TeamVLO CanSat Critical Design Review

Team Name: TeamVLO

Country: Poland

www.cansat.eu

Contents

1 CHANGELOG

CDR

- One of the team members left the team. In her place, we have a new member.
- We specified the Mission Objectives.
- Due to lack of appropriate CO_2 sensor, we removed it from our CanSat.
- We swop the BMP280 air pressure sensor with Waveshare IMU 10DoF. It is only 15 mm longer and offers much more sensors. We also added a new temperature sensor.
- The electronic circuit prototype was built and a code for it was written.
- The exact models of batteries, sensors and modules have been specified.
- We made changes in the model of the CanSat.
- We built and tested a mass prototype of the CanSat with a parachute.
- New information in “Budget”, “External Support” and “Outreach Programme”

2 INTRODUCTION

2.1 Team organisation and roles

Our mentor is **Dr Dawid Kotrys**. He is our math's teacher and tutor of our class. He always devotes to all projects proposed by his students. He supports our team computationally and he motivates us to the action.

Emil Kielar is our team leader. He found the information about the competition and created a team. He supervises all the work and sets the tasks individually for every team member. Emil is interested in coding as well as electronics. He is responsible for them during the mission. Using the help of Mr. Kotrys, they will cover the computational site, which will allow us to design and build our CanSat.

Krzysztof Janota is a great lover of aeronautics that's why he engaged into the project. Krzysiek knows the construction of airplanes and their dynamics very well, what will help us greatly in the project. He is responsible for mechanical design and recovery system design.

Natalia Pierkiel oversees planning our tasks, as she is well organized and can find the most effective way of working. She's willing to help whenever it is needed, so her other duties are not strictly determined. For the time being, she writes posts for social media and is responsible for promoting our project.

Julia Zielińska is responsible for reporting and describing our activities. She is endowed with literary skills. Julka is also picking up on small errors and she is an attentive observer what allows her to correct our errors. She is still looking for her interests and she hopes that this competition will help her in it.

2.2 Mission objectives

The objective of our mission is to collect data from the sensors of the primary mission and the secondary mission to determine whether the planet and area where our CanSat is landing is suitable for growth of plants. We will also take photos that will allow us to measure various remote sensing indices as well as to classify land cover of the area where our CanSat is landing. The mission like this one will allow to determine whether the planet on which our CanSat is landing is inhabitable for humans at a low cost. The satellite can also collect data that will allow the preparation of appropriate equipment for interplanetary missions of humans.

Our CanSat can also be used during a mission on Earth consisting of measuring various remote sensing indices like Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Green Normalized Difference Vegetation Index (GNDVI), Greenness Index and other, as well as to classify land cover of places where access is difficult (e.g. rainforests, deserts, high mountains) and other places that are in our area of interest. During the flight and after the landing, the satellite will collect data such as temperature, pressure, sunlight intensity and air humidity. Such a CanSat will allow us to perform field and environmental analysis of the landing area.

We were inspired to select this secondary mission by the mission of Perseverance rover which is looking for signs of life on Mars as well as by missions of Landsat and Sentinel satellites taking photos of Earth’s surface. In order to consider our CanSat launch successful, we have to get several images of the landing area from different heights as well as the readings from the sensors.

3 CANSAT DESCRIPTION

3.1 Mission overview

The secondary mission of our CanSat is to determine whether the planet and the landing site is suitable for growth of plants. When our CanSat is launched from the rocket, the parachute will be opened, and the satellite will take photos of the landing site using the near infrared camera (Raspberry Pi NoIR camera) located on the bottom. Every photo will be analyzed, and we will measure various remote sensing indices using a code written by our team. The code will prepare photos with marked remote sensing indices in colors (as on the picture below) and a photo with classification of land cover.

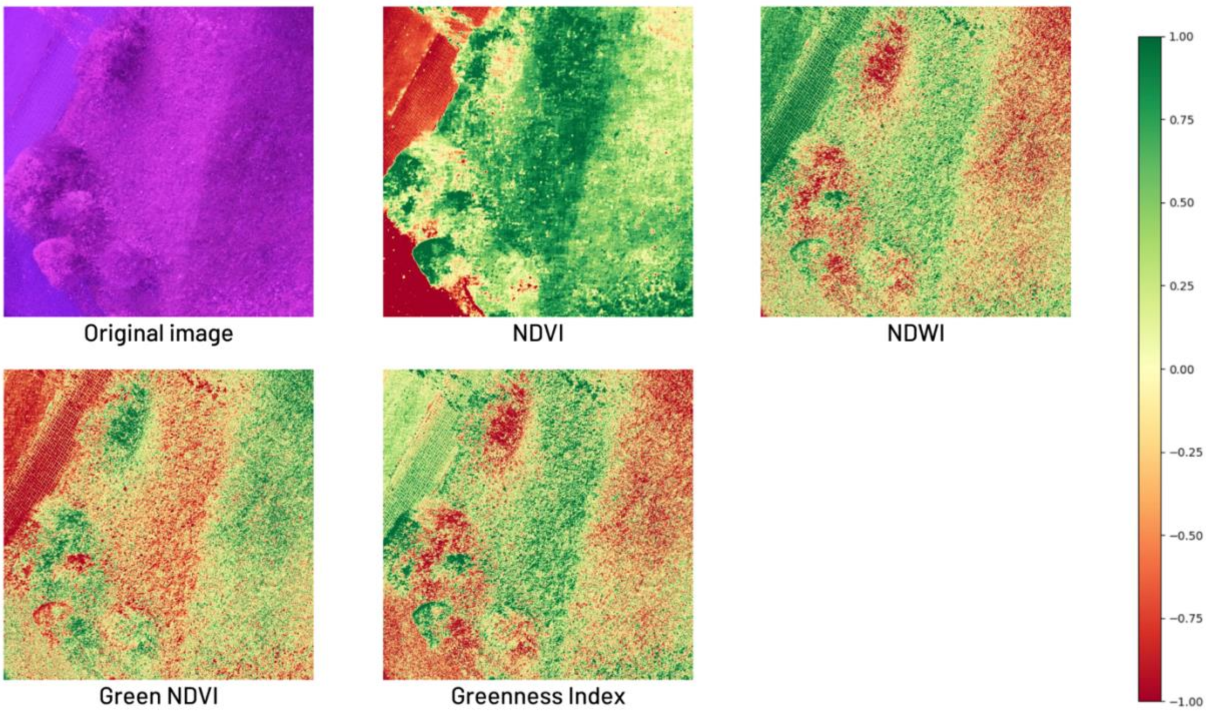

Figure 1: Composition of images

During the flight our satellite will measure temperature, humidity, air pressure, and sunlight intensity. These data will allow us to determine whether conditions in the place of landing are suitable for growth and life of plants (water, temperature and sunlight needed for photosynthesis).

We will analyze all the data after the landing and after an analysis of it, we will determine whether the landing site is suitable for growth of plants and if it's inhabitable. In case our CanSat isn't found, we will send via radio few photos and the readings from the secondary mission sensors after the landing of CanSat.

The primary mission of our CanSat will be conducted using temperature sensor, air pressure sensor and radio transmitter sending the data from those sensors to our ground station.

We will also use a GPS module, that will send the GPS coordinates to our ground station via radio. The block diagram of our CanSat looks as follows:

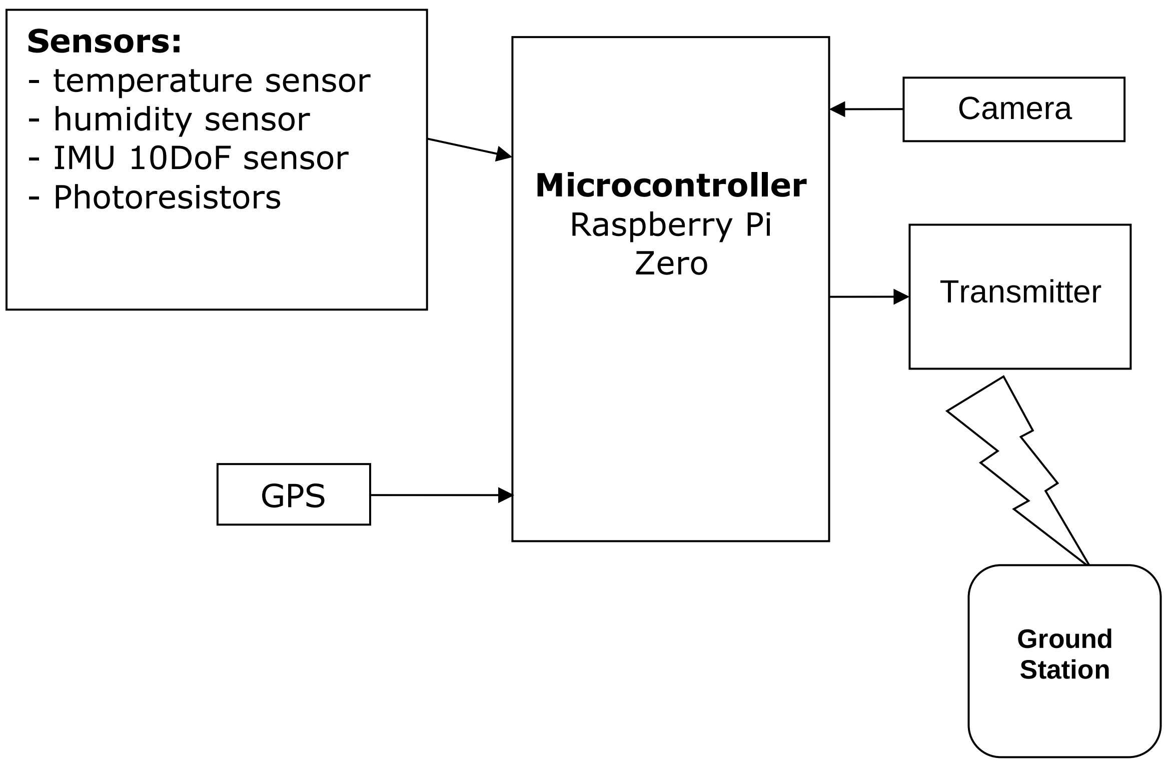

Figure 2: Block diagram of our CanSat

3.2 Mechanical/structural design

3.2.1 General idea

The overall structure of our project is far different from the first models designed and presented in the previous report. The main axis of our model will consist of two bolts going through the center of the CanSat along its entire length. As we planned at the beginning, the division into three internal sectors will remain. Because of that, we will gain a lot of space to work with and to mount all the necessary modules.

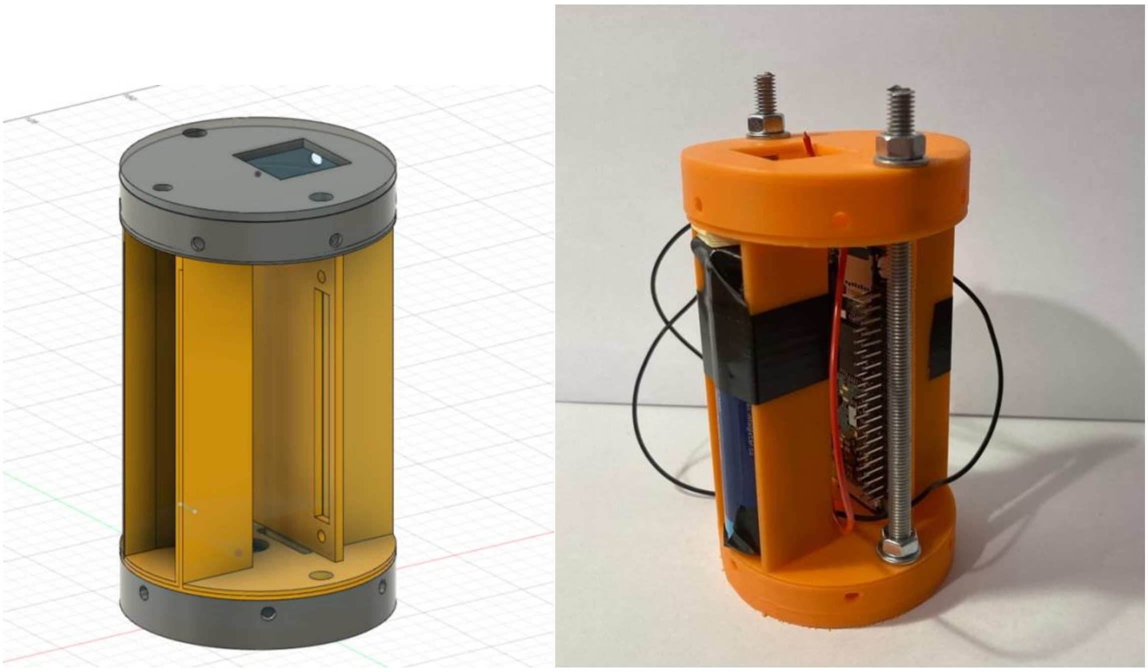

Figure 3: 3D model of the casing (on the right), Printed CanSat prototype (on the left)

3.2.2 Materials used

The main material that we will use to build CanSat is ABS plastic, of which we will print the casing, as well as most of the internal elements, including sector separation plates. ABS material is characterized by high mechanical strength, as well as high tolerance to temperature changes, what makes it ideal for the task it's assigned for. The main axis two screws in the center of the model, will be made of stainless steel. The same applies to any other screws used to attach the modules.

3.2.3 Modules mounting

We will use steel screws to mount the modules inside the CanSat and we will try to limit their use as much as possible, so that it will not increase the weight of our device. If it is necessary, we will place the modules on special pins, so that we can adjust the height of every individual module and prevent reduction of durability of our CanSat as screws are screwed directly into the main structure.

3.2.4 Sectors

As mentioned before, our CanSat will be divided into 3 interior sectors each of them fulfilling a different task:

- **Sector 1** is the place where the 10 DoF IMU sensor and the camera will be located.

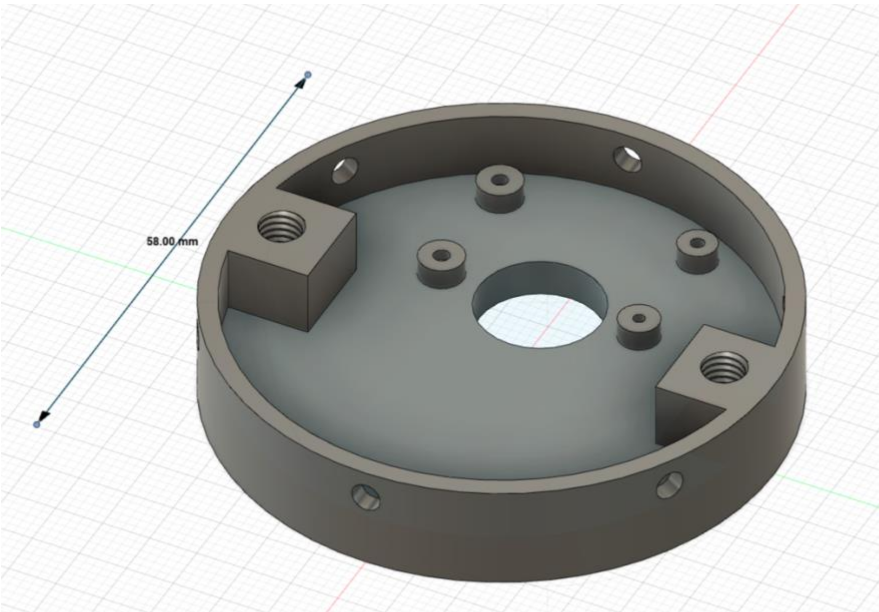

Figure 4: Sector 1 of the CanSat

- **Sector 2** is the largest section in which the power supply, the main computer, the radio transmitter and the rest of the sensors will be located.

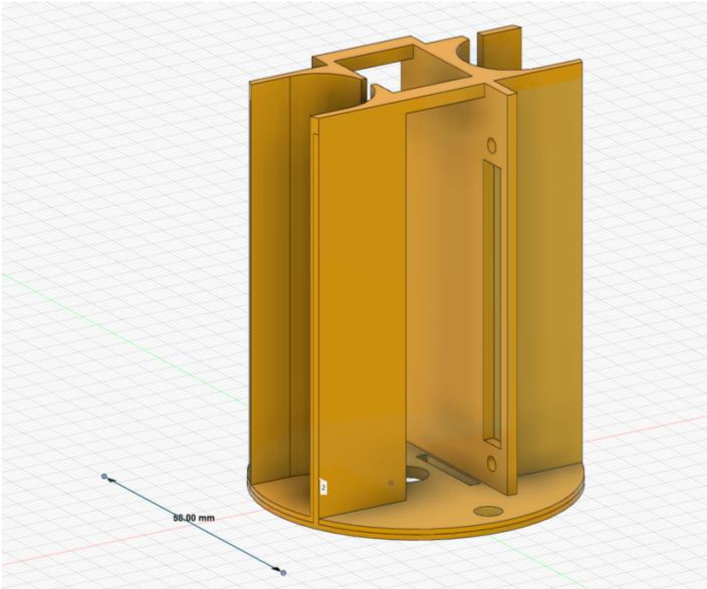

Figure 5: Sector 2 of the CanSat

- **Sector 3** is where the GPS module and a parachute mount will be located.

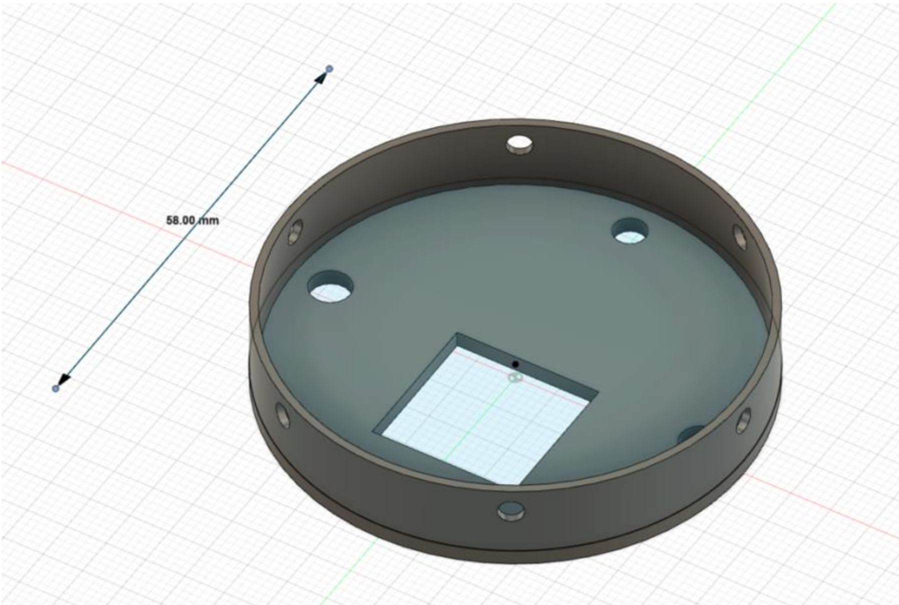

Figure 6: Sector 3 of the CanSat

3.2.5 Mass budget

The table below represents masses of all parts in our CanSat.

Element	Mass(g)
Raspberry Pi Zero W 512 MB	9.0
Raspberry Pi NoIR v2 Camera	2.0
Temperature sensor DS18B20+	5.0
Waveshare IMU 10DoF sensor	3.0
2x 18650 XTAR – 3500mAh battery	98.0
Servo SG-90	9.0
Case	~72.0
GPS module for Raspberry Pi	7.0
SX1278 LoRa RA-02 433 MHz radio module	2.0
DHT-22 Temperature & humidity sensor	0.6
Step-down converter 5V 2.5 A	3.0
2x 110 mm M5 Screw	37.0
Total	**~247.0**

The overall mass is 247 g. As a minimum weight of CanSat is 300 g, we will add at least 53 g to our CanSat.

3.3 Electrical design

3.3.1 General architecture

The system of our CanSat will be powered by two 18650 lithium-ion batteries (3500 mAh each). Our main onboard computer will be Raspberry Pi Zero. We will also use consecutive sensors: Raspberry Pi NoIR Camera v2, DHT22 temperature and humidity sensor, DS18B20 temperature sensor, Waveshare 10 DoF IMU sensor, 2 photoresistors, SX1278 radio module and Adafruit Ultimate GPS module. Our CanSat will also consist of a 5V 2.5A step-down voltage regulator, a buzzer and a swith-key. An electronic drawing of our CanSat looks as follows:

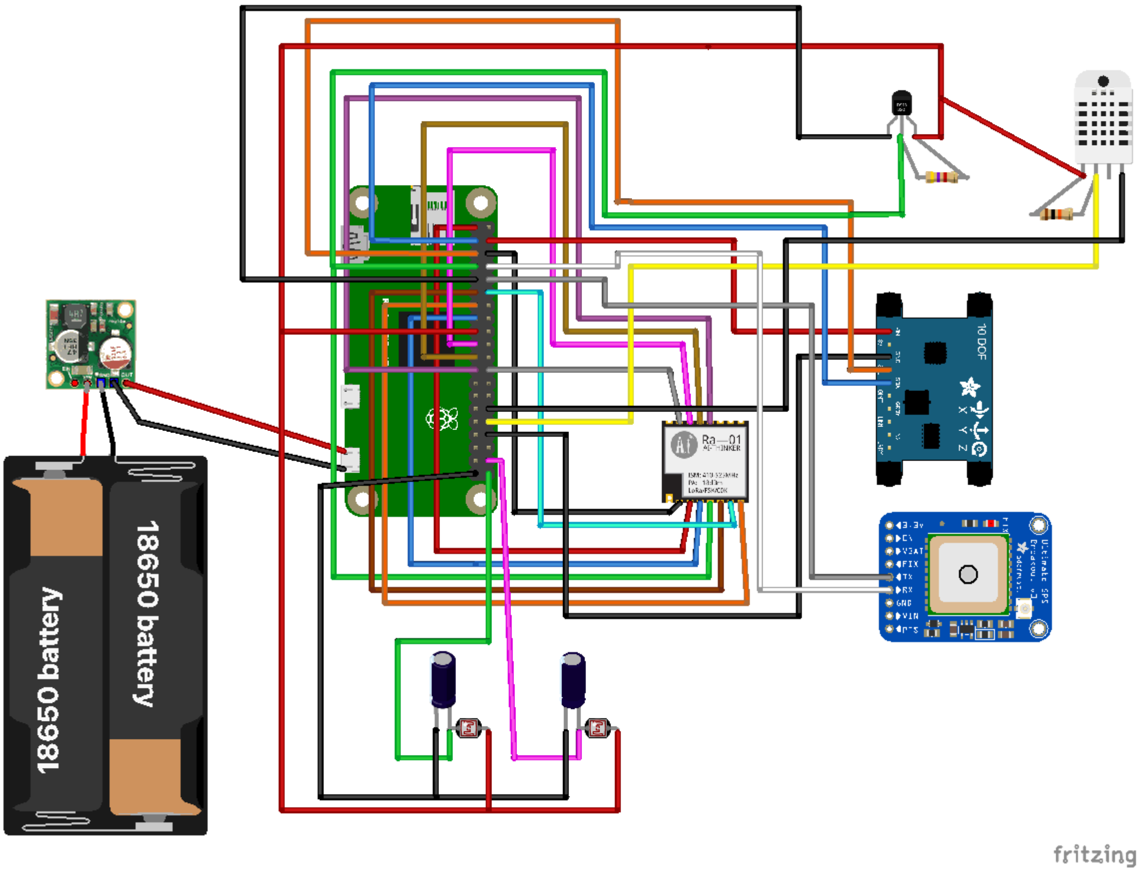

Figure 7: The electronic drawing

3.3.2 Primary mission devices

The primary mission will be conducted using consecutive sensors: DS18B20 temperature sensor to measure the temperature and a BMP280 located in Waveshare 10 DoF IMU sensor to measure the air pressure. The data from those sensors will be sent to our on-board computer - Raspberry Pi Zero W. The computer will send the readings via SX1278 radio module to our ground station. There will also be a buzzer that will start vibrating after the touchdown.

3.3.3 Secondary mission devices

The secondary mission will be conducted using consecutive electronic components: Raspberry Pi NoIR camera taking Red – Green - Near-Infrared images used in calculation of remote sensing indexes (NDVI, NDWI, Green NDVI, Greenness Index) and in land cover classification.

The DHT22 sensor will be used to measure air humidity, DS18B20+ temperature sensor to measure the temperature, Waveshare 10 DoF IMU sensor to measure acceleration, orientation, magnetic field and air pressure as well as two 50-100 kΩ photoresistors to measure sunlight intensity.

Our CanSat will also be equipped with Adafruit Ultimate GPS Breakout board that will gather latitude, longitude, altitude, speed and real time of our satellite.

3.3.4 Power supply

Our CanSat will be powered by two XTAR 18650 lithium-ion batteries (3500 mAh each) in series circuit. Assuming 90% efficiency of batteries, we get 6300 mAh capacity and a voltage of 7.4 V. As Raspberry Pi Zero W works at 5V/2.5A, our CanSat will also consist of a Pololu 5V 2.5A step-down voltage regulator. Assuming 85% efficiency declared by producer of voltage regulator, we will get 7925 mAh and a voltage of 5V (39.6Wh). This will be enough to power our CanSat for 12 hours. We chose Li-Ion batteries due to its excellent energy to mass ratio and their reliability in different conditions.

Electronic component	Current usage	Voltage	Power consumption
Raspberry Pi Zero W	~200mA	5V	1500mW
Raspberry Pi NoIR v2 Camera	-	-	1000mW
Temperature sensor DS18B20+	1mA	3.3V	3.3mW
Waveshare IMU 10DoF sensor	4mA	5V	20mW
Servo SG-90 (only one turn)	-	-	-
GPS module for Raspberry Pi	20mA	5V	100mW
SX1278 LoRa RA-02 433 MHz radio module	<130mA	3.3V	430mW
DHT-22 Temperature & humidity sensor	0,2mA	5V	1mW
Photoresistors	4mA	3.3V	13.2mW
Buzzer	30mA	5V	150mW
Total	**~400mA**		**~3.3W**

The maximal lifetime of our CanSat:

$$\frac{39.6Wh}{3.3W} = 12h$$

The batteries will power our CanSat for about 12 hours.

3.3.5 Communication system

We are going to use radio communication to receive data from our CanSat. The communication is one-directional as there is no need to send any commands to the CanSat. We used SX1278 radio module in both the satellite and ground station. The module in the CanSat is equipped with an antenna made of a wire. In the ground station we want to use a Yagi-Uda directional antenna.

Both CanSat and ground station are configured to the frequency of 433.0 MHz and a 125 kHz bandwidth. The spreading factor was set to 8 and coding rate to 4/6 to get the communication speed at about 2600 bps what gives about 325 characters per second. The emitting power of the radio is 100 mW.

3.4 Software design

Our team is going to use three programs: one for our CanSat, one for the ground station and one for image analysis. The code on CanSat will be responsible for getting and saving data from sensors, taking images, sending data via radio, and turning different operation modes: preflight mode, flight mode and postlanding mode. We will get data from the sensors every 500 milliseconds. The data gathered from sensors will be saved in a CSV file and images will be saved directly on the SD card in JPG format. All software is going to be written in Python.

3.4.1 Preflight mode

This mode will be turned on during the boot of our CanSat. During it, CanSat will only gather data from temperature sensor, pressure sensor and the GPS module as well as send them via radio. Using the readings from GPS and pressure, the code will calculate the altitude of the satellite. If the difference between the initial altitude and current altitude will be bigger than 200 meters for 3 times, our CanSat will switch to flight mode.

3.4.2 Flight mode

During this mode all the CanSat sensors will be gathering data and the camera will be taking images. The data and images will be gotten once every 500 milliseconds and saved to SD card. Temperature, air pressure, humidity, sunlight intensity, latitude, longitude, and altitude will be sent via radio to our ground station once a second. The photos will be taken in two resolutions: the images in 324x243 pixels resolution that will be sent via radio during the postlanding mode and the images in 1296x972 pixels resolution that will be stored on the SD card. This mode will be working for 30 minutes and then the postlanding mode will be turned on.

3.4.3 Postlanding mode

During the final mode, all the CanSat sensors will be turned off. Only the radio module and the buzzer will be working. The radio module will be sending the readings from accelerometer, magnetometer, gyroscope, GPS module as well as images in low resolution to the ground station. The buzzer will be turned on once every 3 seconds for 1 second. This mode will last till the batteries are discharged or until the CanSat is turned off using the switch-key.

3.4.4 Ground station software

The ground station software will receive radio data, save it to CSV file or the SD card (images) and present it in a web framework. The framework will be written in Python and Flask.

3.4.5 Image analysis software

The image analysis software will be responsible for calculation of remote sensing indexes (NDVI, NDWI, Green NDVI and Greenness Index) as well as in land cover classification. The code will create a composition of images.

We also created a GitHub respiratory for our codes that will be updated regularly.
Link: https://github.com/EmilK5/CanSat

3.5 **Recovery system**

3.5.1 General idea

We will use a hexagonal parachute with an area of 1200cm^2. We have added, a new feature - parachute vent, to our previous project. It will stabilize the flight of our CanSat and reduce the speed of the landing.

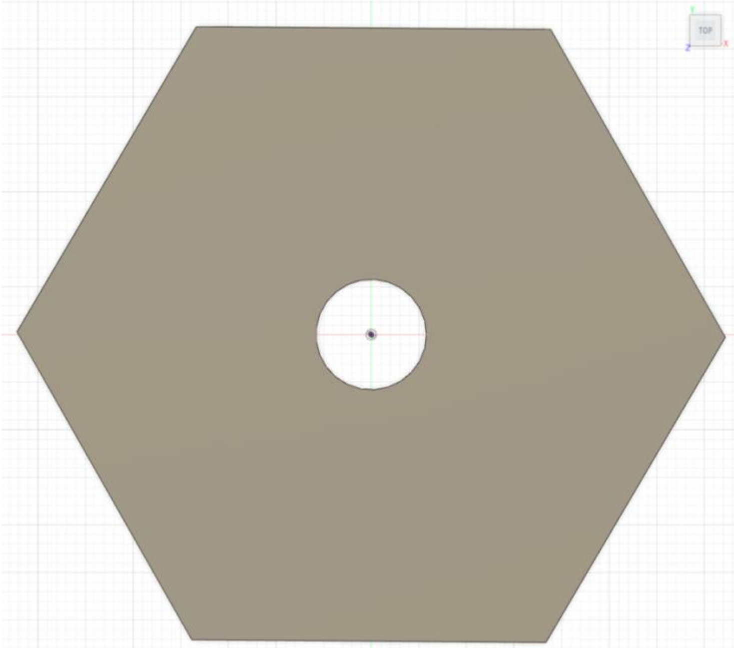

Figure 8: The design of the parachute

3.5.2 Materials

The material used to sew our parachute is a polyester-nylon ripstop fabric. It has a high durability and is also waterproof. Its bright blue colour has not been chosen by an accident. It will help us to find our CanSat after the landing. To attach our parachute, we will use 6 nylon lines with a diameter of 3mm.

3.5.3 Tests and estimate performance

We have already carried out the necessary calculations, thanks to which we were able to calculate the parachute area needed to maintain the falling speed of our CanSat around 8m/s. To do it we used the following formula:

$$F = \frac{1}{2} CdAv^2$$

F – resistance force; C – drag coefficient; d – density; A – surface; v – speed

Resistance force must be equal to gravity force:

$$F = mg = \frac{1}{2} CdAv^2 \leftrightarrow A = \frac{2mg}{Cdv^2}$$

We have already done out the first tests to check if our calculations were correct. We used test model made of a soda can, which weight was increased to 300g - the weight of our final model. We still have some doubts, but in near future we are planning to test many different configurations of the parachute surface that should clear them up.

3.5.4 Mounting of the parachute

To attach our parachute, we will use nylon lines inserted into interior of our model through holes in its case. At the end of these lines, we will attach spherical objects that will prevent the lines from falling out of the CanSat and keep the parachute attached to the model. As the holes will have a diameter of 3mm, the diameter of these "balls" will be 5mm. Thanks to such solution, we will be able to adjust the height of the parachute canopy quickly and easily above the model.

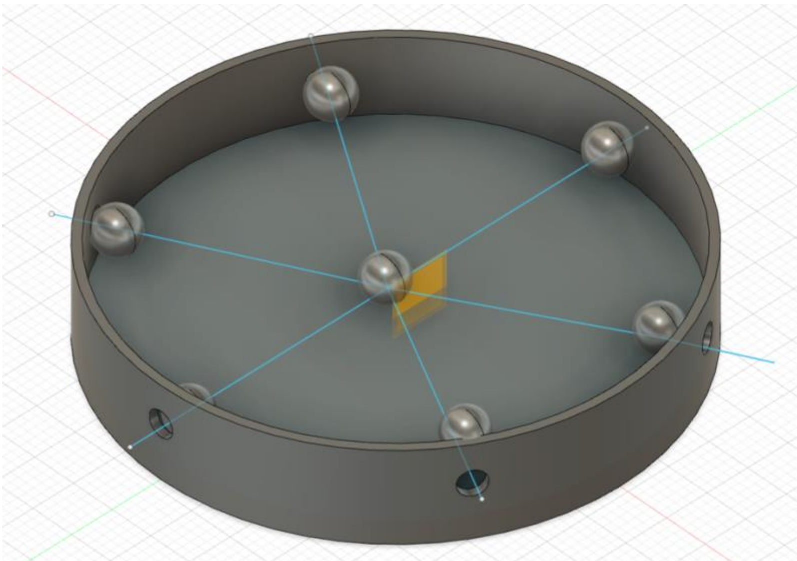

Figure 9: The parachute mounting

3.6 Ground support Equipment

Our ground station will consist of a Raspberry Pi 3B+ with SX1278 radio module, a Yagi-Uda antenna and a laptop. All the data from the CanSat will be sent to Raspberry Pi via radio and stored in the CSV file. The photos will be stored on the SD card and later analyzed on our laptop using a code for calculation of remote sensing indexes and land cover classification.

4 TEST CAMPAIGN

4.1 Primary mission tests

We have already tested our primary mission sensors by running several tests. We compared the obtained results with measurements from other sensors and weather stations to check if the sensors are accurate. The temperature was measured using three independent sensors: DS18B20 (the main temperature sensor in our CanSat), DHT22 and BMP280. The gathered records are similar with an error of ±1°C. A diagram showing obtained measurements:

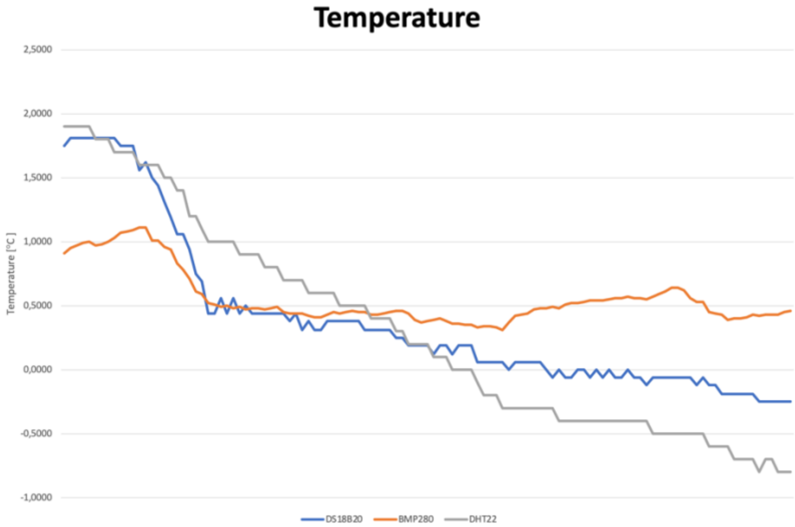

Figure 10: Temperature measurements

The obtained pressure measurements were also accurate compared with the measurements from an independent weather station. The error was ±2 hPa.

4.2 Secondary mission tests

While testing primary mission sensors we also tested the secondary mission components. The data gathered from DHT22 humidity sensor had an error of ±1%. The readings gathered from light sensors can't be compared due to lack of other light sensors. During the test in the night the sensors showed a value of 0.0, in the daylight 0.4-0.6 and with a torch directed at them a value of 0.95-1.0 what shows that the sensors are correctly measuring light intensity. We also tested a GPS module several times. The obtained results were with an average error of 10 meters in latitude and longitude what is an accurate result, allowing us to easily find our CanSat:

Figure 11: The proper localization of the CanSat (on the left), the localization measure by the GPS module (on the right)

We have also tested our camera and the code for photo analysis. The obtained images are of good quality and indicators are calculated correctly:

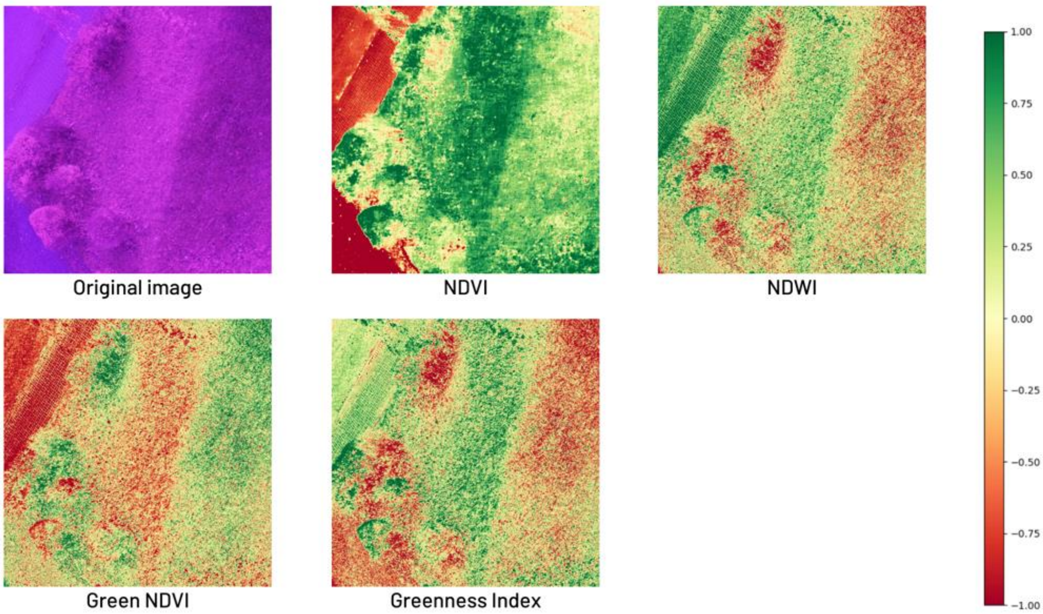

Figure 12: Composition of images

4.3 Tests of recovery system

4.3.1 Plans

We plan to test the recovery system by dropping the 300g (the weight of the final model) test models from buildings of different heights. Of course, the higher the more accurate the test will be. As the model falls, we will measure the time and record the moment of flight. This will allow for a detailed analysis of movement track, as well as the calculation of the average speed on specified route (we know the distance and time of movement).

4.3.2 First tests

We decided to use our school building to conduct the first tests. We dropped our test model (made of a soda can) with an attached parachute. The model was falling for about a second. It gave us a lot of valuable knowledge how to improve our parachute's design. A footage from the test:
https://drive.google.com/drive/folders/1ux45yJf1KgxFwuyOm8f3HTM_z8gVIK-9?usp=sharing

4.3.3 Conclusions

After conducting the first tests, we decided to increase the area of our parachute from 900 cm^2 to 1200 cm^2 to lower its falling speed. We also decided to add a parachute vent to our parachute as the CanSat flight was not stable. We plan to test parachutes with different surface, as well as change of the test site, in nearby future. It will result in an increase in the height from which the model will be dropped.

4.4 Communication system range tests

We have already performed 2 radio communication tests. One on the distance of few meters in our workroom and the second one on the distance of several dozen meters. In each test we sent a line consisting of 50 characters (numbers, dots and semicolons).

At first, we set the Coding Rate to 4_8 and the Spreading factor to 12 as we wanted to embiggen the certainty of transmission. Unfortunately, at those settings the majority of message was sent with errors, so we tried other settings of those parameters. At last, we found a golden mean for them: we set a Coding Rate to 4_6 and the Spreading factor to 10.

During the second test we checked our antennas: On the CanSat there is going to be a 17 cm long antenna made of a wire and in the ground station there is going to be a 10-element Yagi-Uda antenna:

Figure 13: Antennas used in the CanSat and ground station

4.5 Energy budget tests

We conducted a battery test to check whether our electronic circuit is giving appropriate voltage and amperage for our CanSat. The Raspberry Pi turned on correctly and it was working without "Too low voltage errors". This test assured us that we chose appropriate components for our electronic circuit.

In near future we are planning to perform the energy budget test leaving a Raspberry Pi on with sensors collecting data and camera taking images (only for 30 minutes). It will also measure the time until when it was turned off.

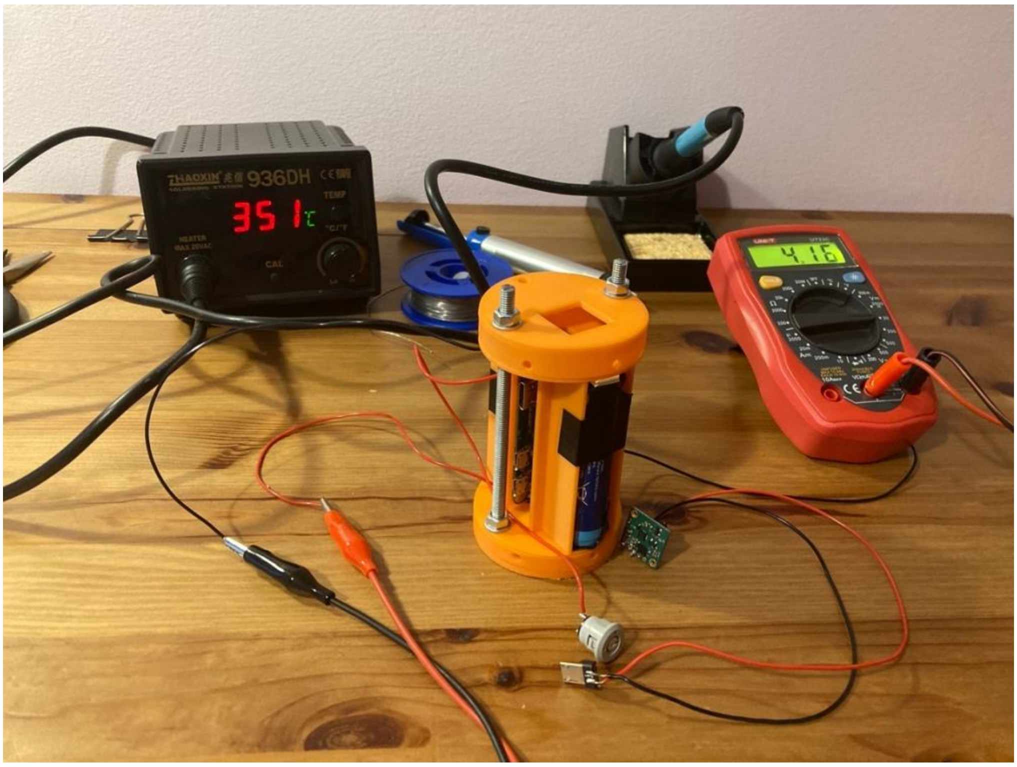

Figure 14: Assembly of the electronic circuit

5 PROJECT PLANNING

5.1 Time schedule

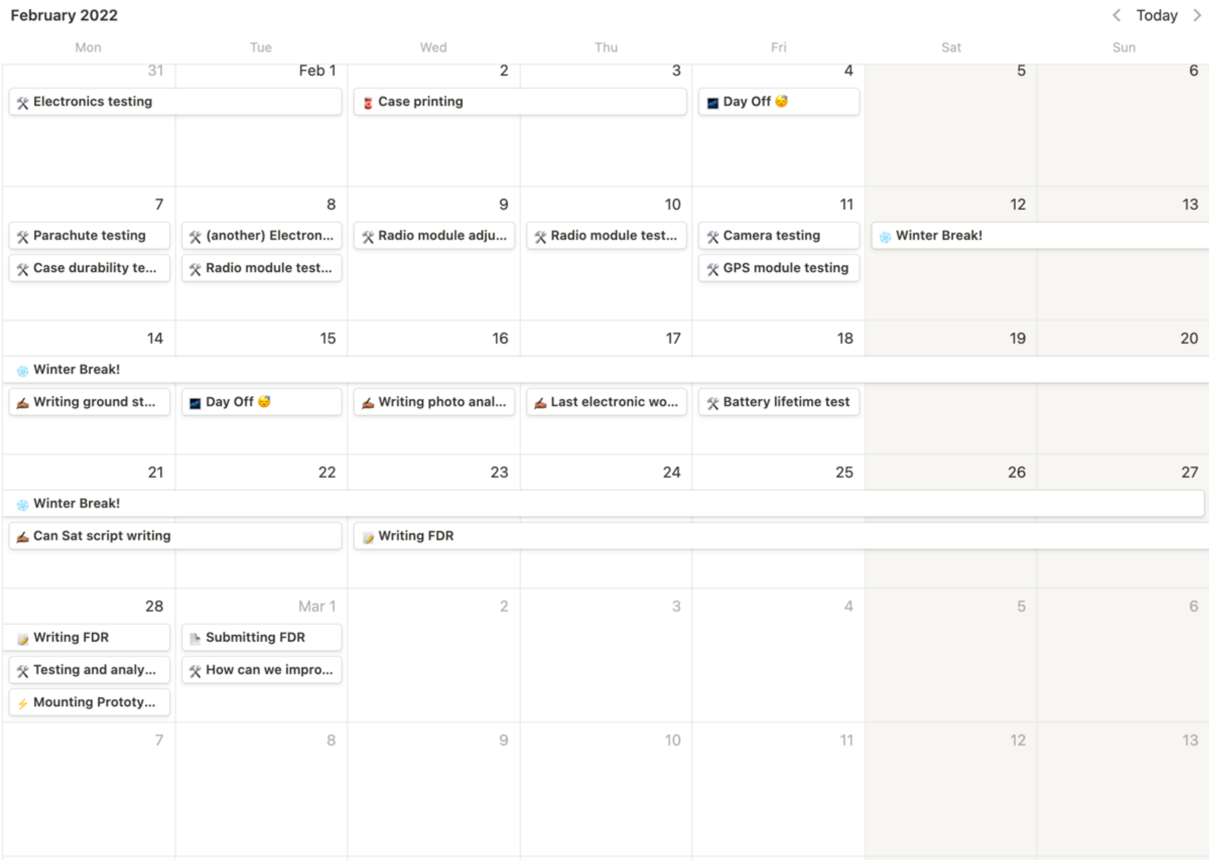

Figure 15: Calendar – Time schedule

5.2 Task list

HIGH-LEVEL TASK	LOWER-LEWEL TASK	STATUS
Writing CDR	Dividing work	Done
	Submitting CDR	Done
Outreach	Creating Facebook account	Done
	Creating Instagram account	Done
	Establishing new cooperations	Done
	Posting updates	Done
	Giving presentation in school	
	Giving presentation in training center for teachers	

Planning	Inventing mission's objectives	Done
	Designing electronics	Done
	Designing satellite	Done
	Approximating the budget	Done
	Approximating mass of CanSat	Done
Gathering all necessary things	Choosing materials and modules	Done
	Buying elements	Done
	Eventual changes in budget	Done
Prototypes	Parachute	Done
	Case	Done
	Electronics	Done
Testing	Testing parachute	
	Testing GPS module	
	Testing case durability	
	Testing camera	
	Testing battery lifetime	
Communication	Choosing antenna and radio module	Done
	Calibrating radio modules	Done
	Writing a script for radio modules	Done
	Testing radio module on short distance (few meters)	Done
	Testing radio module on medium distance (few hundred meters)	Done
	Testing radio module on long distance (3 kilometers)	
	Testing radio module	
GPS	Choosing GPS module	Done
	Testing GPS module	Done
	Installing GPS module	
Software	Writing an algorithm for each sensor	Done
	Writing script for ground station	
	Writing script for CanSat	
	Writing photo analyzing program	Done
Electronics	Choosing sensors and components	Done
	Making electrical design prototype	Done
	Testing and calibrating sensors and components	Done
	Testing final version of electrical model	

Final model	Printing case	
	Testing the final model	
	Installing electronics, modules, sensors in case	
Writing FDR	Dividing work	
	Submitting FDR	

5.3 Resource estimation

5.3.1 Budget

Here is a table showing all costs of our CanSat (€180):

Element	**Cost (€)**
Raspberry Pi Zero W 512 MB	13.00
Raspberry Pi NoIR v2 Camera	32.00
Temperature sensor DS18B20+	2.34
Waveshare IMU 10DoF sensor	14.10
2x 18650 XTAR – 3500mAh battery	21.60
Servo SG-90	4.10
Case (filament)	12.20
GPS module for Raspberry Pi	46.00
SX1278 LoRa RA-02 433 MHz radio module	7.60
DHT-22 Temperature & humidity sensor	6.50
Step-down converter 5V 2.5 A	15.21
Others (switch-key, wires, filament)	10.00
Σ	**184.65**

We took the prices from https://botland.com.pl/

5.3.2 External support

Since October we managed to get a lot of partners and sponsors for our project. Our sponsors are in succession: WizjaNet - an IT company that provides services to companies in field of IT, programming, and e-marketing; Abel IT – an IT company providing computer services; Botland – an electronic and robotic shop; our school's PTA, the school management, and the V High School Association.

Received support allowed our team to buy all necessary parts to build our CanSat as well as prepare promotional materials.

Figure 16: Logotypes of our sponsors and partners

6. OUTREACH PROGRAMME

Since the PDR we made massive advances in the Outreach Programme. We set up Facebook and Instagram pages where we post regularly about advances in our project, our partners, and sponsors as well as about our team: Our Facebook page has 176 followers and 167 likes, while our Instagram page has 89 followers.

Each of our posts easily reaches few hundred recipients. One post on our Facebook page gained 250 recipients and 67 reactions. So much interest was around the post with 3D printing of the mass prototype. We plan to take more photos of us building our CanSat so that people can see the results of our work.

Links:
https://www.facebook.com/teamvlo.cansat
https://www.instagram.com/teamvlo.cansat/

Figure 17: An example Facebook post

The leader of our team – Emil Kielar with the help of our mentor - Dr Dawid Kotrys published a research paper on the XI Inter University Conference of Students, PhD students and Young Scientists held at the University of Bielsko-Biala (ATH) in Bielsko-Biała. Emil's paper is about a program, written in Python, which analyzes images using the OpenCV function library. The code determines the Normalized Differential Vegetation Index, what is a main stage in our secondary mission.

Link to the paper: https://doi.org/10.53052/9788366249868.10

Link to the poster: http://www.engineerxxi.ath.eu/wp-content/uploads/2021/12/351.pdf

In order to promote our team, we created our own logotypes that are being used in all promotional materials of our team:

Figure 18: Logotypes of our team

We were also asked by the Head of Bielsko-Biala's Teacher Training Centre (Bielsko-Bialski Ośrodek Doskonalenia Nauczycieli) to give a presentation to the teachers from our city about the CanSat competition and our satellite as well as its the mission. We are going to give this presentation in February.

Our team is also going to give a presentation about our CanSat in May for the students from primary schools that are in our city and county during the workshop that is organized for them by our school ("Zaprzyjaźnij się z V"). We will also give this presentation to the students from our school in February. During it we will tell them about the competition and our team's project.

We also contacted local media that wrote an article about our team: https://bielsko.biala.pl/aktualnosci/47543/uczniowie-v-lo-w-bielsku-bialej-buduja-satelite-konkurs-europejskiej-agencji-kosmicznej

For promotional purposes in our school, we wrote an article on our school's webpage about our team's project: https://lo5.bielsko.pl/aktualnosci/budujemy-satelite