ELEKTROTEHNIŠKO-RAČUNALNIŠKA STROKOVNA ŠOLA IN GIMNAZIJA LJUBLJANA

Critical Design Review

VegaSat

Mentors: Luka Maček, Aleš Volčini, prof.

Authors: Team VegaSat

Ljubljana, March 2023

1. INTRODUCTION

1.1. Team organization and roles

Luka Maček:
Luka is the team mentor. He explains complex calculations and presents new and more practical improvements for our experiment. He also helps us solve problems we encounter.

Aleš Volčini:
Aleš has been teaching computer science for 16 years at Vegova high school. He helps us come up with solutions to our problems and with his knowledge and experience he contributes most with theoretical ideas and how to best implement them in practice. He also tries to make sure we are on time.

Luka Petek:
Luka is in the 3rd grade at Vegova high school. He is working on the primary mission and components that come with it. He is also working on a recovery system.

Lovro Govekar:
Lovro is in 3rd grade at Vegova high school. He is working on the secondary mission and components that come with it. He also manages tasks among team members.

Jaka Kovač:
Like the rest of the team Jaka attends 3rd year of Vegova high school. He took the role of outreach manager, He will develop software for tracking the cansat with the antenna while descending and the transmitters system for guided landing.

Jurij Fortuna:
Jurij is another of our team's programmers. He's responsible for the communication between our CanSat and our base stations. He's also responsible for recreating our flight in Blender. Like others, he is a student at Vegova high school.

Martin Hanzlowsky:
Matin is mostly a front-end professional developer and also a 3rd-grade student at Vegova high school. He can write software in his sleep. He will develop the visualization and ground station software used for monitoring the CanSat while in descent.

Leticija Frumen Čenčur:
Leticija is the team's only female member. She is currently in 3rd grade at Vegova high school. She is working on storing data on two SD cards. She also helps set up different components such as sensors.

1.2. Mission objectives

Our secondary mission is to attempt a guided landing, record all the flight data like acceleration, position, and location, and use said data to create an animation of the flight later. We've selected this mission as we thought it would be quite a challenging task, and could also be applied to other space exploration missions. The animation of the flight would also prove as a useful resource for analysis and improvements of the guided landing system.

Our objectives are:

- to make the cansat land as close to the middle of the landing zone determined by three radio beacons,
- record flight data such as acceleration, position, and location and create an exact flight animation from the data.

Our research will help us to determine the performance of the guiding system and make possible improvements.

2. CANSAT DESCRIPTION

2.1. Mission Overview

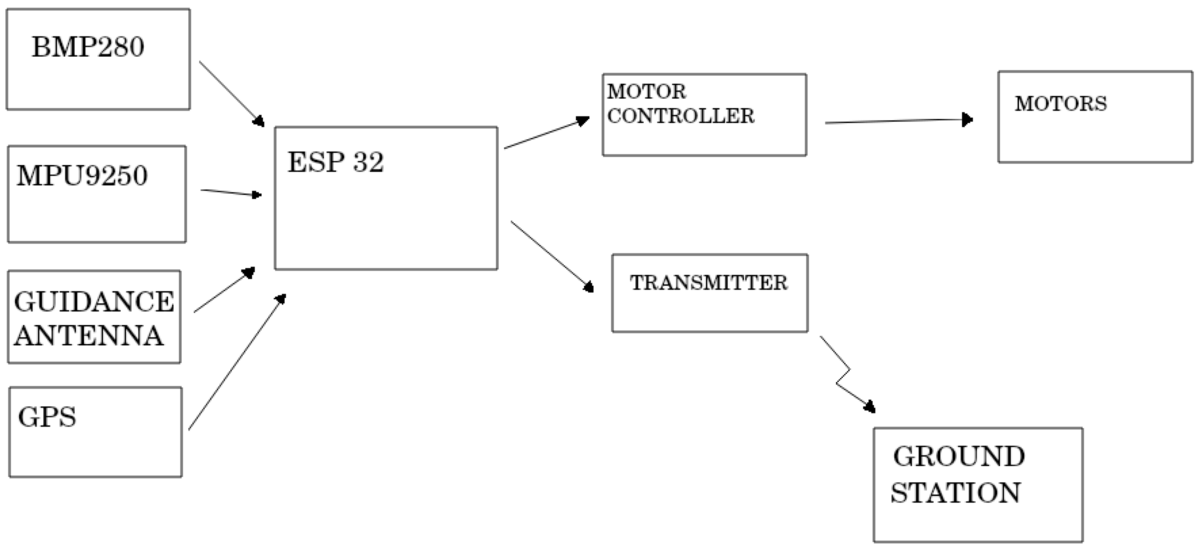
Our goal for this mission is to land the probe between three radio beacons. During the flight, we will also collect all the data regarding the cansat's position, speed, acceleration, and location. This data will be transmitted to our ground station along with the data collected from our main mission. The ground station will then display the data as graphs and also render an animation of the flight. Such visualization of our data will help us diagnose potential problems with the performance of the guidance system.

To collect the data we will use the following sensors:

- BMP280 for humidity, temperature, and pressure,
- MPU 9250 for orientation and acceleration,
- An analog receiver for the locator system-specific model to be determined with testing

Data will be transmitted using APC220 radio modules. It will also be stored on two SD cards on board.

Block diagram:



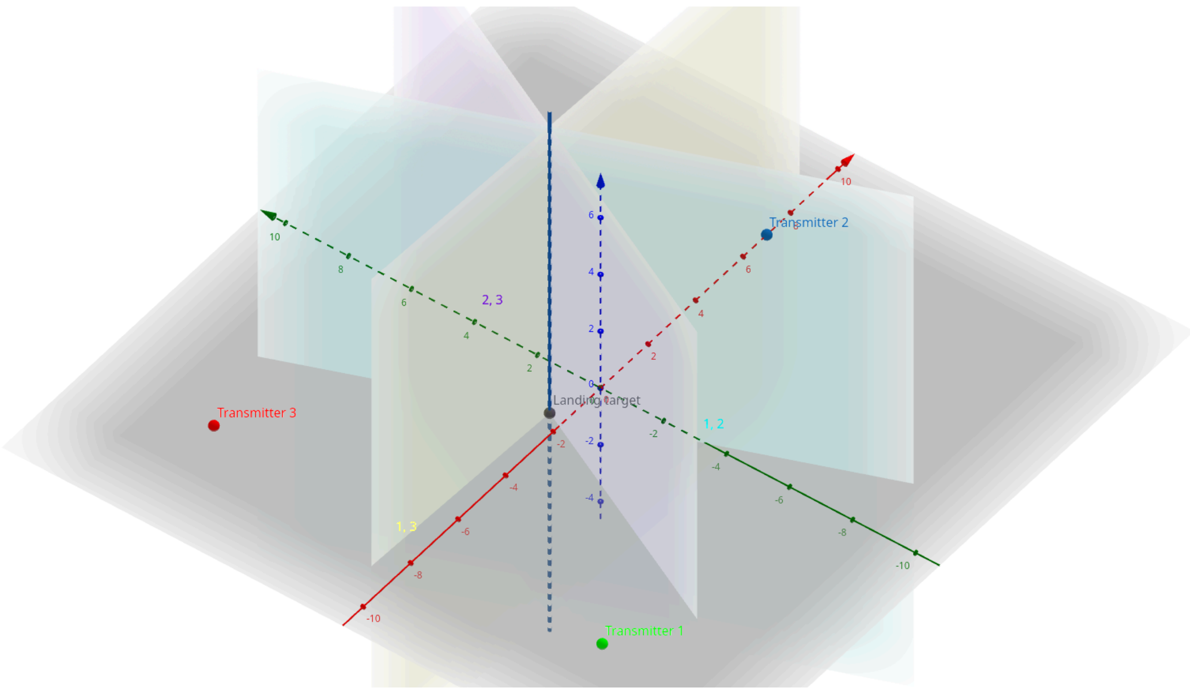
2.1.1. Guidance system

We got the idea for our guidance system from the ILS (Instrument Landing System) used at airports to assist landing aircraft and from the ARDF (Amateur Radio Direction Finding) system. There will be 3 transmitting stations on the ground and a receiver in the cansat.

The transmitter station will consist of a radio transmitter and an ESP-32-based microcontroller board. The microcontroller will generate the signal. Once the radio beacon is activated, it will transmit two sine waves generated by ESP's internal DAC.

Transmitters will be arranged in a triangle with our target area at the center of the circumscribed circle. Each will transmit two sine waves with the same amplitude. We can number transmitters with numbers 1, 2, and 3 counterclockwise. Frequency A is shared between 1 and 2, frequency B is shared between 1 and 3, and frequency C is shared between 2 and 3.

Let's look at transmitters 1 and 2 as an example. Both transmit frequency A with an amplitude of 1. In the middle, both signals dissipate the same amount and their sum is the lowest. Technically, this is true for the whole plane perpendicular to the side of the triangle and going through the middle point. (Note: The amplitude is highest near each of the sources.) We can determine when our CanSat is on each of the planes. The intersection of those planes is the path we want to descend on. The figure below displays the concept made in GeoGebra.

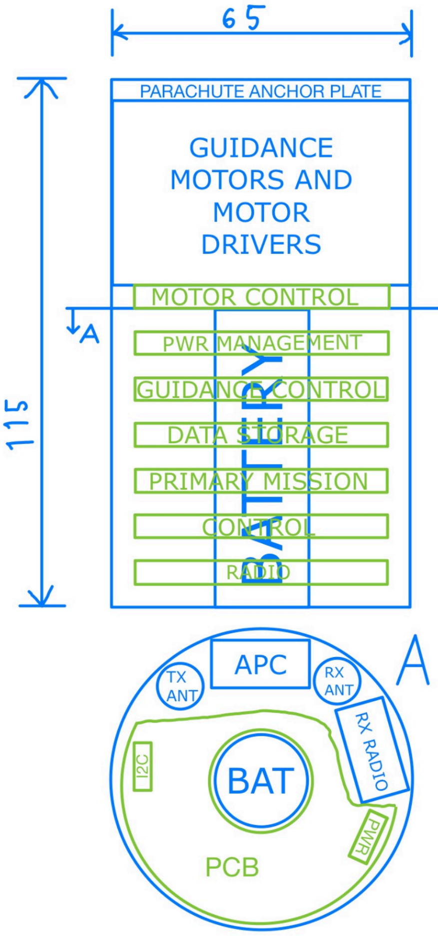


2.2. Mechanical/structural design

Most of our cansat will be 3D printed due to the simplicity of the manufacturing process. PLA filament will be used because of its biodegradable properties.

For guidance, we will use 3 propellers driven by brushless DC motors and angled 120° apart. The diameter of the propellers will be 40 mm. This system will be mounted at the top of the cansat, as we fear mounting it lower might just swing it around.

During the ascent, the propellers will be braced in the upwards position, so as to not cause damage. For the same reason, guidance must not be started until the cansat is out of the rocket.



2.3. Electrical design

We have decided to use the ESP32 microcontroller as it is powerful enough and has enough I/O. All sensors such as the BMP280 and the MPU9250 are connected to it, as well as the APC220 for communication. A GPS module, an L293N motor controller, and a second, analog receiver for the location system will also be connected to it.

The battery used will be a rechargeable 18650 cell outputting 3.7V. This matches the motors used in the guidance system.

2.4. Software design

2.4.1. Primary mission

The job of the primary mission's software is to initialize the BMP280 sensor, read its output, and pass it on to the communication and data storage systems.

2.4.2. Guidance

The cansat receives the signal from the analog radio frequency receiver and determines which beacon is the closest. The software uses that information, as well as the onboard compass sensor to determine the power levels on each of the motors for the correction maneuver.

2.4.3. Communication

All data retrieved from the sensors is encapsulated into a C language struct and transmitted via the APC220 module to our ground station. The ground station parses the received data and saves it into a CSV file for future analysis. An additional two copies of the same data are saved onboard on SD cards, so we have at least one copy of the data in case of a telemetry failure, an SD card failure, or even a loss of the cansat.

2.4.4. Blender simulation

A python script inside the blender software parses our flight data. Afterwards, it generates keyframes on the appropriate timestamps, and thus our model can rotate accordingly. Altitude and inertia data points are used to move the model around the scene, allowing us to recreate the full flight path.

2.4.5. Onboard data storage

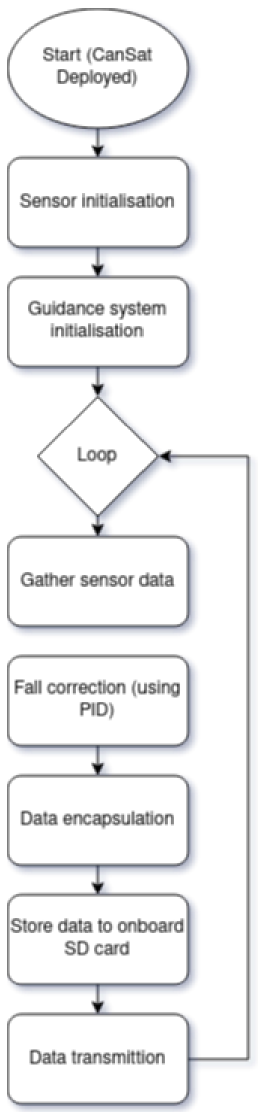
We understand the importance of data in space flights. Every bit of data costs a lot of time and money to gather so it must be treated accordingly. This is why we have done extra work to make our data as safe as possible and we analyzed potential mishaps.

We decided to save our data on SD cards. We will be using two independent SD cards as we identified hardware problems, such as card internal failure or card contact failure are likely. They are connected through an SPI port and selected via two CS signals. They operate at 400kHz. Using two cards dramatically lowers the likelihood that any hardware problem will damage our data. To connect to the SD cards we use an SD card library. Cards are accessed sequentially. This means that we select and mount the first card as an external disk, write the data, dismount it, and then repeat the procedure for the second card.

We decided on several software data protection techniques. We are writing data in two different formats on each card. One is in human-readable text format, and another is in binary (hex) format, where we write raw data.

The text file can be used as a quick check, easy transfer, and decoding, due to its readable form. The binary (raw) form adds an extra layer of protection in the form of a CRC checksum. We calculate a Cyclic Redundancy Check value for each data row in the raw file format and add it to the line. We decided to use the CRC-16 (CCITT-FALSE) variant of CRC calculation. This allows us to identify and discard any damaged data entries easily.

2.4.6. Flow Chart



2.5. Recovery system

The CanSat will be equipped with a single hexagonal parachute. It will also have a spill hole in the center for better control and stabilization. The parachute is made from no-tear nylon fabric and attached to CanSat with braided nylon string.

The surface of the parachute will be around 530 cm^2 and the probe is expected to descend for 100 s. The spill hole of the parachute represents 5% of the total surface area, resulting in 505 cm^2 of the actual area.

We used the force of gravity of 9.81 m/s^2, the drag coefficient of 1.4, and a descent velocity of 9 m/s.

3. PROJECT PLANNING

3.1. Time schedule of the CanSat preparation

This is a rough timeline of the cansat's development.

Task	Deadline	Is finished	Comment
Guidance concepts	1.2.	Yes	
Dummy data generator	1.2.	Yes	
Primary mission prototype	15.2.	Yes	
Data storage and transmission	15.2.	Yes	
Test of centering system	20. 3.	Yes	
CDR submission	31.3.	No	
Choice and purchase of hardware	1.4.	No	Battery and motors/propellers missing
3D design	5.4.	No	
Ground station	28.4.	No	
Live testing	20.5.	No	
Pre-launch report	8.6.	No	

3.2. Resource estimation

3.2.1. Budget

Part	Amount	Market price [€]	SUM [€]
ESA CanSat kit	1	95	95
ESP32	1	11	11
BMP280	1	15	15
MPU 9250	1	6	6
Motors	3	1	3
L293B driver	1	7	7
Battery (18650)	1	6	6
SUM			145

3.2.2. External support

Organizations that support us so far:

Name	Website	Manner of support
VEGOVA Ljubljana	https://www.vegova.si	
ARNES (Academic and Research Network of Slovenia)	https://www.arnes.si/en	merch T-Shirts and domain

Organizations we reached out to and haven't gotten a response yet

Name	Website	Anticipated support
RTVSlo	https://www.rtvslo.si	Help with outreach program
A1	https://www.a1.si/	Financial support
DEWESOFT	https://dewesoft.com/	Financial support
Ljubljana Airport	https://www.lju-airport.si/en/	Tour of the airport and deepened explanation of ILS

Faculty of Mechanical Engineering	https://fs.uni-lj.si/en	Use of their (horizontal) wind tunnel
Aerodium	https://www.aerodium.si/Home	Use of their vertical wind tunnel
General Staff of the Slovenian Armed Forces	https://www.slovenskavojska.si/en/about/scope-and-structure/general-staff/	Drop test of our CanSat before the competition
Slovenian Police	https://www.policija.si/eng/	Drop test of our CanSat before the competition

3.3. Test plan

We have multiple plans for testing the cansat. First, we will test every component of the system by itself. We have made multiple testing plans once we assemble all the components. We are trying to arrange a helicopter ride with either the Slovenian army or the police force during one of their exercises. We are also discussing the possibility of testing it with an actual rocket with the help of some rocket model makers. Not-so-live tests include testing the cansat in a wind tunnel and building a rail system for the cansat to slide along using its guidance system.

To test visualization components we made a Dummy Data Generator or DDG for short. It generates random numbers for all metrics transmitted from CanSat to the ground. Besides using Excel to analyze the CSV data, we will design our bash-based visualization software.

4. OUTREACH PROGRAMME

Our outreach program consists of a website, an Instagram account, and presentations.

In our sponsorship program, we reached out to ARNES (Academic Research Network of Slovenia), the government institution that manages the Slovenian internet backbone and supplies educational institutions and other eligible organizations with internet services and is a .si TLD registrar. They supplied us with the domains cansat.si and vegovasat.si. We host our website on those domains (https://cansat.si and redirected to https://vegovasat.si). We (do and) will write blog posts after big achievements like meeting with the ESA crew or after hitting a major milestone.

We also have an Instagram @vega.sat where we post about those small achievements that summed up paint a bigger picture.

We present our activity in school events like the so-called “Informativni dan” where primary school students visit their future high schools. It was hosted on the 17th and 18th of February and our team made quick presentations of the competition and our to-be CanSat. We are also planning to present this year’s solution at MIDEM, an international conference organized by the society for Microelectronics, Electronic Components and Materials on 27th-29th September 2023.

Infodrom is an informational TV show focused on reaching kids and teenagers that airs once weekly on national TV. We will try to present our work in the show and spread awareness of the competition and ESA.

5. REQUIREMENTS

Characteristics	Figure (number + units)
Height of the CanSat	115 mm
Mass of the CanSat	approx. 320 g
Diameter of the CanSat	65 mm
Length of the recovery system	
Flight time scheduled	100 s
Calculated descent rate	9 m/s
Power consumption	5 W
Total cost	145 €

5.1. Preliminary power budget

Device	Voltage [V]	Current [mA]	Power [mW]
ESP32	3,3	80	2640
BMP280	3,3	1,2 peak	4
MPU 9250	3,3	4	14
Motors 3x	3,7-4,7	120 (3x)	540
L293B driver	4,5	60	270
Total power (sum of all)			4550

On behalf of the team, I confirm that our CanSat complies with all the requirements established for the 2023 European CanSat competition in the official Guidelines,

Signature, place, and date:

Ljubljana, 31. 3. 2023

Lovro Govekar, Jaka Kovač, Leticija Frumen Čenčur, Martin Hanzlowsky,
Luka Petek, Jurij Fortuna