Project SkyFall, Czech Republic

Final Report

Secondary technical school of electrical engineering and higher vocational school of Pardubice
&
Grammar school, Pardubice, Dašická 1083

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Ing. Vladimír Kašpar

We are team Project SkyFall from Czech Republic. Our CanSat was made to measure the index of habitability of another planets. For this purpose, we installed many sensors of different environmental properties. All the sensors are integrated on custom-made four-layered PCB's. All the parts are inside 3D printed cover with holders for some bigger electronic parts. We also achieved double-sided communication between the Ground Station and CanSat. The whole Ground Station was built in a suitcase. For taking control over the CanSat and for data processing we created custom GUI. The index of habitability was computed to 86.4, which means the landing site of the satellite is relatively good for human life. We had some minor malfunctions of some sensors, but we concluded the error was around 2 points. The index worked as expected and is a good way to find planets with possible human-like life.

I. INTRODUCTION

Hello, we are the team Project SkyFall, one of the competing teams in the annual CanSat competition held by ESA.

You can read up all details about our work on preparation for 2023 European CanSat Competition in this manuscript. This includes information about our mission, in-dept technical prospect of both CanSat and Ground Station including telemetry, live data visualisation and live data processing, testing, project management, outreach, and scientific results.

I.I Our team

Our team is still comprised of 5 students from SPŠE a VOŠ Pardubice and one student from Gymnázium, Pardubice, Dašická 1083. Here is a listing of the current team members and what each individual member does.

I.I.I David Haisman

David handles electronics and programming on our CanSat. He designed PCB’s, made some libraries, and wrote the whole CanSat code. During the development of the CanSat he gained a lot of experience regarding PCB design and programming in C++.

I.I.II Radim Leština

Radim oversees designing the outer construction of the CanSat itself. He has a lot of experience in designing and 3D printing mechanical contraptions.

I.I.III Lukáš Nastoupil

Lukáš designed and made the ground station, which is an essential part for our secondary mission. He designed the PCB’s, modelled, and programmed the ground station. He also worked on the real-time transmission of video from CanSat down to the ground station.

I.I.IV Václav Horáček

Václav oversees multiple departments, mainly the ones for documentation and recovery. In documentation he made the styles, graphics and oversees the documentation making process. His contribution in the recovery department is designing and sewing the CanSat’s parachute.

I.I.V Adam Keřka

Adam leads the team itself and the department of publicity. This mainly includes maintaining social networks accounts and communicating with sponsors. He also designed a lot of the graphics used in advertising and posts on social networks.

I.I.VI Vít Brázda

Vít is responsible for data visualization running on ground station, as well as making index of habitability of planet, where CanSat is landing. He has a lot of experience regarding Python.

I.I.VII Ing. Vladimír Kašpar

Ing. Vladimír Kašpar is our mentor in the CanSat competition. We chose Vladimír Kašpar as our mentor based on his experience. In the CanSat 2019 he was a mentor of team Charles the fourth that made it to the European finale. He is also an electronics teacher at SPŠE a VOŠ Pardubice.

I.II Mission Objectives

The primary mission objective was to measure temperature and pressure and send it at least once per second to the Ground Station, where it has to be visualised.

The objective of our secondary mission was to compute an index of habitability of the environment our CanSat is dropped into. For this goal, we measure data of many environmental properties, such as light intensity, concentration of oxygen and carbon dioxide and more, and based on the gathered data compute a point evaluation of the climate.

II. CANSAT DESCRIPTION

II.I Mission outline

As mentioned above, the secondary mission of our CanSat was to measure an index of habitability. Precise computing of this index requires isolation of data after landing of our satellite, because many environmental properties change when measured in higher altitude. For this purpose, we have program created in python that shows us charts of significant climate properties we measure as seen in the picture.

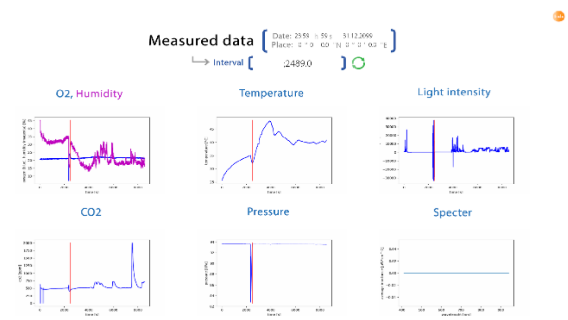


Figure 1: Live visualization of measured data

The program finds moment of landing of the satellite according to pressure dependence on time and shows it with the red line. After that, we can manually cut data after recovering the CanSat and delete any damaged data.

The cut data are then averaged and from the averaged values we compute the index of habitability. The values are passed into dependencies created based on scientific research. The result is number from 0 to 100, where 100 is the best planet for human life.

The dependencies consist of linear functions that are smoothly connected with quadratic ramps and pass through set points. We created these points based on scientific articles. An example of such dependence can be seen in the picture.

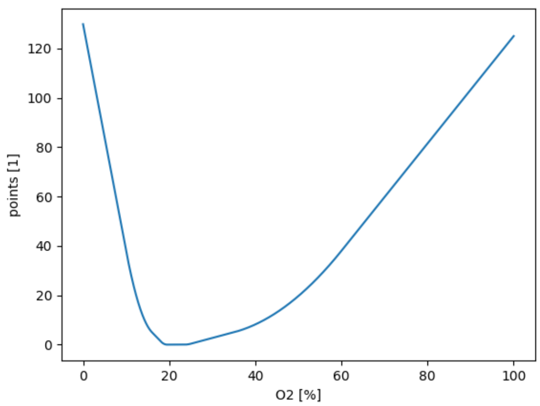


Figure 2: Subtracting reference for oxygen

This chart shows how many points we subtract from the final score for certain values of O2 concentrations. We can see, that between values 19.5 and 23.5 percent we subtract 0 points, because these values are ideal for human life. After that we start subtracting points at slower rate until the values of 18 and 35 percent. These values still allow human life, but are uncomfortable or cause some difficulties, for example higher oxygen values can cause higher chance of fires. After these values we subtract points faster.

We also set a ceiling of subtracted points because of one variable, because even if one environmental property is inconvenient, if the rest is fine, it can be compensated. For oxygen the ceiling was set on 70 points, because it is hardly compensated, but for example for humidity the ceiling is significantly lower.

Such dependence was created for every environmental property we measured. For each of them we researched possible difficulties and influences on the human body. Measured properties were concentration of oxygen and carbon dioxide in the atmosphere, temperature, humidity, pressure, and light intensity. Ceilings and perfect intervals for all the environmental properties you can see in the table.

Variable	Perfect-min	Perfect-max	Ceiling
Oxygen concentration	19,5%	23,5%	70
CO2 concentration	0 ppm	500 ppm	40
Light intensity	1000 lux	30000 lux	40
Humidity	30%	60%	40
Temperature	-5 °C	30 °C	40
Pressure	50 kPa	300 kPa	70

Table 1: Variable's ideal range and subtraction ceiling

Important thing to notice is that the Earth is not the best planet in terms of habitability. Similar indexes were made by official institutions and universities that concluded the Earth scored only 83%.

II.II Mechanical and structural design

Construction is divided into two main parts. The internal infrastructure and the CanSat cover.

The internal infrastructure is made of the Oxygen holder, the Battery household, and the Camera holder.

II.II.I Main structure

The main structure is made of four shredded rods, two aluminium plates and the CanSat cover.

Four shredded rods make main rails for everything in our CanSat (Power Unit, Control unit and internal 3d printed infrastructure).

CanSat cover is mounted between two aluminium plates. The aluminium plates are holding CanSat cover in his place.

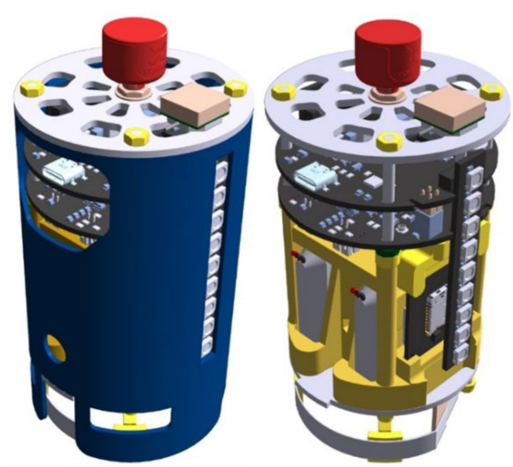


Figure 3:CanSat's main structure with and without cover

II.II.II Cover

The CanSat cover is 3d printed from the PETG material.

The biggest hole in the front of CanSat cover is there for easier way to manually control our CanSat with CanSat cover included. With it we can manipulate with DIP switches and reset button. USB C cable and micro-SD card can be plugged or unplugged through this hole.

Three vertical holes with 90° offset are holding Side Units. Side Units could be all time inserted in these holes, they aren't affected by CanSat cover movement, if we take it off.

With holes placed at the bottom of CanSat cover nuts M3 can be easily grabbed with wrench.

The hole under the biggest hole is there for easier way to manipulate with screw M3, which is holding Battery household, bottom aluminium, and Camera holder together.

Figure 4: CanSat's cover

II.II.III Oxygen holder

Oxygen holder is a 3d printed part, that supports the Oxygen sensor under the Power Unit. It is also holding the camera module.

It is attached to the holding rods with its three supports. One is missing since it made accessing the camera module significantly harder.

It has three arms with 3mm holes in them to fit between shredded rods. One arm is missing due to camera connector accessibility.

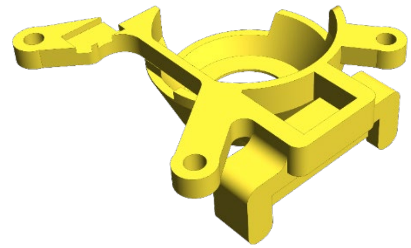


Figure 5: CanSat's oxygen holder

II.II.IV Battery household

The battery household is placed under the Oxygen holder.

It's supporting the batteries, so that they will stay in their positions and makes It easier to put CanSat together.

On the right side there is a camera PCB socket. With similar socket as in the Oxygen holder, together these sockets are holding this camera.

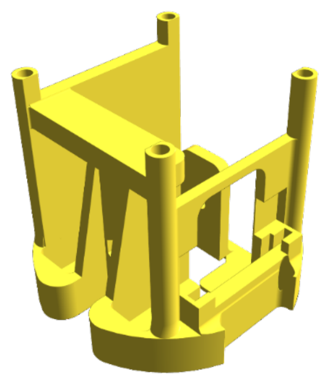


Figure 6: CanSat's battery household

II.II.V Camera holder

It's holding the camera on the bottom of CanSat. Thanks to the Camera holder, the CanSat cover can't be seen in the field of view of the camera.

It can be connected to the Battery household via one M3 screw with a M3 nut.

These two higher towers help to hold batteries to prevent side moves.

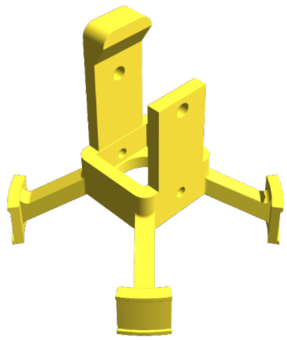


Figure 7: CanSat's camera holder

II.III Electronics

Without the electronics, the CanSat would just be a weight falling on a parachute.

With our electronics construction it is possible to power and gather data from multiple sensors to fulfil the requirements of our primary and secondary mission.

II.III.I Control

ESP32-MINI-1: microcontroller
CP2102N – QFN24: USB to UART converter
PT7C4339: real time clock
PCA8574: GPIO extender

II.III.II Power

104050: 2 in series connected LiPo accumulators
MAX1626: 3.3 and 5 V step-down regulators

II.III.III Sensors

BME280: combined temperature, pressure, and humidity sensor
DS18B20: secondary temperature sensor
SCD41: NDIR CO_2 sensor
INA219: power monitor (voltage and current)
BNO055: 9 axis inertial measuring unit
ME2-O2: electrochemical O_2 sensor
AS7265x: spectroscope triad
BH1730: light intensity sensor
Caddx Loris 4k: 4k analogue camera
NEO-M9N: GNSS system

II.III.IV Transmitters and receivers

TBS-UNIFY PRO32 NANO 5G8: FPV video transmitter.
RFM96W: LoRa 433 MHz transceiver

II.III.V Indication

WS2812E: 16x 5 V NeoPixel

II.IV PCB design

To avoid having a whole lot of cables in your CanSat for inconvenience's sake, a PCB (Printed Circuit Board) is ideal. A PCB can host a lot of sensors without taking much space.

This year we are using multiple four-layered, double-sided PCBs to conserve as much space as possible. To double down on this, we also fully integrate our sensors into the PCB's. Our PCBs now don't include any commercially available sensor's breakout boards.

The specific PCBs are the Power Unit, the Control Unit, and the Side Unit.

II.IV.I Control Unit

The Control Unit, as name suggests, is a PCB dedicated to control the whole CanSat. The PCB groups peripheries that only makes sense when used together (for example: microcontroller and RTC).

The Control Unit is capable of stand-alone completion of primary mission when suitable power source is provided.

USB-C has huge advantages over other USB type connectors. Nowadays it is the most used connector offering highest transfer speed (that is not used due to speed limitation of USB to UART converter), highest current and it is over time the most mechanically stable USB type connector.

Two buttons are mounted in case that the auto uploader does not work.

The CP2102N converts USB data to UART. 2 LEDs are used to indicate active communication between the microcontroller and the host computer.

A Square hole is placed in the middle of the board because of a SMA connector placed on top plate and its connector extends through top unit. U.FL must go through the Control Unit, so hole size and shape is adjusted to this.

Three battery connectors are used to created contact between the Control Unit and each Side Unit.

A separated ground plane is created for DC-DC converter. This ground plane is than connected to global ground through 0 Ω resistor.

A push-push microSD card slot is placed at the bottom side of Control Unit, right under the USB C connector. Thanks to this, the microSD card can be removed without the need of disassembling whole CanSat construction. The push-push slot has an advantage over push-pull slot, that being that the inserting and removing card is easier and the slot can be placed further from board' edge.

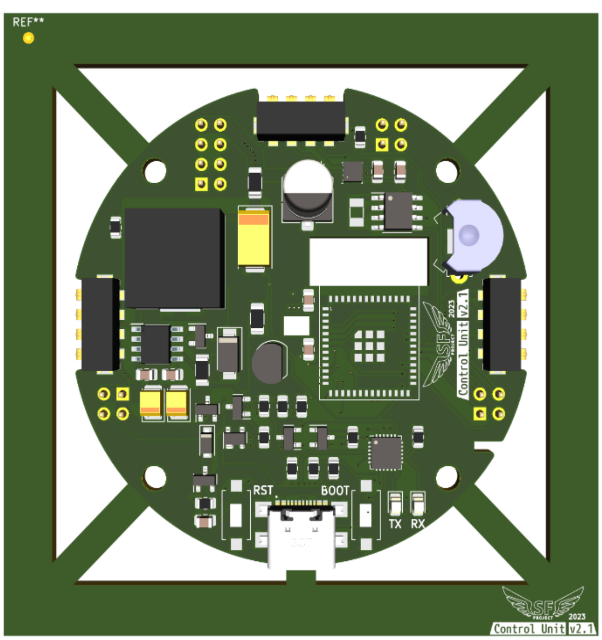
A U.FL connector is used to connect RFM96W to the unique CanSat antenna at the bottom of construction. The track connecting module to this connector is narrow as possible to limit RF leakage.

DIP switches are used control some of CanSat's features.

In the integration manual of ESP32 microcontrollers is a mention, that at least 15×10 cm spare area is needed for proper Wi-Fi functions. This is not possible in CanSat so right under PCB antenna of ESP32-MINI-1 square hole is created to try balance out this design violation.

The PT7C4339 requires some kind of backup power source. It is nearly impossible to find miniature a 3 V power source. One option was to use a supercapacitor and keep it charged with built in trickle charge function. In the end, two different 1.55 V batteries are placed into battery holder originally designed to hold only one battery. To avoid a short circuit, little bits of electric tape are used to prevent batteries from an unwanted contact.

In a bit of spare place, a pin and a DIP switch legend is printed out to make working with the CanSat easier.



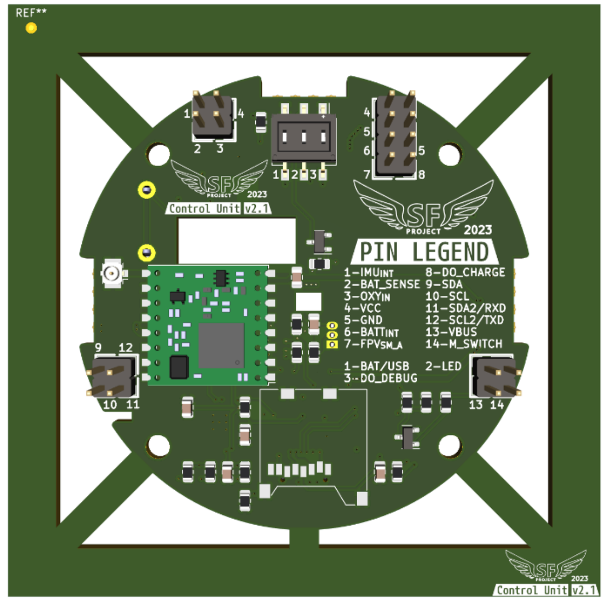


Figure 8: CanSat's PCB - Control Unit (top and bottom)

II.IV.II Power Unit

Power Unit v2 is a succeeder of Power Unit v1 from CanSat 2022, whose purpose was solely to regulate and distribute power across other PCBs. Power Unit v2 still use this name although beside power distribution it hosts most of the CanSat's sensors and peripheries.

The accumulators are connected through JST-PH connectors. Charging and balancing of those accumulators is done via external charger and balancer connected through 3-pin JST-PH. Charging is disabled when CanSat is on.

The input power is monitored with INA219A. Kelvin connection ensures that the current is measured with high accuracy.

An 8-bit GPIO extender controls some of sensors and peripheries. Spared pins are connected as inputs to some sensors.

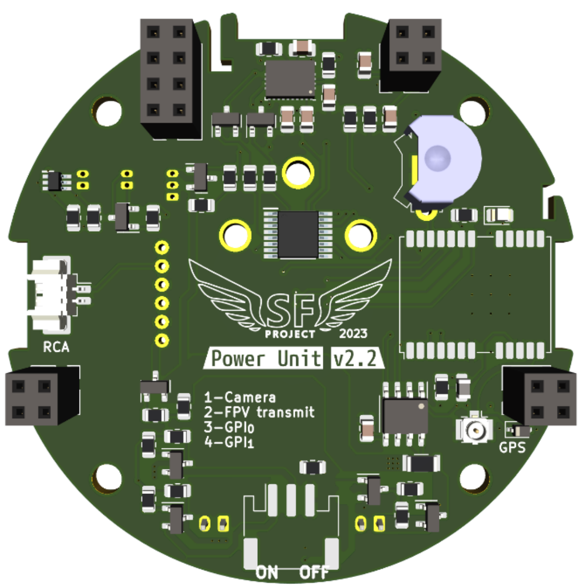
Whenever the GNSS module is controlled with UART or I2C1 depends on the jumper position. By default, NEO-M9N communicates via I2C1. To indicate GNSS's fix LED is mounted. When power is removed, IC automatically switches to backup power. Impedance isolation of bus pins is required.

Same as on Control Unit, the MAX1626 regulates accumulator voltage to stable 5 V. This voltage then goes to Control Unit, where it is used to power up LEDs on Panel 2 & 3 and as input for another MAX1626 that creates stable 3.3 V. To filter out nasty high frequency noise on power line, set of tantalum capacitor is used.

The camera is connected to the Power Unit with set of Molex PicoBlade connectors. The camera's control board is modified to enable electronical controlling of the camera. The RX and TX pins are mounted on a control board, but manufacturer does not offer any documentation over this topic. The board doesn't react on any given baudrate. Camera is now controlled with transistor that "pushes" the built-in button.

The analogue video output from the camera can be easily transmitted through an RCA cable. A Molex PicoBlade connector is mounted specially for this cable.

The FPV transmitter is mounted on pin headers to be easily removable and reusable. To secure it in place, a special platform is put underneath it.



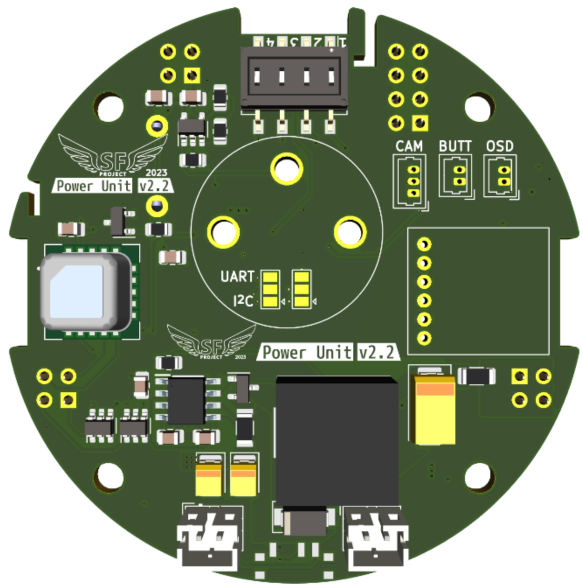


Figure 9: CanSat's PCB - Power Unit (top and bottom)

II.IV.III <u>Side Unit</u>

Side Unit in fact consist of three separated board or as we call them, Panels. These Panels are placed perpendicular to other CanSat's PCBs and connected to the Control Unit through pads on back side. These pads create contact with battery connectors.

All light dependent sensors are placed on Panel 1. This includes a triad spectroscope AS7265x and a light intensity sensor BH1730.

Remaining two Panels are each filled up with eight RGB addressable LEDs. Every LED serve as a status indicator of each sensor or periphery. LEDs are and the turned off or lit up on low power. LEDs. WS2812E can be boosted up to ease finding CanSat in conditions with lowered visibility.

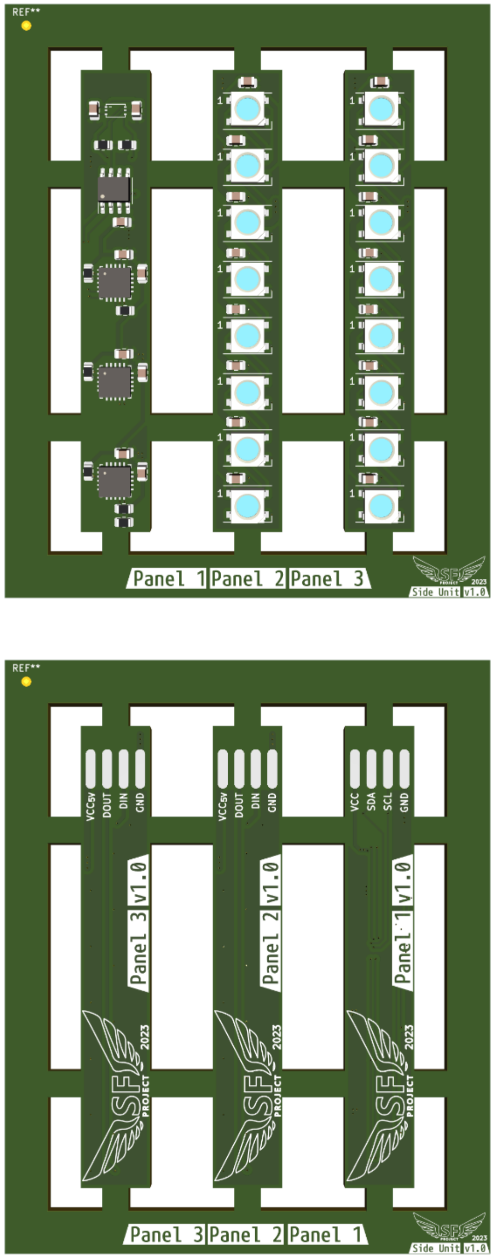


Figure 10: CanSat's PCB - Side Unit (top and bottom)

II.V Software design

CanSat's software is written in Platformio, Visual Studio Code's extension. This extension is well known for offering Visual Studio Code environment and functions, runtime debug, Git source control, full Arduino's Wiring library implementation and much more, while keeping things easy to use with integrated compiler, uploader, terminal, and Serial monitor.

Software itself runs dualcore with help of FreeRTOS operating system. Several security features like watchdog and wireless controlled interrupts are used to ensure smooth operation.

Each sensor has own class that makes software clear to read and more Arduino friendly.

Most of the sensors consists of three individual class methods: *setup*, *getData* and *printData*.

II.V.I Setup

At the very beginning, all buses are started.

After that, each in dividual sensor and periphery runs through its own setup function.

Then things related to FreeRTOS are created like semaphores and tasks itself.

II.V.II Get Data Task

This is the main CanSat task that handles getting data out from all sensors and peripheries, saving data to removable storage, and sending data to Ground Station.

Status of each sensor is set to *Status_NACK*.

Tasks responsible for handling slow peripheries are resumed for async read-out on second core.

Data are then read out from rest of sensors.

Software waits until task handling slow peripheries are done or until max wait time passes.

Data are then sent to Ground Station and saved to already opened allocation space on microSD card.

Task once again suspends itself until saving to microSD card is done or until max wait time passes.

Status and measured data are then printed out from now resumed *printData task*.

Task finally suspends itself for duration remaining to start of next cycle.

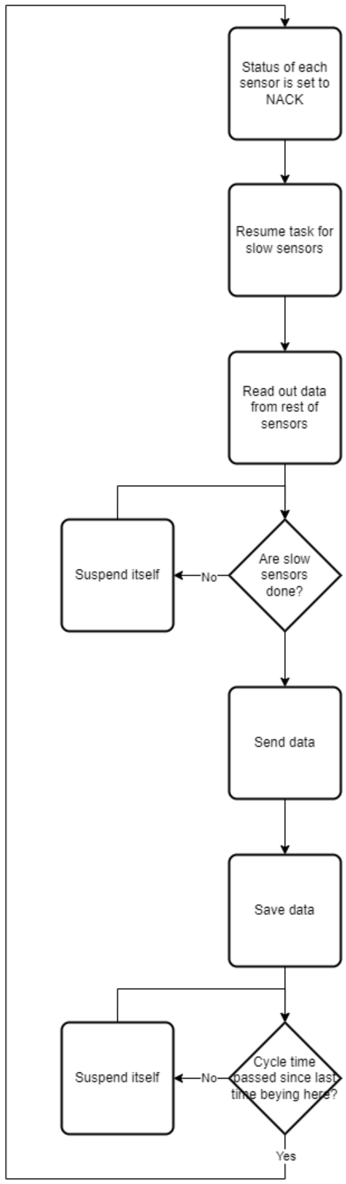


Figure 11: CanSat's software - Get Data Task flowchart.

II.VI Recovery

Every CanSat in the competition should be able to survive more than one trip in the rocket. A large contribution to this probability is to have a recovery mission.

While there are many ways of safely getting your satellite from the sky back on the ground safely, by far the easiest is to make a parachute.

There are many important things to take into consideration while making a parachute, most notably what shape you want your parachute to be, how fast you want the CanSat to fall and how you want to attach it.

II.VI.I Parachute shape

The parachute's shape is mostly determined by the way you want to attach it to the CanSat. For our purposes we chose an octagonal shape since we only have four structural rods, and a square parachute is rather impractical.

The shape of the parachute also changes the drag coefficient Cd. Octagonal parachutes have a drag coefficient of 0.8.

II.VI.II Physical properties

The rules of the competition subject us to make a satellite in the mass range of 300-350g. After some thinking we estimated that our CanSat will have a mass m of 330g, so we went with that.

We are aiming to achieve a falling speed v of 8m/s, which is the lowest that the competition rules allow us to. The reason behind this exact speed is to have the longest flight possible for gathering as much data as we can.

However, these parameters aren't the only ones regarding the calculations, but are the main ones, nonetheless. Other parameters are the air density ρ, since the air get less dense the higher you go. The same happens with the gravitational acceleration g which also decreases the higher you go.

The area of your parachute is determined by this equation:

$$S_p = \frac{2mg}{v^2 \rho C_d}$$

II.VI.III Parachute manufacturing process

Now that the parachute's area is calculated, the process of making a parachute can begin.

The parachute is made of parachute nylon, which is ideal because it is light and durable, this year we chose a pink parachute, since it is much easier to lose int the sky.

The shape of the parachute is drawn onto the sheet of nylon and then cut out via a soldering iron; this is because the heat prevents the edges from tearing. A spill hole is also cut out to balance out the parachute.

This year, eight strings are used to attach the CanSat to the parachute. The strings are tied into the parachute via clews. Clews are place on the edges of the parachute.

Figure 12: CanSat's parachute

III. GROUND STATION DESCRIPTION

The ground station is a key component for our secondary mission.

The device is capable of double-sided communication and able to run the visualization script to run real-time data analysis. The ground station is mostly the receiving end to the double-sided communication between is and the CanSat.

III.I Construction

New model of Ground Station uses a “in-suitcase technology. That means, that every Ground Station component is fit right inside the suitcase and no other component is necessary for operation.

Figure 13: Ground Station's "in-suitcase" technology

The circuit board cover is made of two parts, the top and the bottom part. Both parts are connected by a threaded rod, which also works as a joint. On the bottom part there are holes for mounting the main circuit board. To keep the cover closed, M3 nuts are glues in bottom part in their printed holders. On the right side, there are four M3 holes for mounting the display cover.

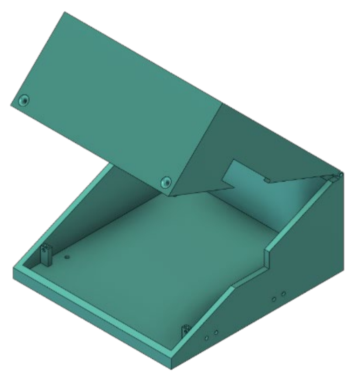


Figure 14: Ground Station's circuit board cover

The circuit board cover is then lowered into cut foam, inside the suitcase.

III.II Electronics

III.II.I Control

Raspberry Pi 4B: microprocessor
Lenovo laptop: monitor

III.II.II Power

3s 5500 mAh LiPo accumulator

III.II.III Sensors

BME280: combined temperature, pressure, and humidity sensor
ADS1115: ADC of battery voltage monitoring
GY-NEO6MV2: GNSS system

III.II.IV Transmitters and receivers

RFM96W: LoRa 433 MHz transceiver
EWRF OTG 5G8 receiver: FPV 5.8 GHz transceiver

III.III PCB design

There are three printed circuit boards in the ground station. Two of them are simple breakup boards, which convert the 2mm spacing to 2.54mm. The last and most important one is the main board. The main board contains all electrical components in the ground station.

III.III.I LoRa breakout board

This board is used to convert 2mm spacing of LoRa module to standardized 2.54 mm spacing. Eight and six pin headers are used as a connector into the main board.

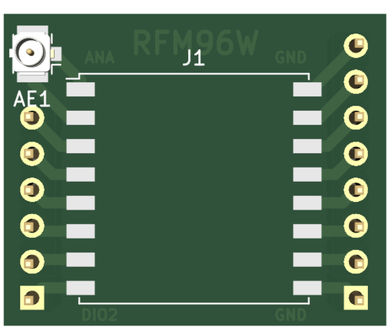


Figure 15: LoRa breakout board

III.III.II Stepdown breakout board

This board is used to convert SMD Stepdown converter to standardized 2.54 pitch. Two pin headers are used as a connector into the main board.

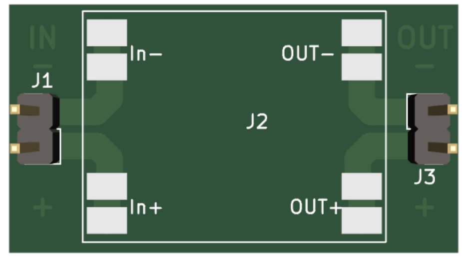


Figure 16: Stepdown breakout board

III.III.III Main board

This board connects every module together and contains control elements. There is two parts on this board.

First part is power supply. On the board there is a battery holder mounted for two batteries. These batteries are connected in series and led to the stepdown breakup board input. The negative path is brought up to the power switch. From the stepdown breakup board output is the voltage led to the power connector.

Second part is the control and sensor section. Raspberry pi is located there, and it is connected to the other sensors. Power for the sensors is also distributed in this part.

Connectors used for the power switch and for the power connector are JST-XH. From these the power is distributed into desired places.

All modules and breakup boards are attached to the boar by M2 and M3 distance pillars. This makes the ground station quite stable.

Display and FPV receiver are connected directly to the Raspberry Pi. Display image is connected via VNC over Wi-Fi. Power of the display is secure by USB power cable. FPV receiver is wired up using data USB 3.0 cable.

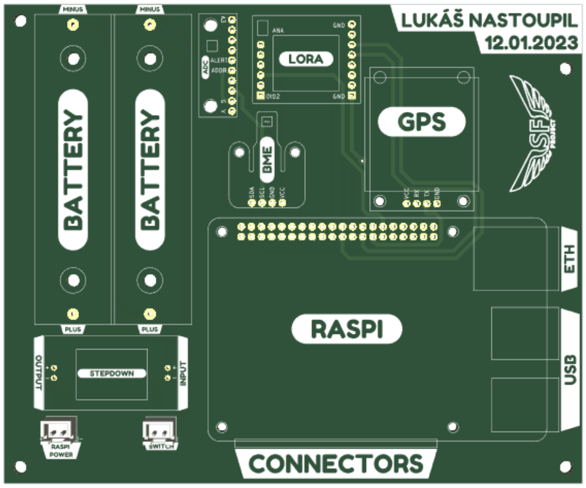


Figure 17: Ground Station's main PCB

III.IV Software

The Ground station is programmed in Python. Python is by far the most used language on Raspberry Pi. There also is a giant community around this language. The program is divided into four separated scripts. Each one can work independently of the others.

III.IV.I I2C communication script

This script handles communication via I2C bus with BME280 and ADS1115 and reads data out of them. The script reads data out of the sensors and then edits them the into desired form and then they are saved into a file for the next use.

III.IV.II UART communication script

This script handles an UART communication between the Raspberry Pi and the GNSS module. The communication is established on port ttyAMA1 which is the second hardware UART port on Raspberry Pi. The baudrate is set to 9600.

Each message from the module is recognized by the code at the beginning of the message. Desired messages are decoded and received data is saved into a file for further use.

III.IV.III SPI communication script

This script handles communication between Raspberry pi and the LoRa module connected on SPI bus. It starts with hardcoded a sync word to one of the registers of the module. After the LoRa module receives the packet, it sends the response immediately. Then the received packet is decoded and checked by implemented check sum. The last step is to save data into a file. This script also controls the communication in the opposite way. So once there is a command typed into a GUI script, it will load the command into the buffer. In the next cycle, the command in the buffer is sent with the response message.

III.IV.IV Data editing script

The final script's task is to load all the data from the files and reorganize it in the desired order. The remaining data are also calculated, such as the height between the ground station and CanSat. Lastly, organizing the data into a final file, which is used by the GUI. This script also saves the flight data over time for the flight analysis.

III.V GUI

GUI is a shortcut for Graphical user interface. It is a type of interface that allows users to interact with the script through graphical icons. In our project, we use GUI as a tool for visualizing acquired data. The visualization script is running on the ground station. It is coded in Python using the library Pygame. Charts are created using the library Matplotlib.

Our program is divided into 3 main phases.

III.V.I First phase

The first phase is for visualizing data in real time measured by the satellite during the fall. GUI will also be showing the data after the satellite lands.

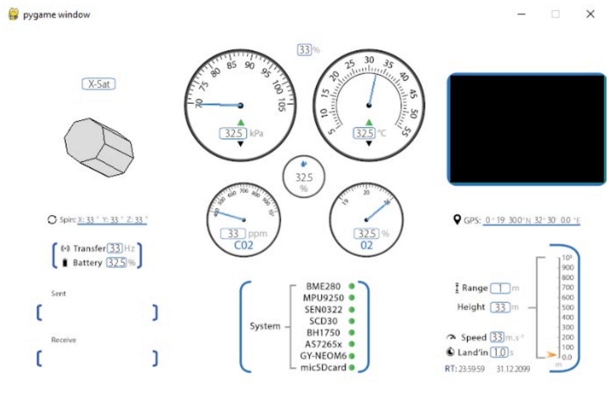


Figure 18: GUI - first phase

We are visualizing many variables on dials and with text. In the top right corner, we have camera video from CanSat and in top left corner model of CanSat, on which we show rotation of our satellite. This model is computed as octagonal prism. We use multiple symmetries to reduce the number of computed points to three.

By the time we finish demonstrating the control over the CanSat on long range, the program will move to the second phase.

III.V.II Second phase

Second phase reports stored data that the ground station received during the first phase. This phase is designed for making a preview of received data through charts and their following modification.

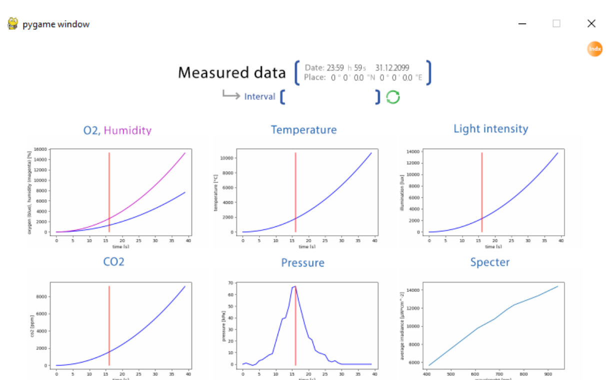


Figure 19: GUI - second phase

When starting this phase, the program will offer us how to cut the data. This is computed by development of pressure chart to get the most relevant for last phase. If we are not satisfied with the offered cut or see any damaged data, we can adjust the cut using time interval. If we delete relevant data by mistake, we can always reload all data.

III.V.III Index of habitability

From the second phase of the GUI, we can run computing of index of habitability of planet CanSat is landing on. For most precise computing, we must carefully choose how to cut data in second phase, as any damaged or unwanted data could result in wrong value of this index.

For more information, see [Mission outline].

III.VI Telemetry

An important part of CanSat's mission is telemetry, that is responsible for bidirectional communication with Ground Station.

Telemetry runs on two frequency bands.

III.VI.I 433 MHz

All measured data are sent with LoRa™ modulation on 433 MHz frequency.

The maximal allowed transmit power is established by Czech laws to 10 mW. When operated by person with necessary certificates, transmit power can be boosted up to CanSat's maximal 50 mW.

Transmitting and receiving is done through same antenna that has been specially designed for our CanSat. Type of this antenna is called "Inverted F". It is a small antenna with high gain and good shape parameters.

The Antenna is built-in to CanSat, and it is not exceeding CanSat's height. In fact, antenna is barely visible.

The Ground station receives and sends data through 5 elements Yagi antenna build from PVC pipe. Antenna is then connected to Ground Station through 3 m long SMA cable.

Figure 20: CanSat's inbuilt "inverted F" antenna

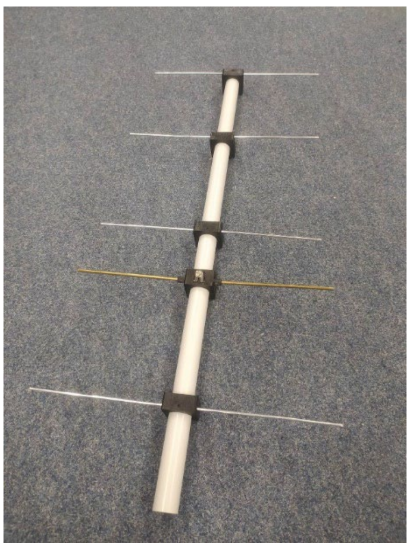


Figure 21: five element Yagi antenna for Ground Station

III.VI.II <u>5.8 GHz</u>

This band is used for CanSat's FPV video transmitter.

The maximal transmit power established by Czech laws is 25 mW, but same facts in 433 MHz applies here. Maximal transmit power could be as high as 300 mW.

A small omnidirectional SMA antenna is mounted on top of CanSat. This small antenna than handles FPV transmit.

Ground Station is equipped with directional 5.8 GHz antenna, that will significantly boost transmit range.

Figure 22: CanSat's 5.8 GHz antenna

Figure 23: Ground Station's 5.8 GHz directional antenna

IV. TESTING

Testing is an important part to every project. In our case testing was done in many places over the time.

IV.I Technecium's stratoballoon

Our CanSat's electronics was sent into the stratosphere via a stratospheric balloon.

Thanks to our Lo-Ra module the balloon was later found after the landing.

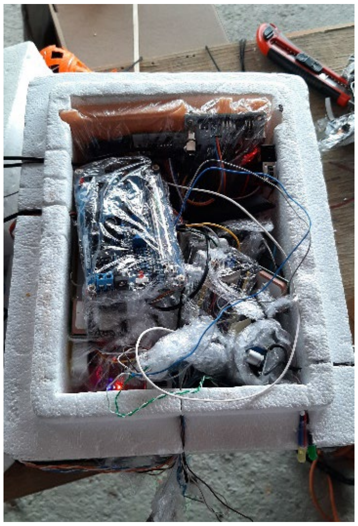


Figure 24: Payload of stratoballoon

IV.II The national finale of 2022

In the national finale of 2022, our CanSat worked fine the whole way. We got data from the beginning to the end of the launch and the fall. Our CanSat collected the data and the visualization then made graphs from them.

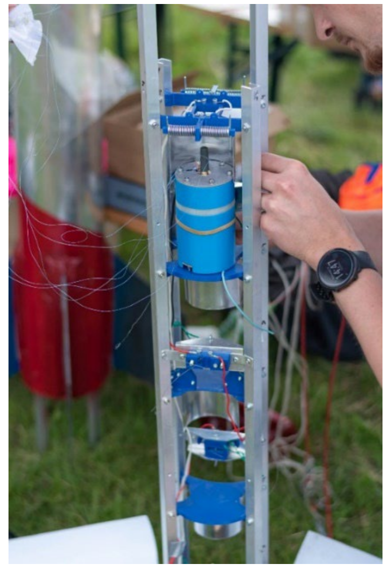


Figure 25: Our CanSat 2022 inside rocket

IV.III The national semifinals 2023

In the CanSat semifinals of 2023, we tested our communication and our ground station.

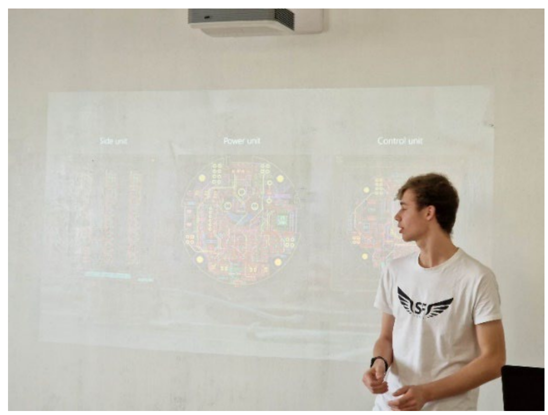


Figure 26: David presenting PCBs on National semifinals 2023.

IV.IV Technecium sessions

Most of our work on the CanSat was made in the 2023 Technecium sessions. We once again tested our double-sided communication and sent packages back and forth. We also tested our new CanSat boards, which work as intended.

IV.V Parachute testing

Our parachute attached to a bottle filled up with water was thrown off the Technecium building to find out if it will serve its purpose. It fell for 2 seconds from a 16-meter-tall building. That means that the targeted falling speed of 8m/s was achieved.

Figure 27: Parachute testing bottle

V. PROJECT MANAGEMENT

During our project, correctly managing our tasks and communicating with our sponsors was one of the most important things. We managed to gain many sponsors who helped us financially, by providing electronic parts or by sharing know-how.

V.I Project planning

The work on our CanSat was split into different departments. Every person had been assigned at least one department as his main responsibility, but everyone could contribute with his ideas and proposals into the other departments. When certain part of our satellite was finished, testing session was scheduled. We started working on our current satellite in september and ultimately worked towards a deadline of the national semifinals.

V.II External support

Due to the limits of team composition, we have some special people that helped us in one way or another that we cannot include in our team. Here is a listing of them:

V.II.I Jan Novotný

Jan Novotný is a freelance developer who makes web and mobile applications. He programmed the Project SkyFall webpage and supports our team on various other competitions and outgoings.

V.II.II Ing. Zdeněk Nosek

Ing. Zdeněk Nosek is an electronics teacher at SPŠE a VOŠ Pardubice that also has a little bit of experience with CanSat competition.

V.II.III Ing. Petr Bubák

Ing. Petr Bubák is an electronics teacher at SPŠE a VOŠ Pardubice who gave us many useful pieces of advice about electronics.

V.II.IV Tereza Truncová

Bc. Tereza Truncová is a graphics teacher at SPŠE a VOŠ Pardubice who helped us with making identity of this team and several graphics.

V.III Sponsors

Special members of our team are our sponsors, who help us finance our ideas, but not just that. We always could communicate with them any bug or just things we aren't sure about. Finally, is propagation. Some of our sponsors offered to share our project on social media or write an article for example. Thanks to them our publicity has an even bigger impact.

V.III.I LaskaKit

LaskaKit belongs to the biggest e-shops with electronics and microcontrollers in the Czech Republic. Most of the electronics we have used come from their racks.

Source: https://www.laskakit.cz/

V.III.II T-CZ

T-CZ is a successor of the well-known Tesla Pardubice in radiocommunication. The company helps us with telemetry and provided us with an aluminium part of CanSat that we designed. We often visit them to communicate any troubleshooting or just thing things we want to help with.

Source: https://www.tcz.cz/

V.III.III FYFT

FYFT is a store focusing on free-time activities including building drones. FYFT gave us a tiny camera with 4K resolution.
Source: https://www.fyft.cz/

V.III.IV Voltio

Voltio is a store installing smart home devices and offering 3D printing as a service. Voltio purchased a filament we chose and printed for us most of construction in CanSat.
Source: https://www.voltio.cz/cs/

V.III.V Espressif

Espressif is one of the biggest world-wide companies when it comes to microcontrollers and chips. They provided us with chips and microcontrollers.
Source: https://www.espressif.com/

V.III.VI Foxconn

Foxconn is one of the biggest world-wide companies when it comes to electronics. Foxconn financed our project.

• Source: https://www.foxconn.cz/

V.III.VII RPi shop

RPi shop is the only official shop providing Raspberry in the Czech Republic. They offered us electronics.
Source: https://www.rpishop.cz

V.III.VIII Technecium

Technecium is a free-time centrum that provided a workplace for us to hold our developing sessions.

V.III.IX Schools

Special thanks go to our schools GYPCE and especially SPSE that also finances our project.

• Source: https://www.spse.cz/
• Source: https://www.gypce.cz/

V.IV Outreach

The goal of our publicity department is to inform as many people as we can about the CanSat competition through our project. To accomplish such a goal, we use multiple social media accounts, our website, articles, posters, and through other events, such as technical exhibitions. We are trying to make all our posts and media in English for better readability for non-Czech speaking people.

We tend to advertise mainly to technical groups and companies.

V.IV.I Identity

Every group of people, from a large company to a small team, should have their own identity before trying for any form of publicity. Identity should express culture and mainly make society unique. It may be for example the name of the organization, logo, or design that's specific to it.

Figure 28: Black and white version of team logo

V.IV.II Name

Our team's name is "Project SkyFall". This is the only right version of how it should be written. SkyFall is a conclusion of Sky and Fall, therefore there are two capital letters in it. Word "Project" is also part of the name. Based on our experience this is the most common mistake.

V.IV.III Logo

Our logo was designed in Illustrator version 2021.Logo mainly express fall of the CanSat and signifies team's name by capital letters S and F and small "project" bellow. There are two colour versions, black and white. These colours represent our team the most.

V.IV.IV Social media

Social media is one of our most significant, when it comes to propagation. We have active accounts on Instagram and Facebook.

Instagram

Our most attended social media platform is Instagram. There we created a public account: the_project_skyfall, by the beginning of the year 2022. On the profile we share news about our project and propagate the CanSat competition.

Source:
https://www.instagram.com/the_project_skyfall/

Instagram analytic tool insights doesn't visualize profile data that is older than 3 months. Therefore, we are going to share with you most of the profile numbers in interval of 3 months.

There were 357 accounts that we reached in this interval. Reach is a number of unique accounts that have seen your content, at least once.

49 of accounts that we reached, somehow interacted with our content. Interaction may be for example likes, comments, shares, or saves.

Total followers that we get since we've created the project account is 120. That is about 39 followers more than last year.

We have connected Instagram account with our Facebook website. That means these accounts are synchronized. So, when you want to release a post, you can synchronize this action and take it at the same time.

Facebook

Our Facebook website serves mostly for people who doesn't have an Instagram profile. Otherwise, we don't use it because there isn't our target group. Therefore, we don't have a significant impact here.

- Source:

https://www.facebook.com/theProjectSkyFall

Website

Our website is written in a library which allows you to create your own server called Express. You can use more utilities such as graphs from values measured by CanSat and 3D model of our satellite.

Source: https://www.projectskyfall.cz/

V.IV.V Articles

Since we have participated in CanSat for our first time in 2021 we have published several articles mostly on the websites of our sponsors. However, we have also published an article in a school magazine Elektronka.

School

Both schools provide us opportunities to propagate our project via websites. We also wrote an article in a school magazine Elektronka.

T-CZ

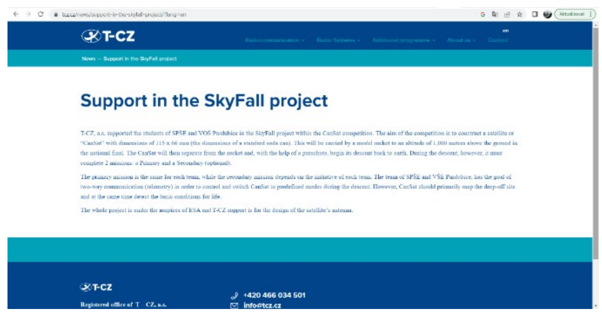


Figure 29: T-CZ project promotion

Source: Webpage link

FYFT

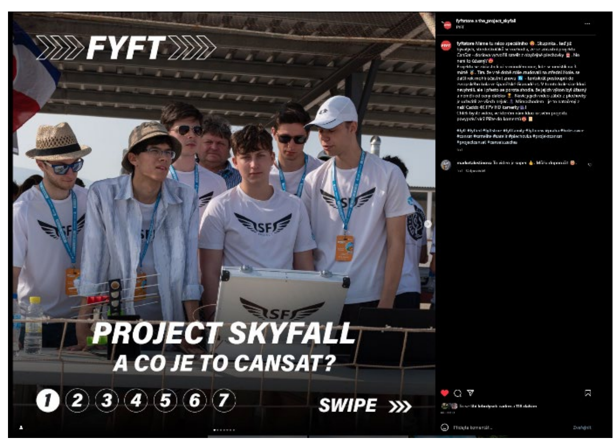


Figure 30: FYFT project promotion

Source: [Instagram link]

YATE

Figure 31: YATE project promotion

Source: Facebook link

Foxconn

Figure 32: Foxconn project promotion

Source: Facebook link

V.IV.VI Events

We have participated in many events since we registered in CanSat for our first time. These events help us to earn new sponsors and propagate our mission. Previous year we took part at Maker Faire Prague where we get a new contact and get to know people with the concept of CanSat competition. This year we participated in Amavet competition, where we had also chance to show wide audience what is a CanSat.

We have also participated on Maker Faire this year, where our CanSat interested many people. We were also invited to Maker Faire Hannover.

StreTech is a show of high school student projects organised by ČVUT, Czech technical university in Prague. We had there our stand, where we presented our project and the CanSat competition.

VI. SCIENTIFIC RESULTS

We managed to acquire approximately 2000 datapoints between landing of the rocket and recovering the CanSat. You can see charts of the environmental properties in the picture.

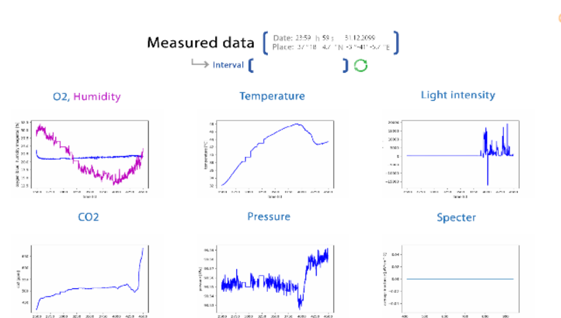


Figure 33: Live visualization of measured data

After averaging this data, we got following values.

Variable	Averaged value	Relative deviation
Oxygen concentration	(21,38 ± 0,28) %	1,31%
CO2 concentration	(506,6 ± 17,87) ppm	3,53%
Light intensity	(4065,3 ± 3198,8) lux	78,69%
Humidity	(20,27 ± 4,56) %	22,50%
Temperature	(42,58 ± 3,66) °C	8,60%
Pressure	(93,56 ± 0,01) kPa	0,01%

Table 2: Variable's averaged values and relative deviation

We found that values of oxygen concentration, pressure and light intensity were suitable for human life. The concentration of carbon dioxide only exceeded perfect values (0-500 ppm) by a little. Slightly higher concentrations of carbon dioxide can cause tiredness, but in open areas its effect is not significant, so only a small number of points was subtracted.

However, more points were subtracted because of temperature and humidity. The temperature value is higher than the normal values by 10 °C. Temperatures this high can lead to tiredness, dehydration and can cause lack of green plants. Especially in combination with low humidity we also found on landing site. Low humidity can cause similar effects as high temperature as the lack of air in the air affect the human body to sweat more.

Combination of these two main factors in the end resulted in index value equal to 86.4. More detail about subtracted points can be seen in the picture.

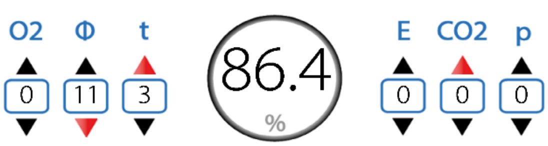


Figure 34: Index of habitability

VII. DISCUSSION

Our index of habitability showed that the Earth, at least the environment at the landing site in Granada, is good enough environment for human life. Some complications can occur because of the combination of low humidity and high temperature, but even without any interventions in the environment people can survive here.

The main thing to improve are the methods of gathering data. As we can see in averages table in previous chapter, the deviations of some of the measured environmental properties are too high. The deviation of pressure, oxygen and CO2 concentrations and temperature are relatively small, meaning the measurement of the sensor was fine. The issue was humidity sensor and especially the light intensity sensor.

If we take a closer look on the data gathered from these sensors, we can identify the causes of these deviations. Firstly, let's look at the light intensity chart.

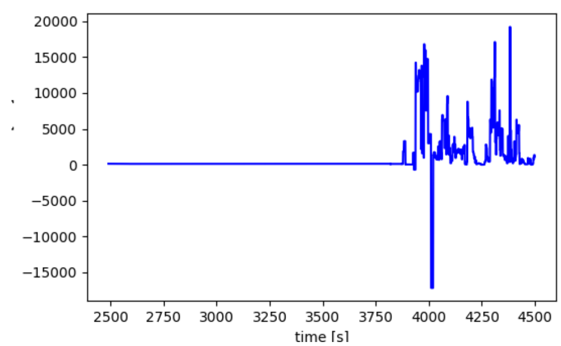


Figure 35: Dependence of light intensity over time

On this chart, we can see the measured light intensity after landing shows very small values. This occurred because our light intensity sensor was placed on side panel of our satellite and ended up facing down. However, these small values were not included when making the index. After the satellite was found, we rotated it and left it on the same place. But even after this manipulation with the CanSat, light intensity still shows some deviations.

There is at least one damaged measurement, which is the negative value. We suspect this value was created by an overflow of the data, as more of them occurred during the flight when the values were higher than on the ground, this value was also not included in making of the index. The last factor of error could have been caused by our shadows, as they could have covered the sensor when it was measuring data.

Taking this to account, we can assume the real value of light intensity was around the peeks in the chart, around 15000 lux, which still fits into the perfect values, so we don't need to adjust the final index value.

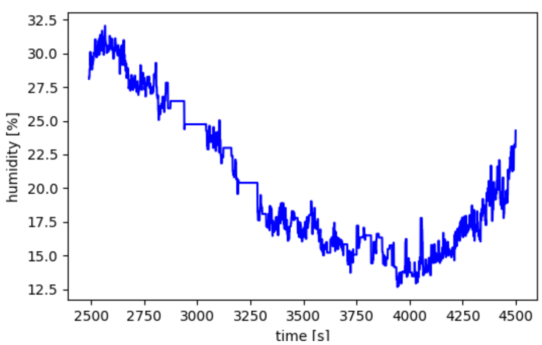


Figure36: Dependence of humidity over time

Now we will examine the humidity chart. We can see local maximum of the function shortly after the landing of our satellite. We suspect this is caused by the position of the sensor. This sensor was inside the satellite, so there was worse air circulation. As the CanSat fell, sensor was still measuring air caught inside the satellite from higher altitudes. It took a while for the air inside the satellite to change and for the sensor to measure the real humidity of the air near the ground.

The other change in dependence development again seems to be connected to our manipulation with the CanSat to measure light intensity. Similar changes can also be seen in temperature and CO_2 charts you can see in a previous chapter.

In account to these inaccuracies the real value of humidity on the landing site is probably slightly lower than the average value we computed, so the real index value would be probably around 82-84 points.

Even with these mistakes in measurements, the index of habitability was computed relatively accurately. If enhanced with more measured environmental properties and better sensors, it would be very useful in scanning the universe for possible human-like life or finding the best planet for colonizing.

VIII. CONCLUSIONS

Our project was overall a success. We managed to create functional satellite that accomplished its purpose and gathered enough relevant environmental information for us to determine, whether the landing site was habitable or not. The minor measurement errors were irrelevant in comparison to the amount of correctly measured data.

Even though we managed to finish desired functionality of our CanSat, we know we didn't plan our project properly. For future projects, we need to plan exact tasks for every team member to focus on. On the course of our project, many times we encountered situations, where one or more of the team members couldn't continue or test their work, because they were waiting for necessary part of the project another member was supposed to create but was focusing on different task. This ultimately caused lack of time at the end of the project. Fortunately, we were able to finish all parts of the project on time.

Mentioning the teamwork, another problem was with division of work. Every team member got at least one department assigned as his main responsibility, but some departments were more difficult to master then other. At the beginning, we divided the work so people wouldn't have to learn too different things. This resulted in many difficult tasks assigned to one person, while others had only little work. We tried to reassign the departments, but during the project it was hard to do so efficiently.

Another setback was during the competition itself. After the launches, we mainly focused on data processing and showcase of functionality of the GUI, instead of preparing the presentation and training it. Because of this, we were easily distracted by malfunction of the presentation system and forgot to mention lots of interesting and important details.

On the other hand, the biggest accomplishments were successful creation of double-sided communication enabling us to take control over CanSat's functionality, four-layered PCB design providing connections between all the electronic parts, the Ground Station in-suitcase design allowing all the essential components for communication and data visualisation to be in one portable suitcase and finally the index of habitability correctly indicating the Earth as habitable planet.

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