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Skadi: Seed to success - Autonomous Trajectory Control and Analyzing Plant Growth Potential in Exoplanet Environments

A. Vitis, A. Heddadj, Y. Taia, N. Mohamed
AeroIpsa

ABSTRACT

This study procides a brief description of the Skadi project elaboration. Led by AeroIPSA, this CanSat revolves around the development and deployment of a micro-satellite capable of conducting various experiments during its controlled descent using a triangular parachute. It represents a significant advancement in system miniaturization, incorporating innovative embedded technologies to gather precise scientific data. The primary objective of the Skadi CanSat is to be able to land autonomously in a safe zone previously defined by GPS coordinates. It also aims to investigate the environmental characteristics of exoplanets and their potential for plant growth by measuring atmospheric pressure, humidity, and temperature during landing. The Cansat is also equipped with a camera to analyze potential information left by a previous mission via a QR code on the ground and collect pictures of the environment.

Furthermore, the Skadi CanSat project serves as a platform to showcase advancements in space-efficient technologies and inspire future innovations in the aerospace industry. The team at AeroIpsa is committed to successfully executing the missions, acquiring invaluable scientific data, and pushing the boundaries of technological innovation in the field of aerospace engineering.

1. INTRODUCTION

The Skadi project, undertaken by AeroIpsa, is centered around the development and deployment of a CanSat - an innovative type of micro-satellite with the capability to conduct a multitude of experiments throughout its controlled descent using a parachute. These micro-satellites have the potential to be deployed to exoplanets for extensive research purposes, providing valuable data to understand the environmental characteristics of these foreign bodies, including atmospheric pressure, humidity and temperature. Building upon this information, any CanSat project has to follow the fundamental principle of maximizing functionality within a limited volume, emphasizing the development of a compact and self-contained payload.

The specific purpose of the Skadi CanSat project is to develop a system able to gather various data by scanning the landing territory while controlling its own trajectory to arrive on a given point. The name Skadi was chosen after the Nordic goddess of mountains, as the initial aim of the project was to be able to land on rugged terrain such as mountains. Upon airdrop, the micro-satellite is designed to execute three missions: 1. Control its triangular parachute using GPS coordinates and three gear motors, 2. Scan a QR code located on the trajectory with an on-board camera and saving the decoded data on an SD card, 3. Release plant seeds at the designated timing.

The CanSat's distinguishing feature lies in its focus on miniaturizing the QR code scanning and seed release systems. Its compact design incorporates an array of sensors that provide reliable data, facilitating a comprehensive study of the efficiency of triangular parachutes compared to other existing types.

Overall, the scientific questions addressed by this CanSat revolve around understanding the viability of unfamiliar exoplanet environments and studying their growth potential. First and foremost, the project seeks to ensure a safe landing in a designated zone using a triangular parachute, which would be crucial for successful data collection and mission execution. Also, by capturing still images of QR codes to decode and launching seeds during a short descent, the project aims to investigate quite rapidly a selected exoplanet landing area with mountainous or rough terrain.

2. CANSAT TEAM

2.1. Club description: AeroIpsa

Founded in 1992, AeroIpsa is a student association from IPSA School of Engineering, in Ivry-Sur-Seine, France. For more than 30 years it has been dedicated to the design and implementation of scientific projects in the aerospace sector using the rocketry model.

Counting around 90 members each year, one of the club's main goal is to bring together students who are passionate about space exploration by taking part in various projects such as experimental rockets and CanSats. These projects enable students to apply the knowledge they have acquired during their studies to meaningful projects, while acquiring the essential skills needed for their future careers as engineers.

Additionally, the association aims to foster a knowledge-sharing culture, where senior members actively support and guide new members in various fields, including mechanics and electronics; through courses or more personalized help enabling them to master design software such as CATIA or Altium.

Figure 1, Members of the association during the C'Space

2.2. Team description: Skadi

As part of the CanSat France 2023 Competition, organized in partnership by CNES and Planètes Sciences, and taking place during the C'Space campaign, the Skadi team is made up of a group of around seven members, each contributing their expertise and passion to the project. The team members and their respective roles are as follows:

- Project Manager: Anouk Vitis, 3^{rd} year
- Electronics Manager: Alicia Heddadj, 3^{rd} year
- Members: Yahia Taia, Nour Mohamed, Jude Coquement Berreby, Clement Gomel and Maxence Burdeau , 1^{st} year

With two 3rd year students assuming management roles, Skadi' team is structured to efficiently oversee the project, with members assigned to various roles such as the primary mission, secondary mission, and additional tasks. This division of responsibilities ensures comprehensive coverage of all aspects of the CanSat project. Furthermore, the team is comprised of individuals with diverse skill sets and a shared commitment to the project's success. Some members prefer mechanics, while others excel in electronics. This diversity allows for a well-rounded approach to problem-solving and promotes collaboration within the team.

It is also worth noting that all equipment and work related to the project was carried out in our dedicated workshop at IPSA. This workshop not only provided us with useful resources, including 3D printers and composite materials, but also created an optimal environment for the fabrication, assembly, and testing of the CanSat, enabling the team to progress efficiently and to work together more easily.

3. CANSAT MISSIONS

As mentioned in the introduction, the project involves three key missions: a mandatory mission, a secondary mission, and a bonus one. Each mission had specific objectives focusing on different aspects of the CanSat's capabilities at analyzing the landing territory.

3.1. Mandatory Mission: Controlled Descent and Targeted Landing

The primary mission of the project is to achieve precise control over the descent trajectory, aiming for a targeted landing as close as possible to a predefined GPS position. Given that the desired landing position may vary depending on the conditions, we have implemented a mechanism to quickly transfer updated GPS coordinates. This is accomplished through a small slot in the tube providing access to the USB port of our electronic system.

To control the descent trajectory, we have chosen to utilize a triangular parachute, similar to the reserve parachutes used in paragliding. Unlike a paraglider, this type of parachute offers improved horizontal stability due to its three-corner structure, which also allows us to control the heading.

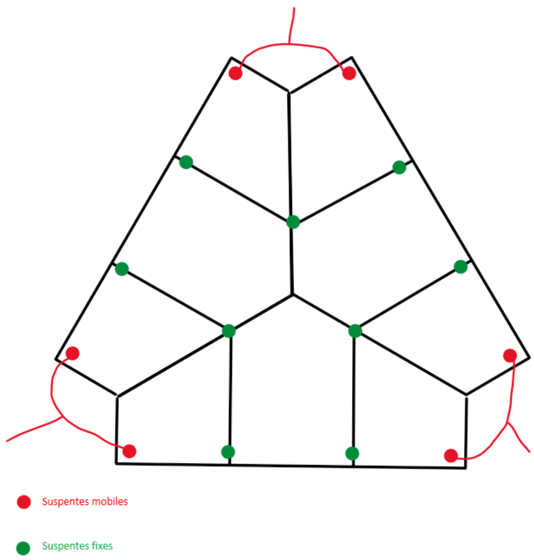

Figure 2, Parachute sewing pattern

The control mechanism resembles that of a skydiver pulling on suspension lines. Thus, we have equipped the CanSat with a system comprising three DC motors, each capable of winding or unwinding a suspension line through a pulley system. Using a Teensy 4.1 - which has a better accuracy and processing power than Arduino - as command board, this enables us to direct the CanSat towards the desired landing position through an automatic real-time trajectory estimation algorithm.

It is also important to note that, for an equivalent surface area, a triangular parachute has a higher descent speed compared to other types of parachutes. [1] Therefore, by

considering the estimated mass of our CanSat and doing numerous trials of dropping it from our school's building, we managed to determine an appropriate surface area of 30 cm² that ensures a sufficiently slow descent for proper CanSat navigation at around 6 m/s.
In addition, our experimentation with suspension line length has shown that reducing one of the lines effectively modifies the heading of the CanSat.

In terms of spatial orientation, we leaned towards the use of a Grove GPS module, which offers improved position accuracy and faster coordinate update frequency as the sensitivity of tracking and acquisition both reach up to -160dBm. This module not only consumes less energy than other available options but also ensures swift control of the suspension lines to reach the targeted location. To accurately determine the heading, the GPS will be coupled to a small magnetometer and accelerometer module by Adafruit. [2]

Figure 3, Lis3mdl + Lsm6ds3 module

Once dropped, the CanSat system should estimate the right trajectory to follow and command the motors accordingly to slowly descent while spiraling around the targeted landing point.

Regarding additional components of our electronic system, we have chosen to display the GPS coordinates on a 128x64 pixel OLED screen in real-time. This low-energy display allows us to clearly visualize the target coordinates before the flight, minimizing objective errors, and then display clearly the final position along with its distance to the target.

By successfully accomplishing the mandatory mission of controlled descent and targeted landing, our CanSat project aims to demonstrate the effectiveness of our chosen parachute design, navigation control system, and spatial orientation methods.

3.2. Secondary Mission:
Ground QR Code Recognition

The secondary mission of our CanSat project involves retrieving data from a QR code placed on the launch site in advance. This data will be captured using a camera installed at the bottom of the CanSat and saved on an SD card.

Figure 4, ESP32 CAM module

To read and decode the QR code data, we have chosen to utilize the ESP32CAM module. This module combines a camera, microcontroller, and a micro-SD card port, saving us the space of having to use another command board. Its direct programmability through the ESP32 provides a compact and autonomous solution for our CanSat project. [3]

While the decoded information will be saved on a .txt file on the SD card, during the descent, the CanSat may experience vibrations that could affect the quality of the video feed from the camera, making QR code recognition more challenging. To address this issue, on top of realizing the scan using grayscale, we have also decided to regularly save pictures of the descent on the SD card which we will be able to analyze through a python code afterwards. This solution offers a better chance at decoding more blurry images.

Overall, the successful completion of this secondary mission will demonstrate the functionality and reliability of our camera module and decoding system. This capability will enhance the CanSat's data collection abilities and provide valuable information for future applications in unfamiliar landscape exploration.

3.3. Bonus Mission: Seed Release

Our bonus mission focuses on seed release and environmental analysis. We aim to study the CanSat's surroundings by analyzing temperature and humidity data, providing insights into the suitability of the environment for the selected seeds and their growth potential.

To achieve the environmental analysis, we will equip our CanSat with a BME280 sensor known for its compact size and efficiency. In addition to temperature and humidity, the sensor will also provide pressure readings.

Based on the launch site conditions, we have chosen to carry poppy and damask flower seeds, which are suitable for dry soils and high sunlight exposure

The seeds will be ejected using a drawer deployment mechanism. Our design incorporates multiple compartments, similar to the iris mechanism found in cameras. These compartments will be located at the center of the CanSat, and a servo motor will rotate the first ring, causing the compartments to slide outward.

Figure 5, Seeds drawer deployment

These bonus missions will enhance the overall capabilities of our CanSat by conducting environmental studies, assessing the suitability of the landing area for seed growth. The data gathered will contribute to a deeper understanding of exoplanet environments and provide valuable insights for future scientific research. This knowledge could be invaluable for future long-duration space missions and the cultivation of plants in extraterrestrial environments, aiding in sustainable food production and life support systems for astronauts.

3.4. Data processing

As part of the CanSat project, data processing plays a crucial role in achieving the mission objectives. To ensure that the data from our sensors is correctly interpreted and to reduce interpretation errors, we can add a few filters to provide more relevant data.

An accelerometer is used to measure the acceleration of the CanSat along its different axes. However, the raw accelerometer data can be noisy, especially during the descent phase where the CanSat experiences important vibrations. To obtain more accurate estimates of the CanSat's position and velocity, we used a Kalman filter to process the accelerometer data. The Kalman filter is a mathematical algorithm that combines sensor measurements and uncertainties in the measurement to continuously refine the data collected to estimate the true state of a system. It provides optimal and accurate estimates by minimizing the errors between predicted and measured values.

We also use a magnetometer to determine the heading or orientation of the CanSat according to Earth's magnetic field. However, magnetometer readings can be affected by external magnetic interferences and have inherent limitations, especially during fast rotations and movements. For a more stable and reliable heading estimation, we decided to use a complementary filter.
The complementary filter is a sensor fusion technique that combines data from multiple sensors to improve the accuracy and stability of the orientation estimation. In this case, the magnetometer data, along with the accelerometer-derived roll and pitch angles, are fused using the complementary filter.
The data processed through these filters will be crucial for analyzing the landing trajectory.

By accomplishing these diverse missions, the Skadi CanSat project combines elements of navigation, imaging, environmental analysis, and experimental research. It serves as a platform for applying theoretical concepts, acquiring practical skills, and fostering teamwork among the project members. The ultimate goal is to contribute to the exploration and understanding of new environments, paving the way for future advancements in space exploration and scientific research.

4. CANSAT DESIGN

4.1. Mechanical structure

For the global shape of the cansat, we wanted to have a cylinder, indeed with this form we have been able to protect the inside structure and system by a fibre glass tube. We have implemented our PCB on two threaded rods, and we have separated the stages using nuts. This system allows us to remove the electronics and access the next stage more quickly. The size follow the specifications, with a diameter of 78 mm and a height of 200 mm. The weight will be about 480g. Here are pictures of complete CAO of our cansat and the realization of it.

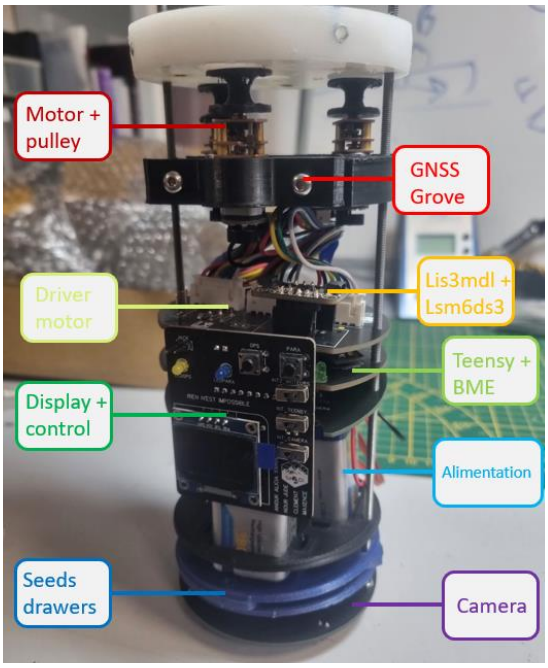

Figure 6, Assembly of Skadi

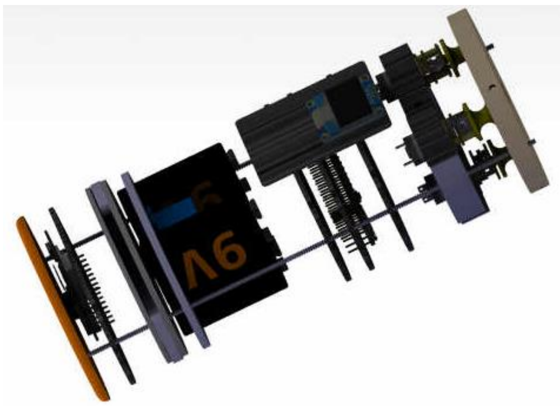
Figure 77, CATIA modulization of Skadi

We chose to make a composite fiberglass envelope to protect the sensors and electronics. We used a Pringles tube as a support to give us an internal diameter of

76mm. This project was also an opportunity to teach our new member how to make composite materials.

Figure 88, Realization of fiberglass envelope

To secure the parachute and ensure a safe landing, we used polyoxymethylene (POM) to make the ring. Each fixed line is attached to a hole, while the moving lines are connected directly to the 3D-printed pulleys. Because of the triangular shape of the parachute, we adapted the hole for the suspension. As one of the suspension lines is movable, we decided to add a small piece of brass tubing to reduce the risk of melting with the friction of the moving suspension.

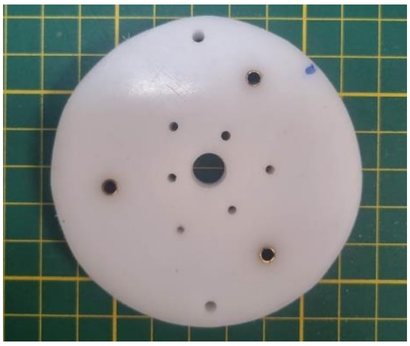

Figure 99, Parachute ring

4.2. Electrical design

The electrical design of the CanSat project incorporates five PCBs, each serving a specific function. They were all designed using EasyEda software and manufactured by JLCPCB, enabling efficient development and production of the electrical system.

To optimize space utilization, four circular PCBs have been employed, respectively dedicated to power supply, Teensy/command module, motors and other sensors, and camera.

Additionally, a rectangular PCB has been developed to accommodate the display featuring an OLED screen, as well as power switches and test buttons. While some PCBs can be clipped one to another (Teensy-Motor PCBs connection), this particular PCB acts as the central connection hub, facilitating the integration of all components once the CanSat is enclosed within the fiberglass tube.

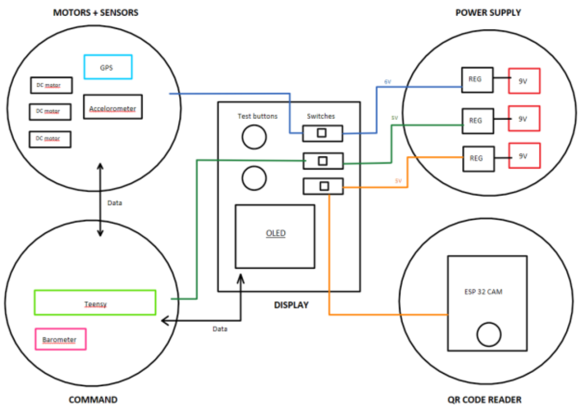

Figure 1010, Overall electrical structure

For power supply, three 9-volt batteries have been positioned underneath the main electrical block to ensure sufficient energy.

5. DISCUSSION & CONCLUSION

As a conclusion to all the work done so far, the Skadi team has faced and overcome numerous challenges while trying to reach the objectives of the competition, particularly in achieving trajectory control and QR code reading simultaneously. However, these challenges have provided valuable opportunities for our team to improve and grow in our skills. We have been able to apply theoretical knowledge to practical applications and foster effective teamwork throughout the project.

While trajectory control has been difficult to test solely by dropping the CanSat from a building, we remain confident in our design and the capabilities of our control system. Further optimization and refinement may be necessary to ensure accurate and reliable trajectory control in real-world conditions.

The success of QR code reading poses another significant challenge due to potential image quality issues during the descent. We are aware of the remaining need to experiment with various parameters to optimize image quality and enhance the decoding process. Continuous testing and refinement will be necessary to improve the chances of successful QR code recognition during descent.

The seed release mission appears feasible to accomplish; however, monitoring the growth of the planted seeds on the landing territory poses a limitation. Nonetheless, this mission showcases the potential for studying environmental conditions and evaluating the suitability of the landing area for plant growth.

Looking ahead, the knowledge and experience gained from this project can be valuable for future CanSat missions. For instance, analyzing atmospheric conditions as initially intended could be a potential avenue for further exploration. By building upon our current capabilities and continuing to push the boundaries of our system, we have the opportunity to contribute in making small advancements in space exploration and scientific research.

Despite the challenges ahead, we remain dedicated to the success of the Skadi CanSat project and are excited to see our hard work and innovation come to fruition during the CanSat France 2023 Competition.

6. ACKNOWLEDGEMENT

We gratefully acknowledge the financial support provided by EgyptAir and Azimuth in the realization of this CanSat. They both showed unwavering commitment to the project and played a crucial role in facilitating the procurement of necessary equipment and resources. Their generous contributions were instrumental in the successful realization of this project and significantly impacted the outcome of our research, enabling us to progress smoothly and achieve our objectives.

We would also like to express our gratitude to our club AeroIpsa and all of its members for the help throughout the year, their support and for providing the necessary equipment.

Most importantly, we would like to sincerely thank everyone at Planète Sciences for their hard work in organizing this competition and for the assistance and guidance that they provided to us throughout this project. Their support and mentorship have been valuable in helping us navigate through the challenges and work towards our goals.

7. REFERENCES

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