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SONDA MONITORUJĄCA ROŚLINNOŚĆ PRZY POMOCY TELEDETEKCJI: CANSAT TEAMVLO

Streszczenie: Artykuł ten opisuje sondę CanSat, której misją jest ocenienie czy miejsce jej lądowania jest odpowiednie do życia i rozwoju roślinności. W tym celu sonda wykonuje zdjęcia powierzchni Ziemi, na podstawie których oblicza wskaźniki wegetacji roślin oraz pobiera odczyty z czujników pogodowych.

Słowa kluczowe: sonda, teledetekcja, NDVI, zdrowie roślinności, poziom wegetacji, CanSat

A SONDE MONITORING THE VEGETATION USING REMOTE SENSING: TEAMVLO'S CANSAT

Summary: This article explains a CanSat sonde, which mission is to determine whether the place of its landing is suitable for life and growth of plants. For this purpose, the probe takes pictures of the Earth's surface, based on which it calculates plant vegetation indices and takes readings from weather sensors.

Keywords: sonde, remote sensing, NDVI, plant health, vegetation level

1. Introduction

A rapid development of remote sensing (a method used to obtain information about objects and phenomena occurring on Earth (and other planets) by devices that are not in direct contact with assessed object) has enabled monitoring the plant health using a camera and other sensors. In this purpose, a sonde described in this article has been built.

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The main idea of the project was to create a low-cost, reliable, and multi-purpose device that can be used in remote sensing projects. For the purpose of CanSat competition focus was placed on monitoring the vegetation. To monitor the plants, a Python code was written that calculates three remote sensing indices: Normalized Differential Vegetation Index, Green Normalized Differential Vegetation Index and Greenness Index. The code prepares a following composition of images (Fig. 1).

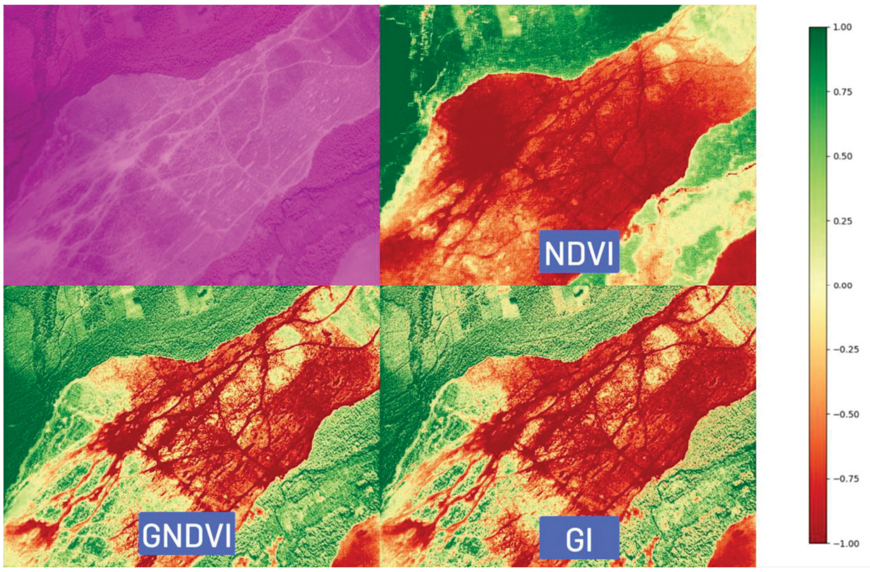

Figure 1. A composition of images

By minor changes in the code and the optical filter, it can be re-tasked to calculate other remote sensing indices such as Normalized Differential Water Index or Modified Triangular Vegetation Index.

On-board the CanSat there also are sensors that collect data about the environment: temperature, air pressure, humidity, and illuminance sensors. These factors significantly influence the growth of plants and are important data in monitoring the plant health.

2. Project description

2.1 CanSat – parameters

According to parameters set by European Space Agency, CanSat is a sonde within the volume and shape of a soft drinks can, that is launched on a rocket up to the altitude of 1-2 km. A CanSat must be designed meeting the following requirements:

- All components of the CanSat must fit inside a cylinder with a diameter of 66 mm and height of 115 mm, with the exception of the parachute and Radio antennas that can be mounted externally on the top or bottom of the probe.

- The mass of the CanSat must be between a minimum of 300 grams and a maximum of 350 grams.
- The CanSat must be powered by a battery and/or solar panels for a minimum of 4 hours.
- The CanSat's descent speed must not be lower than 5 m/s and higher than 12 m/s.
- The CanSat must be able to withstand an acceleration of up to 20 g.
- The total budget of the final CanSat must not exceed 500€

2.2 Material and structural design

The main structure of the CanSat are two bolts that go through the center of the sonde along its entire length. The probe is divided into the following sectors that host different modules (Fig. 2):
- **Sector 1** is the place where the camera and air pressure sensor are located.
- **Sector 2** is the largest section in which the power supply, most of the sensors, radio transmitter and on-board computer are located.
- **Sector 3** is where a GPS tracker, light intensity sensor and parachute mount are.

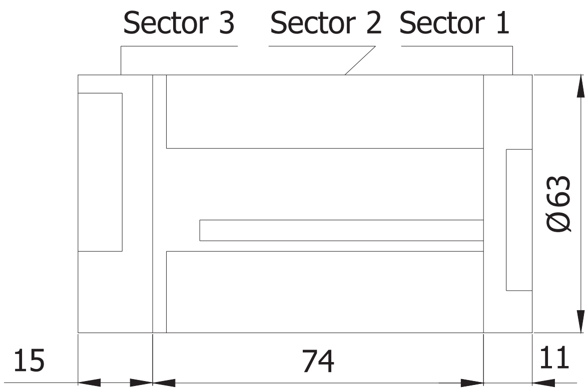

Figure 2. Division of the sectors

The Casing of the CanSat is divided into 6 individually printed elements. The outer casing is put together using fasteners, while the inner casing elements are mounted on two screws which are the main axis of the construction. In the outer casing there are hexagonal windows that allow the air flow into the interior for cooling the computer and more accurate sensor readings. All modules are mounted into the casing using either Velcro tape or dual-sided tape to prevent reduction of durability of the casing by screwing screws directly into main structure (Fig. 3).

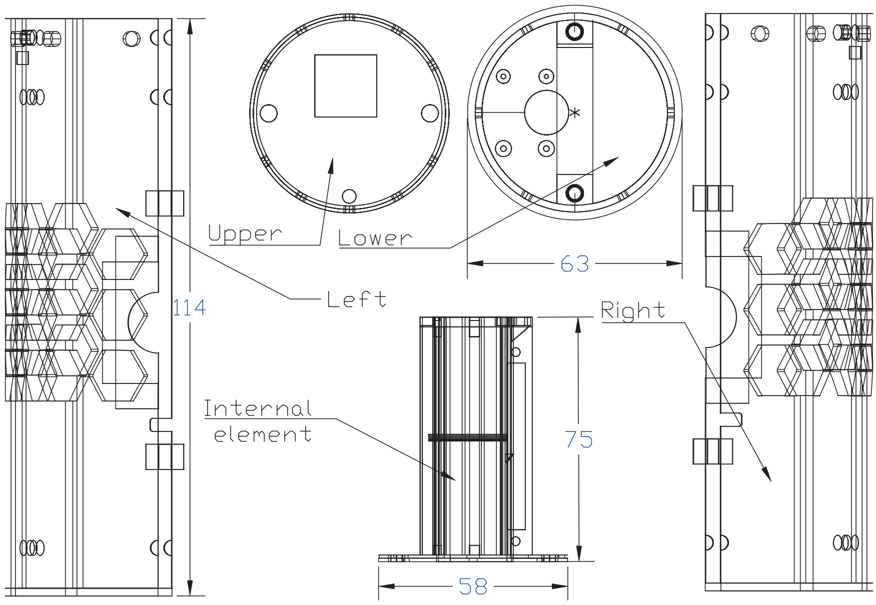

Figure 3. The casing of the CanSat

2.3 Electrical design

CanSat is constructed using following electrical components (Fig. 4):

- **Raspberry Pi Zero W** – the on-board computer responsible for collection and sending of the data. It is running a Linux distribution adjusted to Raspberry Pi. Located in sector 2.
- **Raspberry Pi Camera module 2 NoIR** – the infrared camera responsible for taking images in Visible Red, Visible Green and Near Infra-Red spectrum of light (the Visible Blue spectrum is blocked by Roscolux #2007 Storaro Blue optical filter). The camera has 8-megapixel Sony IMX219 sensor. Located in sector 1.
- **BMP280** – the air pressure and temperature sensor located in sector 1 of the CanSat. The sensor offers measurements every 5.5 msec as well as high accuracy (±0.12 hPa, ±1°C).
- **DS18B20** - the temperature sensor located in sector 2 (in the window of the casing). This sensor has a very high accuracy (±0.5°C) and high frequency of measurements.
- **DHT22** – the humidity and temperature sensor located in sector 2. The sensor has a frequency of 0.5 Hz and accuracy of ±2% for humidity as well as ±0.5°C for temperature. It is used as main humidity sensor and backup temperature sensor.
- **SX1278 LoRa radio module** – the 433 MHz radio module that offers low power consumption and high speed of data uplink. It is located in sector 2.
- **Photoresistor** – responsible for collecting data about illuminance. Located in sector 3.
- **Adafruit Ultimate GPS module** – enables to track up to 33 satellites on 99 channels. The module has very low power consumption. It is located in sector 3.

- **Pololu 5V 2.5 A step-down converter** – reduces the voltage of the batteries from 7.4 V to 5 V required by Raspberry Pi. It has an excellent efficiency of 90%. Located in sector 2.
- **2x 18650 lithium-ion batteries** – the power source of the CanSat. They offer high capacity of 3500 mAh each and enable our CanSat to work for over 12 hours.

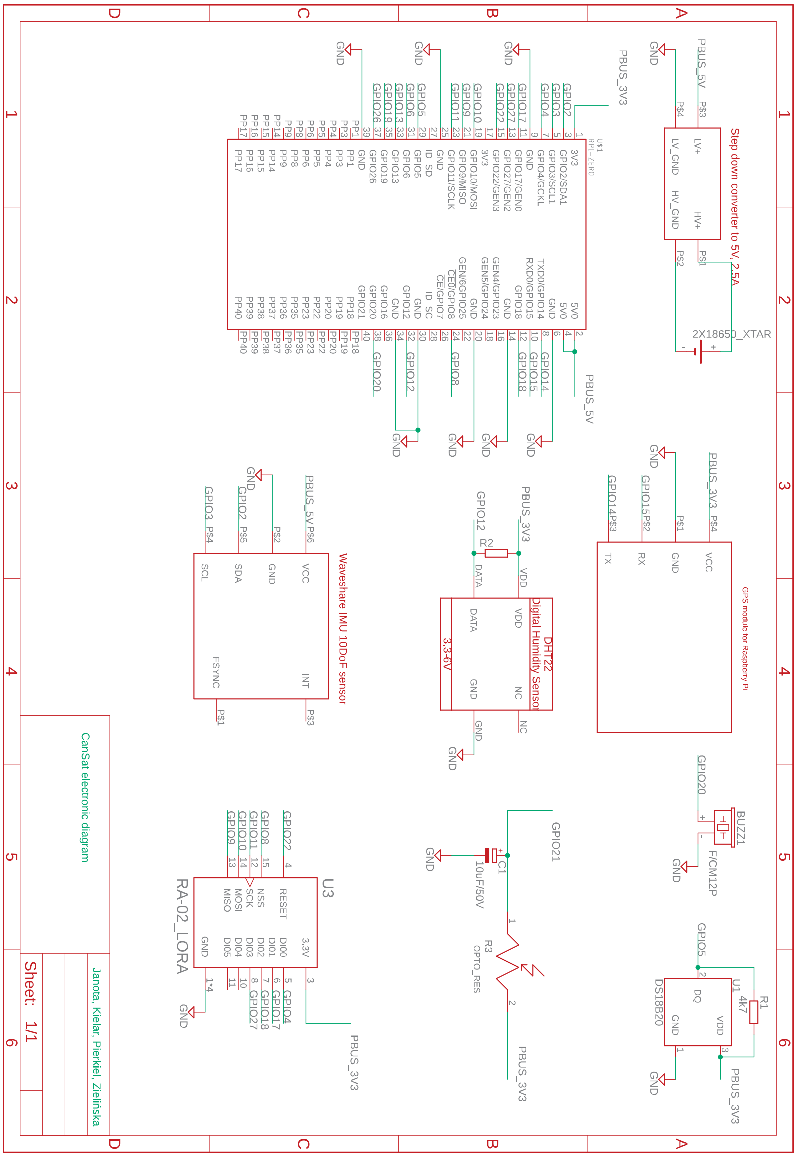

Figure 4. CanSat electronic drawing

All components are connected directly to the Raspberry Pi that saves the data from the sensors and camera on the SD card and sends GPS coordinates as well as temperature and air pressure readings to the ground station.

The radio module and ground station are configured to the frequency of 433.2 MHz and 125 kHz bandwidth. The spreading factor is set to 10 and the coding rate to 4/6, what gives the communication speed at about 2600 bps (325 characters per second). Radio communication is only used to receive data from the CanSat.

The sonde requires about 3.3 W of power. With the 90% efficiency of batteries and 90% efficiency of step-down converter we get 39.6 Wh of power, what enables our CanSat to work for 12 hours.

All connections in the sonde are soldered, what minimizes the risk of disconnection of the wires.

2.4 Software design

The code on the CanSat is responsible for getting and saving data from sensors, taking images, sending data via radio, and turning on and off different operation modes: preflight mode, flight mode and postflight mode. The data from the sensors is gotten every 500 milliseconds. It is saved in a CSV file and images are saved directly on the SD card in JPG format. All software is written in Python. In order not to create a queue, the CanSat's code is using threading. The code is divided into following modes:

- **Preflight mode** is turned on during the boot of the sonde. During it, CanSat is only gathering data from temperature sensor, air pressure sensor and GPS module as well as sending them via radio. Using the readings from pressure sensor, the code is calculating the altitude of the satellite. If the difference between the initial altitude and current altitude is bigger than 150 meters, the sonde will switch to the flight mode.
- **Flight mode** - during this mode, all the CanSat sensors are gathering data and the camera is taking images. The data and images are gotten every 500 milliseconds and saved on the SD card. Temperature, air pressure, humidity, illuminance, latitude, longitude, and altitude are sent via radio to the ground station once a second. This mode is working for 30 minutes and then the postlanding mode is turned on.
- **Postlanding mode** - During the final mode, all the CanSat sensors (except the temperature and pressure sensors) are turned off. Only the radio module, the buzzer and GPS are working. The radio module is sending the readings from GPS module, temperature, and air pressure sensors. The buzzer is turned on once every 3 seconds for 1 second. This mode lasts until the CanSat is turned off using the switch-key.

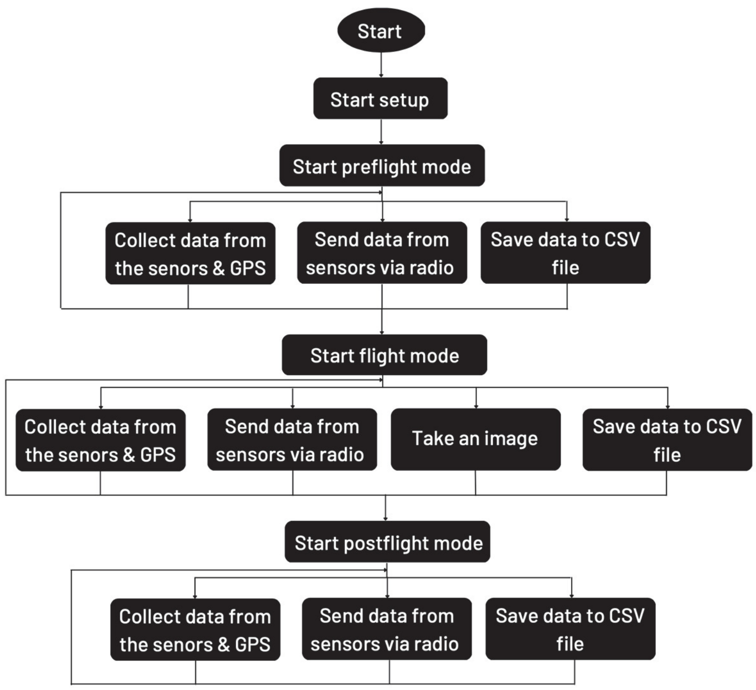

Figure 5. Flow diagram of the code

2.5 Recovery system

The sonde has a hexagonal parachute that has an area of 900 cm^2 and a parachute vent which stabilizes the flight of the CanSat and reduces the speed of the landing. The material used to sew it is polyester-nylon ripstop which has a high durability and is waterproof. The parachute is attached to the outer casing of the CanSat with 6 nylon lines (Fig. 6). The parachute gives the sonde a flying speed of 10.6 m/s.

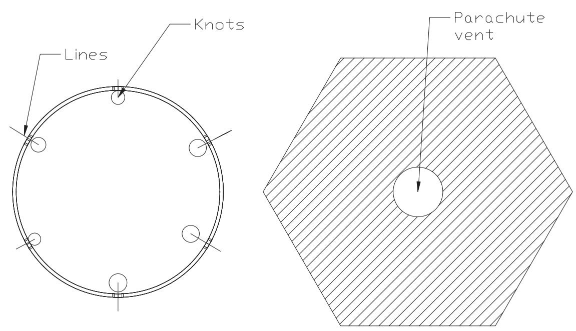

Figure 6. The recovery system design

2.6 Ground support equipment

In order to receive data from the CanSat, a ground station consisting of a Raspberry Pi 3B+ set with SX1278 radio module, a Yagi-Uda antenna and a laptop was constructed. All the data is sent via radio. The ground station receives each second a message, decodes it and saves it in a CSV file.

2.7 Flight data analysis software

After obtaining images from the sonde's SD card, the remote sensing indices are calculated. First of all, the contrast of image needs to be increased. This action allows the results to be more accurate (Fig. 7).

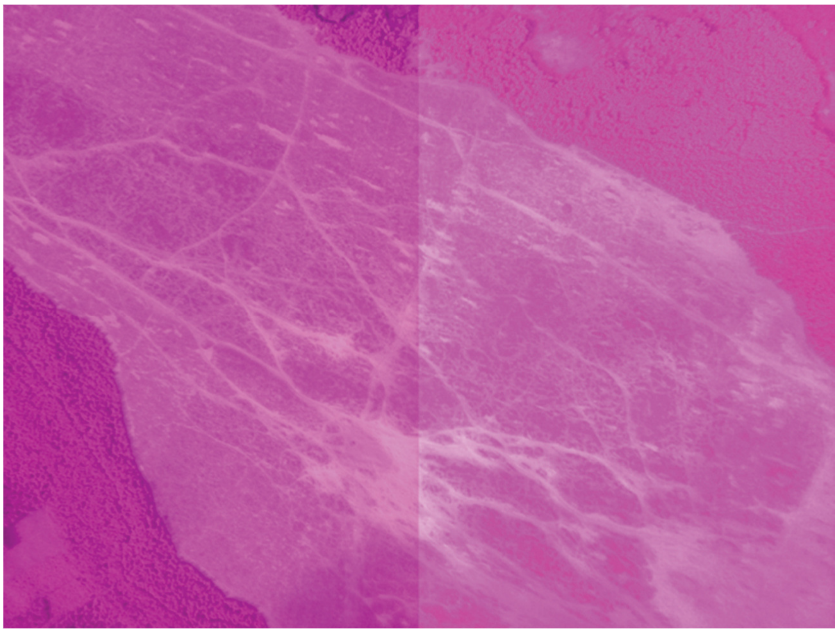

Figure 7. Original image (left), image with increased contrast (right)

After the increasement of contrast, the image is split into 3 arrays. Every array contains one of the three values that each pixel has in RGN (Red, Green, Near-Infrared) color space. Then, the denominator of the index is calculated. If it's value equals 0, it is substituted with 0.01. Next, the numerator is calculated as well as the index (numerator/denominator). The calculated index is in greyscale (Fig. 8). The brighter the pixel is, the higher value the indicator takes.

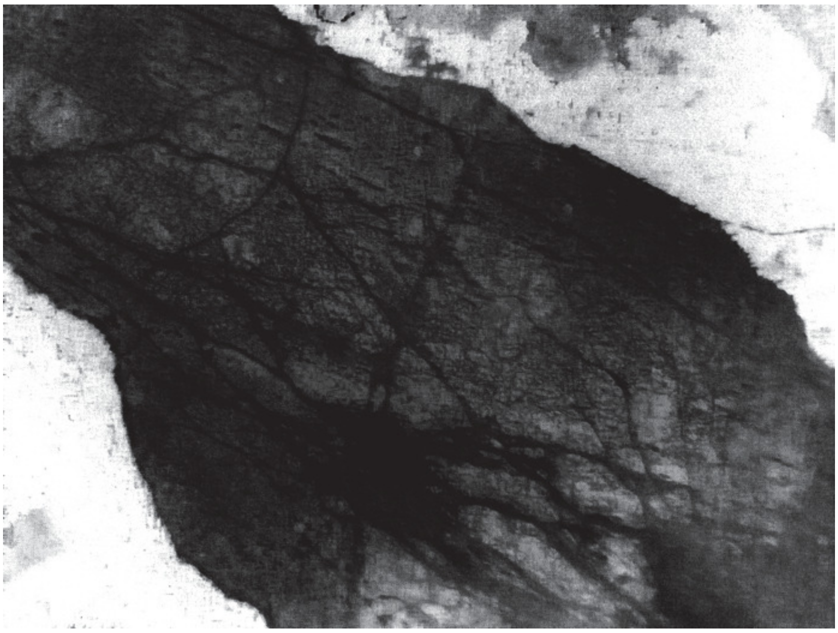

Figure 8. Calculate index in greyscale

In order to improve the readability of the indicator, the code applies *RdYlGn colormap* to the image (Fig. 9).

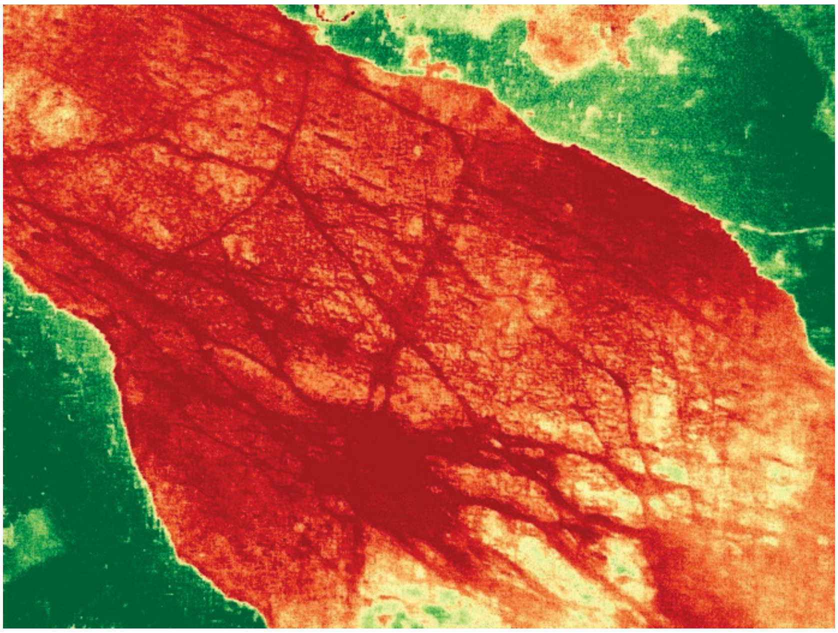

Figure 9. Calculated index with applied colormap

Finally, the code adds a color bar legend to the image and the image is saved in JPG format.

2.8 Remote sensing indices

The flight analysis software is adjusted to calculate three different remote sensing indices. They are as follows:

- **Normalized Difference Vegetation Index (NDVI)** is a graphical indicator that is used in assessing the level of vegetation and health of the plants. It is expressed by the following formula:

  $$NDVI = \frac{NIR-Red}{NIR+Red} \tag{1}$$

  where *NIR* stands for spectral reference measurements in near-infrared spectrum (842 nm wavelength) and *Red* in visible red spectrum (665 nm wavelength). The NDVI takes values from -1 to 1. The higher the value of the indicator is, the bigger and lusher plants are in the area.
- **Green Normalized Difference Vegetation Index (GNDVI)** is a graphical indicator used in assessing the chlorophyll concentration in plants as well as depressed and aged vegetation. It is expressed by the following formula:

  $$GNDVI = \frac{NIR-Green}{NIR+Green} \tag{2}$$

  where *NIR* stands for spectral reference measurements in near-infrared spectrum (842 nm wavelength) and *Green* in visible green spectrum (560 nm wavelength). The GNDVI, similarly as NDVI, takes values from -1 to 1. The higher the value of the indicator is, the older the plants are.
- **Greenness Index (GI)** is an indicator that measures the amount and density of plants in the area. It is expressed by the following formula:

  $$GI = \frac{Green}{Red} \tag{3}$$

  where *Red* stands for spectral reference measurements in visible red spectrum (665 nm wavelength) and *Green* in visible green spectrum (560 nm wavelength). The indicator takes values from 0 to 1. The higher the value of the indicator, the more plants are in the area.

3. Results of the experiment

3.1 The first launch

The probe was first launched on 26th March 2022 in Błędów desert, Poland during the CanSat Polish national competition. The sonde was lifted up to an altitude of 1700 m by Solaris rocket. The data from all sensors as well as camera was successfully collected (Fig. 10, 11 ,12).

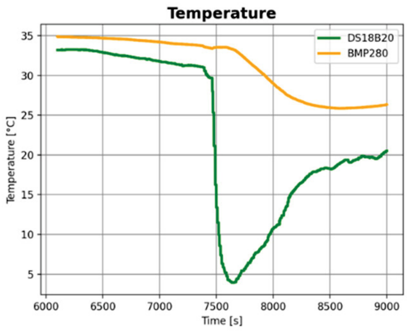

Figure 10. Temperature vs time graph

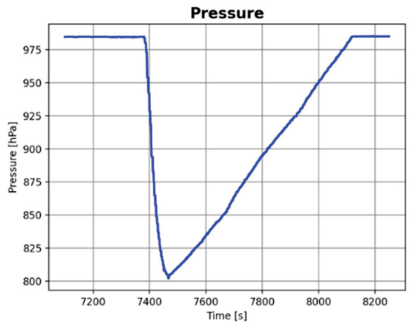

Figure 11. Pressure vs time graph

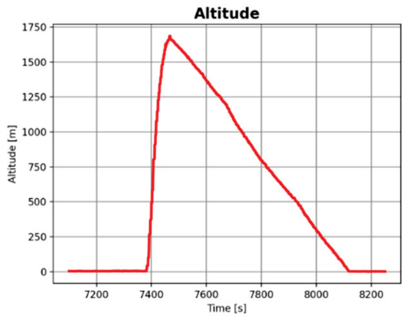

Figure 12. Altitude vs time graph

The humidity during the national competition launch campaign was 30%RH (amount of water vapor present in air expressed as a percentage of the amount needed to achieve saturation at the same temperature) and illuminance was 20 000 lx.
The sonde has also taken over 30 images of the surface before landing. All the images are of very good quality. The image below shows a part of Błędów Desert surrounded by forest in the upper and lower part of the image. There is also another small part of the desert in the bottom right corner of the image (Fig. 13).

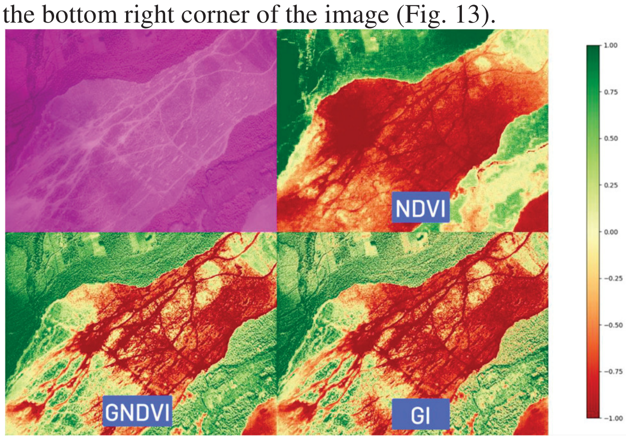

Figure 13. A composition of an original image and calculated remote sensing indices

3.2 The second launch

The probe's second launch was on 22nd June 2022 in Molinella, Bologna, Italy during the CanSat European competition (Fig. 14, 15, 16). The sonde was lifted up to an altitude of 890 m by Sierrafox's Dual CanSat Launch Vehicle (DCLV) rocket. The sonde successfully collected all the data from the sensors as well as it took over 20 images during the descent.

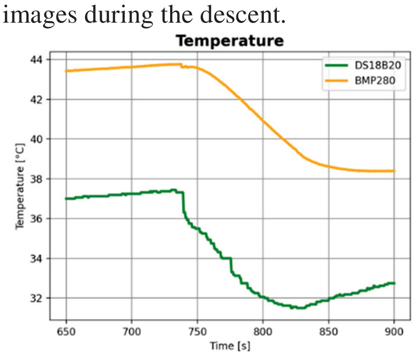

Figure 14. Temperature vs time graph

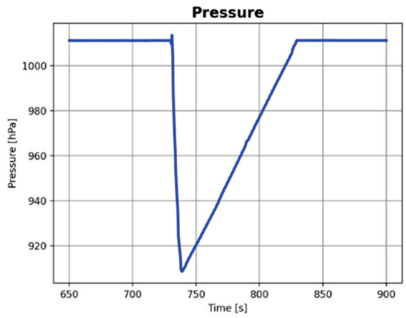

Figure 15. Pressure vs time graph

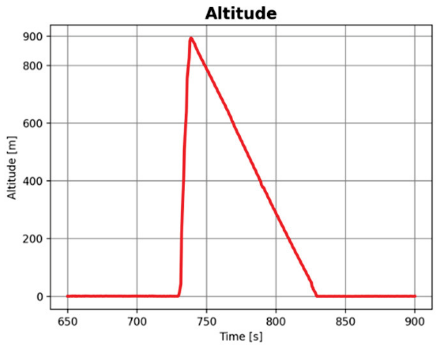

Figure 16. Altitude vs time graph

The humidity during the European competition launch campaign was 42%RH (amount of water vapor present in air expressed as a percentage of the amount needed to achieve saturation at the same temperature) and illuminance was 1000 lx.

During the European launch campaign, the CanSat has taken over 25 images of the surface before landing. All the images are of good quality (Fig. 17).

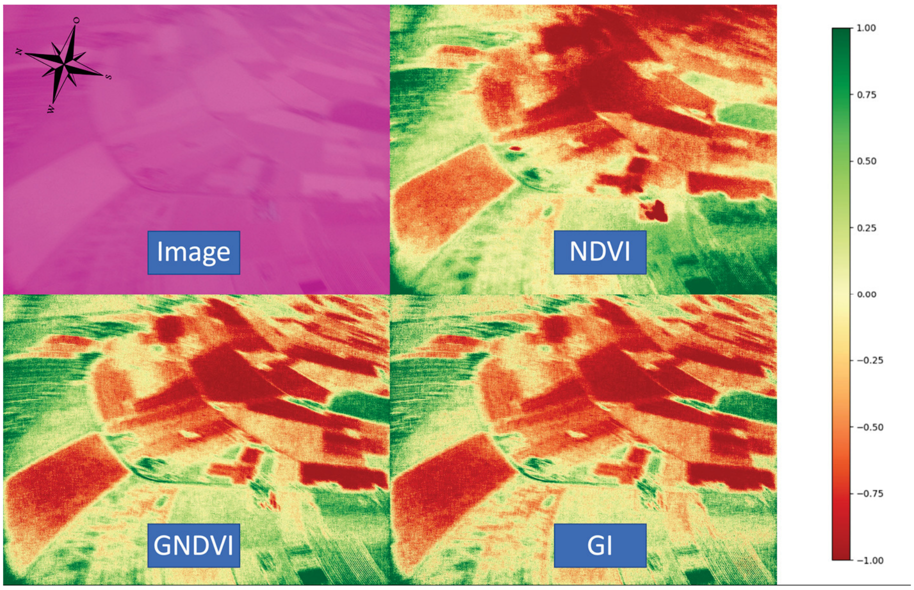

Figure 17. A composition of an original image and calculated remote sensing indices

4. Discussion of the results

4.1 Temperature results

The CanSat has measured the temperature with two independent sensors: DS18B20 that was located in the window of the casing and BMP280 that was enclosed in the Section 1 of the CanSat. A graph relating the temperature with time (see Figure 10 and Figure 14) shows that the location of the sensor has significant impact on the results. The more enclosed the sensor is, the higher the temperatures are (mainly because of the heat generated by the computer) and less sensitive to radical change of temperature.

With altitude, the temperature usually drops by 0.8°C for every 100 m in semi-humid air (that dominated during the first launch). The results from national competition (Figure 10) show that the lowest temperature recorded was 3.94°C and the highest (on the ground level, few minutes after the landing) was 20.94°C. Considering the altitude of the flight (1700 m), the temperature should have dropped by 10.2°C, while it dropped by 17°C what equals to 1°C every 100 m. The main reason for the difference is the sensitivity of DS18B20 sensor to wind, as it wasn't enclosed.

During the second launch, the air was humid. It means that with altitude, the temperature should have dropped by 0.6°C for every 100 m. The results (Figure 14) that the lowest temperature was 31.52°C, while the highest (on the ground level, few minutes after the landing) was 33.13°C. Considering the altitude of the flight (890 m), the temperature should have dropped by 5.4°C, while it dropped by 1.61°C what approximately equals to 0.18°C every 100 m. The main reason for the difference is the heat accumulated in the CanSat during the wait for launch as the windows in the sonde's case were much smaller in comparison to the windows in the casing that were used during the national competition (small, hexagonal vents during the European finals and big, rectangular vents during the national competition).

4.2 Pressure and altitude results

The pressure measurements were used in calculating the altitude of the CanSat. The obtained results are comparable with the apogees of the rockets used during the launch campaigns. The apogee of the Solaris rocket used during the first launch was 1700 m (±5%), while the apogee of the Sierrafox's DCLV (Dual CanSat Launch Vehicle) used during the second launch was 850 m (±5%). The highest altitude recorded by the sonde was 1685.79 m in the national competition and 891.21 m in the European competition (see Figure 12 and Figure 16). The highest altitude of the CanSat is almost identical with the apogees of the rockets.

From the altitude graphs, we can also read that the change of the altitude is linear, what means that the descent velocity was constant. It can be therefore concluded that the parachute worked properly.

4.3 First launch– sensors data

The readings of the temperature, humidity and illuminance show that the studied area is suitable for the growth of plants. The average temperature of 19.5°C is suitable for the vegetation in spring to bloom. Also, the illuminance level of 20 klx is sufficient for the growth of plants. The humidity level of 30%RH shows that the rain frequently occurs in the area.

4.4 First launch – images

The NDVI index calculated in the Błędów Desert shows that the highest values the index (0.75-1) takes in the forest highlighted in dark blue (see Figure 19). The forest in the bottom part of the image (highlighted in cyan) takes much smaller values of the index (0.2-0.5). This situation can be caused by 2 factors:

- The forest in the upper part of the image is older than the one in the lower part.
- The forest in the lower side of the image is being destroyed by a pest.

Some minor parts of the desert (highlighted in pink) take values of 0.1-0.15. This are the parts of the desert with residual vegetation. The remining parts of the desert take values below 0 what means that in these areas there is only bare soil without any plants.

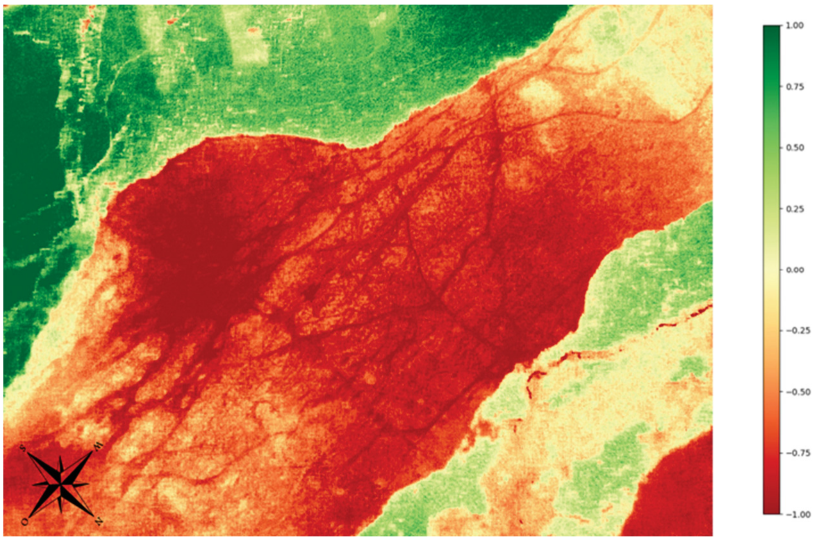

Figure 18. Calculated NDVI

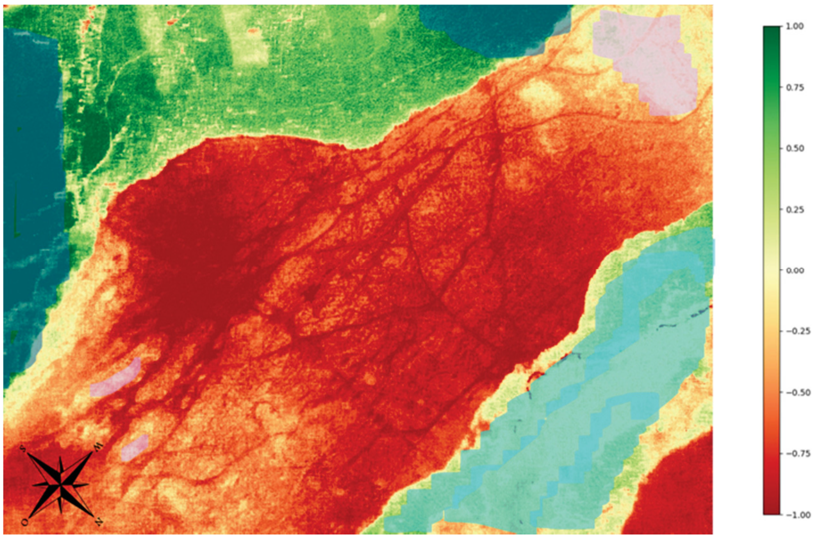

Figure 19. Calculated NDVI (with markings)

The GNDVI index, similarly as the the NDVI index, shows that the highest values the index (0.75-1) takes in the forest highlighted in dark blue (see Figure 21). It means that this forest is the oldest and the healthiest. The forest in the lower part of the image (highlighted in violet) takes smaller values of GNDVI index, than the forest in the upper part. This result proves that the main factor of this situation is the difference in age between the forests.

Some parts of the desert (highlighted in pink) take very high values of the GNDVI index (0.5-0.75). Those are the areas with old, residual vegetation, which are the leftovers from the 20th century experiments aimed at afforesting the Błędów Desert.

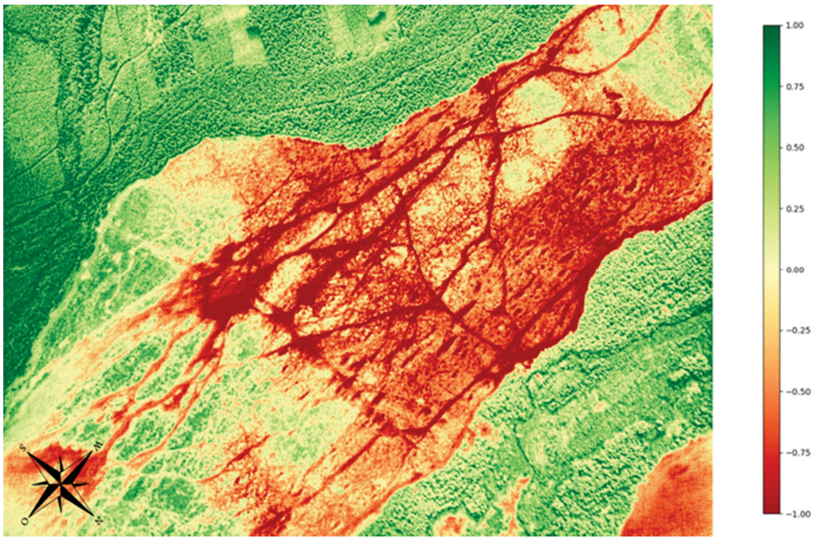

Figure 20. Calculated GNDVI

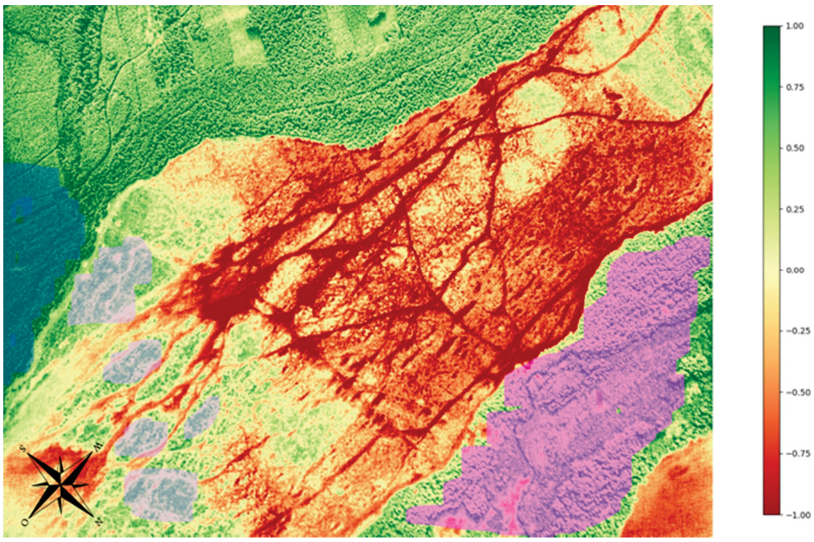

Figure 21. Calculated GNDVI (with markings)

The GI index (see Figure 22) shows that there is a lot of biomass in the forests and in the parts of the desert with residual vegetation, while the remaining parts of the desert have a little or no biomass.

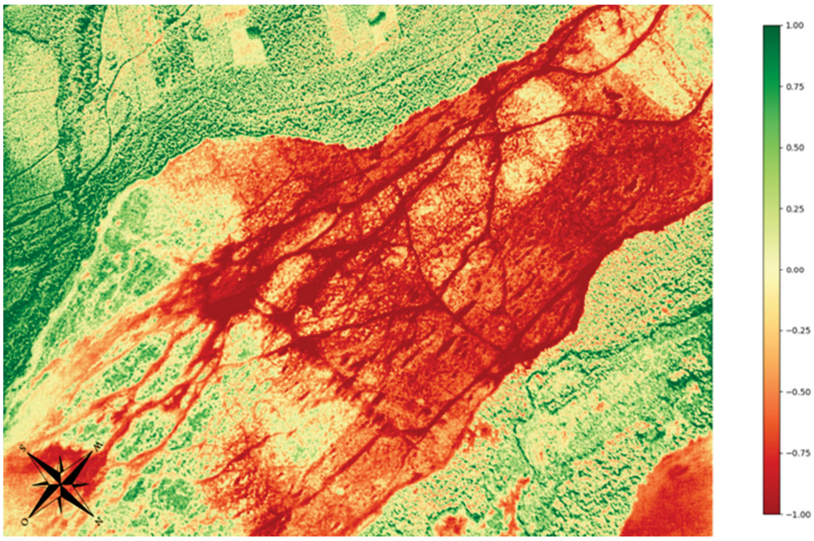

Figure 22. Calculated GI

4.5 Second launch – sensors data

The readings of the temperature, humidity and illuminance show that the studied area is suitable for the growth of plants. The average temperature of 32°C is suitable for the vegetation in summer to ripe. The illuminance level of 1 klx is insufficient for the plants. However, the sky was completely covered in clouds during the launch, so it can be assumed that the illuminance level is much higher (sufficient for the plants) during the cloudless or partially cloudy weather. Humidity level of 42%RH shows that the rain frequently occurs in the area.

4.6 Second launch – images

The NDVI index calculated in the fields next to the village of Molinella, Italy (see Figure 23) shows that the highest values of NDVI take the ripening crops, while the lowest values take the fields with cut and dry crops as well as bare soil (the areas where the crops have already been collected). The medium values of the index take the fields with cut and drying crops.

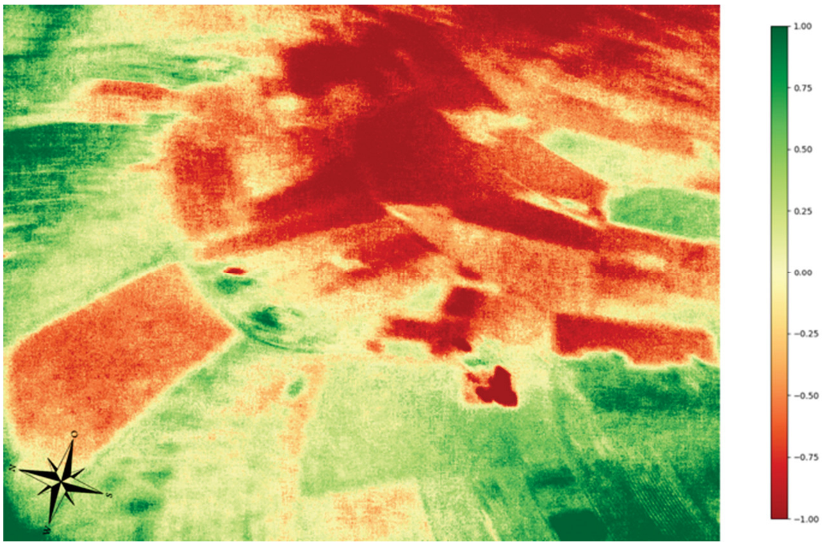

Figure 23. Calculated NDVI

The GNDVI index shows that the highest values of the index take the fruit and olive trees (highlighted in blue, see Figure 25), while the lowest values take bare soil as well as cut and dry crops. The crops take smaller values of the GNDVI index in comparison with trees. The reason for this is the length of life of each plant (trees grow for few years, while the crops grow only for few months).

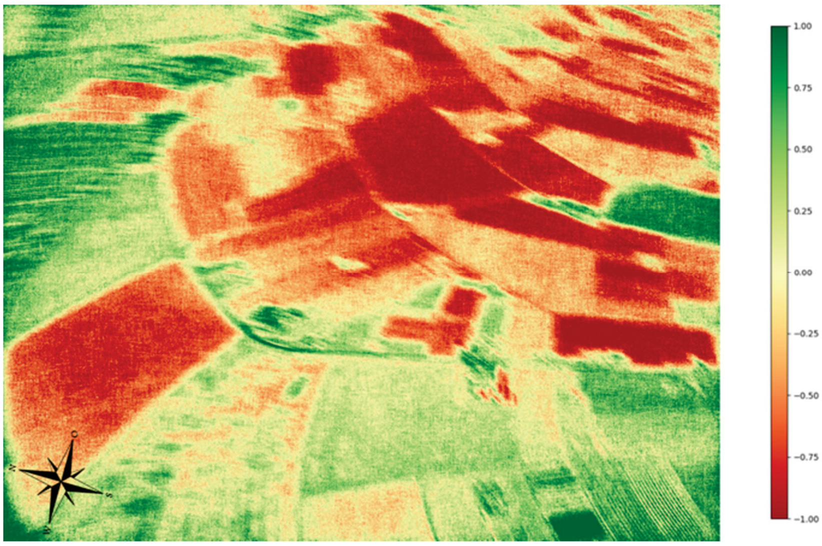

Figure 24. Calculated GNDVI

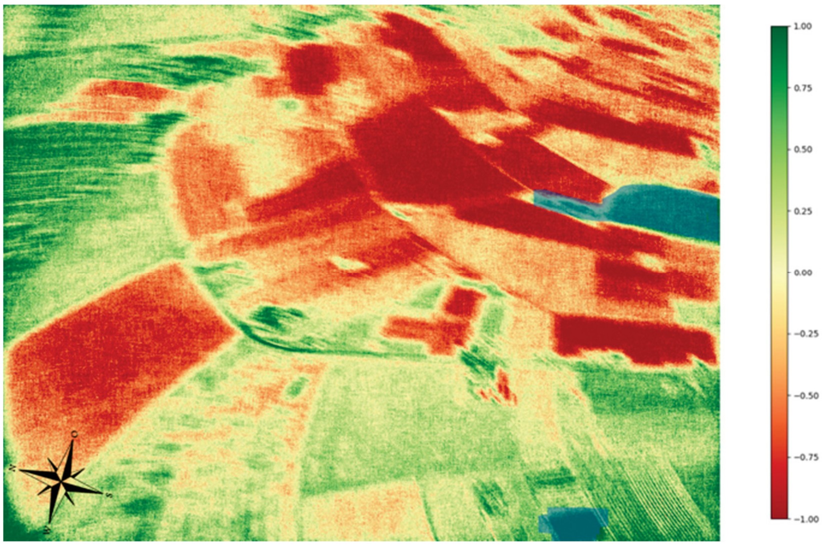

Figure 25. Calculated GNDVI (with markings)

The GI index (see Figure 26) shows that there is a lot of biomass in the fruit and olive trees orchards as well as fields with ripening crops, while the remaining part of the fields (with cut crops) have much less biomass.

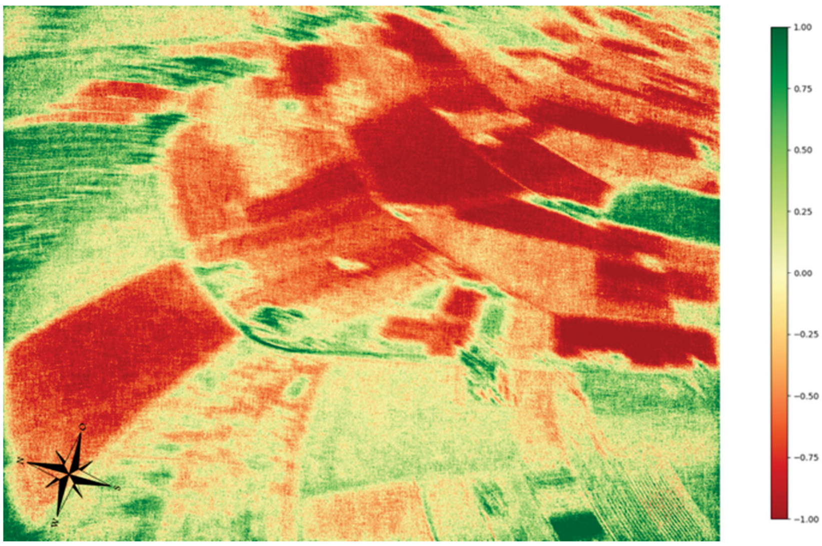

Figure 26. Calculated GI

5. Conclusions

The main goal of the mission was to develop a multi-purpose, reliable and low-cost device that can be used in remote sensing as well as measuring the weather conditions. As a result, such a device has been constructed. By minor changes in the camera (the optical filters), the CanSat can be used in many remote sensing missions. The device consists of very reliable components what ensures that the set task is completed accurately.

All goals have been completed. An accurate code for calculating remote sensing indices as well as a reliable hardware used for obtaining the results have been created. In near future, the experience and knowledge from constructing the CanSat is going to be used in building a quadcopter used for monitoring the health of forests, plants as well as fire risks.

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