
Testing the parachute

The first test will be performed using an electric motor with a 1-metre-long rod attached to which the satellite will be attached.

The electric motor will spin the rod-mounted satellite at a rate of 134 revolutions per minute (rpm), so the centripetal acceleration force on the body will be just over 20 g.

The rpm value was calculated using the following equation:

$$n = \frac{\sqrt{20 \cdot g}}{2 \cdot \pi \cdot \sqrt{r}}$$

Where **"g"** is the value of the earth's gravitational acceleration ($9.81\ \frac{m}{s^2}$) and **"r"** is the length of the rod attached to the motor.

During the second test, a 5.1 kg weight will be attached to the connection point and hung from the top of the CanSat using a rope.

$$F_{rope} = F_{gravity} = m \cdot g = 50\ N$$

$$F_{rope} = F_{gravity} = m \cdot 9.81\ \frac{m}{s^2} = 50\ N$$

$$m \approx 5.1\ kg$$

During the third test, the satellite will be dropped from a lookout tower from a height of about 10-12 metres, with maximum care and in full compliance with safety rules.

4. Outreach programme

On our website you can find useful information about our CanSat in the form of blog posts and other documents. You can also access our cloud station through our website, which is described in more detail in section 2.6. Our website can be accessed via the URL www.onionsat.com.

Our primary social media platform is Instagram, where we share extra news and pictures of the development process with people who are interested in our work. Our Instagram page can be accessed via the URL www.instagram.com/onionsat.

We have an interview under organisation with the editors of the Berzsenyi Dániel Secondary School’s magazine, which will be released approximately in early March of 2024.

A demo version of our CanSat board model and software was exhibited at the "CanSat Viewing" event organised by the Hungarian Astronautical Society on 20 January 2024.

We have a logo, which you can view on the first page of this document.

We will soon upload a more informal video on our blog and YouTube channel, where we will try to promote space exploration and electronics as a hobby.

5. Requirements

Characteristics	Measurement (unit)	Requirement	Eligible (Yes or No)
Height of the CanSat	115 mm	Height <= 115 mm	yes
Mass of the CanSat	302 g	300 g <= mass <= 350 g	yes
Diameter of the CanSat	66 mm	Diameter <= 66 mm	yes

Length of the recovery system	40 mm	Height <= 45 mm	yes
Flight time scheduled	119 s	120 seconds **recommended**	yes
Calculated descent rate	8.4 m/s	5 m/s < velocity < 12 m/s	yes
Radio frequency used	868 MHz, can be changed to any ISM frequency.	compliance with the Hungarian radio amateur regulations	yes
Power consumption	452.1 mW (137 mA * 3.3 V)	minimum 4 hours of constant operation (current * 4h < battery capacity) 548 mAh < 3400 mAh	yes
Total cost	183.89 €	< 500 €	yes

5.1 Preliminary energy budget

The current values shown in the table below are averages of multimeter and/or oscilloscope measurements, sometimes compared with the values shown on the sensor data sheets.

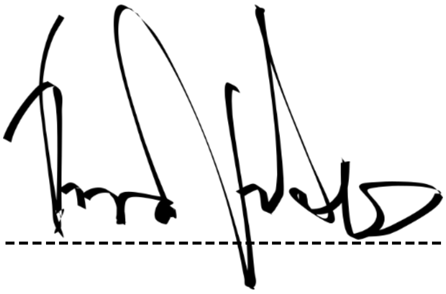
Since the current consumption of the sensors depends on their current load, there may be a few mA difference (±10 mA) from the values shown here.

Device	**Voltage (V)**	**Current (mA)**	**Power (mW)**
Arduino Nano ESP32	3.3 V operating voltage (3.7 V supplied)	60 mA	198 mW
ADXL345 (Accelerometer) sensor	3.3 V	14 mA	46.2 mW
BME280 (Temperature/Humidity/Pressure) sensor	3.3 V	13 mA	42.9 mW
Adafruit Ultimate GPS module	3.3 V	20 mA	66 mW

MicroSD module	3.3 V	17 mA	56.1 mW
WLR089U0 (LoRa) module	3.3 V	13 mA	42.9 mW
Sum	**3.3 V**	**137 mA**	**452.1 mW**

On behalf of the team, I confirm that our CanSat meets all the requirements set out in the official guidelines for the 2024 Hungarian CanSat competition.

Budapest, 17. 02. 2024.



Current state of the CanSat