CANSAT FINAL PAPER - DRILLSAT

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Abstract: The CanSat in Greece competition aims at giving university students the opportunity to work on a multidisciplinary project with technology similar to that used in small satellites and to take their first steps in space. Moreover, the current trend in satellite technology which is to achieve more with a smaller probe, with prime examples being the CubeSats, makes this kind of competition more relevant. Our goal as a team was to design and build a CanSat that could be the basis for an actual space probe with the aim of extraterrestrial exploration. This paper presents our design of the CanSat discussing the mechanical, electrical and software aspects in detail, while showing that all the mission requirements are met. Specifically, our CanSat is launched onboard a research rocket and deployed at the apogee. Then a parachute is used to reach the nominal descent velocity. Equipped with five legs it is able to reach an upright position from where the drills can be activated. First, the leg and drill mechanisms are described in detail. Next, the selected sensors, the measurements taken and the electronics subsystem are discussed. Then, we present the flight software as well as the ground station that receives and visualizes the mission data in real time. Finally, we discuss the challenges we faced and draw conclusions.

I. INTRODUCTION

The mission of our team for the 2018 CanSat in Greece competition consisted of the primary mission, same for all contestants, and the secondary one, selected by our team. In the primary mission we had to integrate sensors in our design, capable of measuring position, temperature and altitude during descent. The secondary mission was inspired from a number of real life projects in extraterrestrial exploration like the curiosity rover, the rosetta space probe, asteroid mining concepts etc. All those projects revolve around analysing the surface and soil of planets or comets, encountering harsh conditions. Our goal was to build a sensor for estimating soil moisture concentration and monitor it over time, in a supposed target planet, in order to further evaluate whether it could eventually host plants and support human activity. For further analysis, we added a UV sensor, since this is proven to be a key factor in the germination process.

II. PROJECT DESCRIPTION

The CanSat is launched onboard a Patriot type-rocket, with an apogee of 1 km where the probe is deployed. During the flight, a velocity of 500 km/h and an acceleration of 22 g could be reached. Next, throughout the descent the probe measures the barometric pressure, temperature and geographic coordinates. These measurements are stored as well as sent to the ground station in real time.

Requirements include the size of the probe, which has to fit inside a cylinder with a diameter of 65mm and a height of 115 mm. The descent rate after the deployment of the parachute should be in the range of 6 - 10 m/s. Also, the probe should be able to operate 4 hours continuously. Lastly, the mass of the CanSat should not exceed 350 grams.

Goal of the secondary mission is to measure the UV radiation and the soil moisture of the environment the CanSat is deployed in, from which we can exclude crucial information that can help us in our efforts to inhabit the target planet . After a successful landing with the parachute, it is able to use its leg mechanism and rise into a position from which it can dig its drills to the ground and measure the conductivity between the two drills, which is related to the moisture of the soil examined. Apart from the pressure and temperature sensor, a UV light sensor is added to determine if there is spectral content in the UV-A and UV-B range.

The data gathered are sent to the ground station, which is equipped with a high gain Yagi antenna with a range of 3 - 4 km. The frequency of the transmissions is 1 Hz. Through a web application the data received can be displayed and plotted in real time on a computer of the ground station.

III. MECHANICAL SYSTEM

In order to achieve our goals, a number of mechanisms had to be implemented in the design. The small size of the CanSat made it challenging to fit everything inside it in a robust way. After many prototypes, the following layout was chosen.

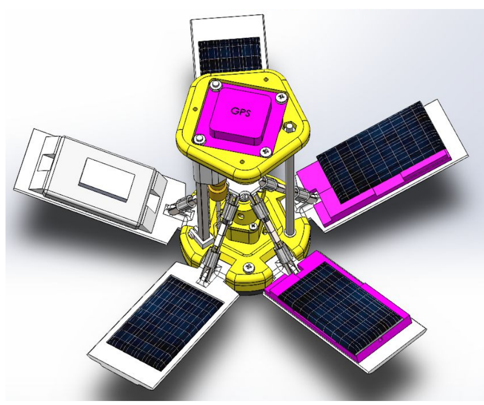

Fig. 1: DrillSat assembly, electronics represented with purple.

All the electronics, the battery and the solar panels were placed on the inside surface of the legs leaving space in the core of the CanSat for the drills and the leg deployment mechanism.

A set of 5 foldable legs were placed in the periphery of the satellite, a number chosen to provide a good balance between leg width and near circular top view. A motor driven platform moving on a threaded rod, along with N clevis joints were used for deploying those legs. The length of each arm and the position of the joints were chosen carefully in order to give the mechanism an appropriate mechanical gain, allowing it to operate with a small motor and minimum current.

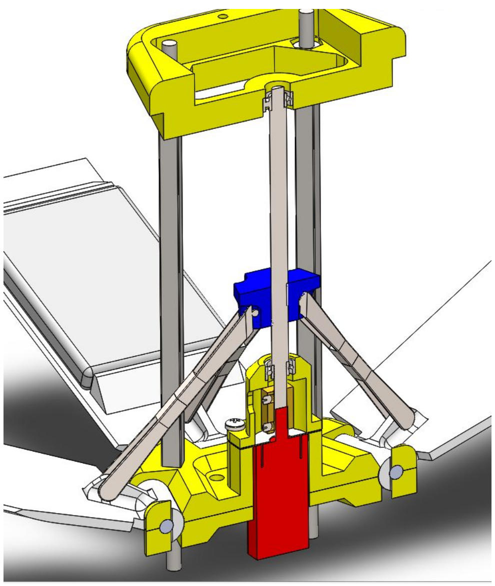

Fig. 2: Legs deployment mechanism

As for the drill mechanism, the drill assembly was sliding on a square 4x4 mm rod. In order to save space and weight, the assembly was moving with the aid of springs instead of actuators. An expendable retainer was used to prevent the drill from deploying. When voltage was applied to the motors, the drills would penetrate the retainer and protrude out of the CanSat, into the ground.

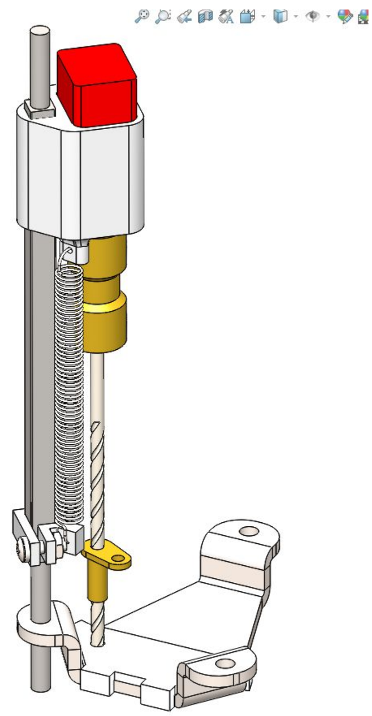

Fig. 3: Drill mechanism

Finally, in order to provide dampening in hard landings, some extra parts were added. A bottom made from TPC rubber was designed to make the first contact with the ground, absorbing most of the energy from the impact. Because the motor moving the legs was also located in the bottom of the satellite, we added a stainless steel metal cover around it.

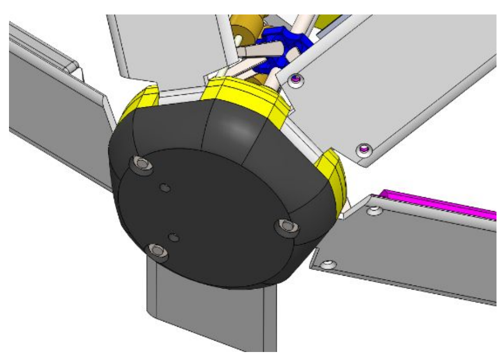

Fig. 4: Rubber damper

Most parts were CNC machined from POM plastic, ensuring high strength and dimensional precision. Metal parts were all made from stainless steel, with the exception of couplers, which were made from brass.

Apart from the satellite, we also constructed the parachute. We chose a classic circular design with a vent in the apex for stability. Its surface was first calculated theoretically using the following formula

$$F_D = \frac{C_D \rho V^2 A}{2} \qquad [1]$$

solved for A, given the terminal velocity (V), the total drag force (F_D), the air density (ρ) and the drag coefficient (C_D). After building the first prototype, fine-tuning was made in the surface area in order to achieve our target terminal velocity at 8 m/s, which we measured using image analysis from a video. Later on, for better precision, we also calculated the terminal velocity by conducting several drop tests in which we measured the height of the satellite in small constant time intervals and analyzed the measurements. The material we used was ripstop nylon. The diameter of the parachute was 48 cm and the diameter of the stability vent was 8 cm. A total of 8 buttonholes were made around the perimeter of the parachute fabric. A simple 2 mm kevlar thread was used for the suspension lines whose length was 50 cm enough to minimize the pitch of the CanSat.

IV. ELECTRONICS SYSTEM

The electronics system of the CanSat is comprised of an Arduino microcontroller, a UV sensor, a pressure and temperature sensor, a GPS, an XBee RF module anda conductivity sensor, all powered by a LiPo battery and four solar panels. The system apart from the battery the solar panels and the GPS, has to fit on top of two legs of the CanSat inside a space of 7x35x71 mm. Due to that two PCBs were designed so that the electronics can be mounted onto them. Also the structure had to be robust and survive any stresses, as well as being to run continuously for 4 hours, constricting the power budget.

IV.I. Sensor Subsystem

The UV light sensor used is ML8511 mounted on a board. Equipped with an internal amplifier it converts the photodiode current to voltage, outputting voltage linearly related to the UV light intensity measured in mW/cm^2. The sensor output is stable across the operating temperature range, from -25° C up to 75° C, although, when measuring in temperatures away from the one on which the sensor was calibrated, a slight error is introduced. The spectral response is highest in the range 280 - 390 nm which covers the UV-B spectrum and significant percentage of the UV-A spectrum. The typical supply current is around 300 μA at the operational voltage of 3 V.

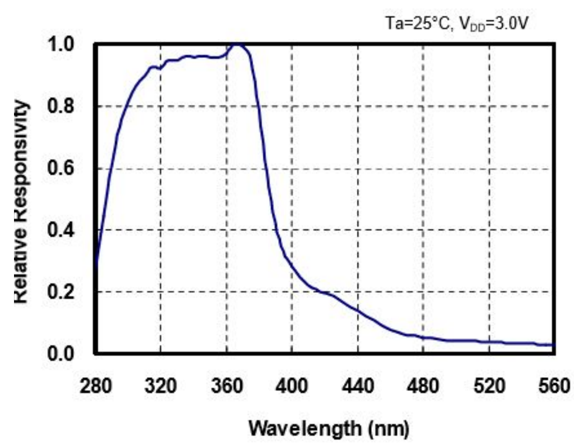

Fig. 5: Spectral response characteristics of ML8511

The sensor used to measure temperature and barometric pressure is BMP280. The interface used to communicate with the microcontroller is I2C. The pressure and temperature data, using the barometric formula, can give the current height with an accuracy of 1m. The operating pressure range is up to 9000 m above sea level and from -40° C to 85° C regarding the temperature range, while the typical current drawn is 2.7 μA.

The sensor used to measure the soil moisture is implemented as a voltage divider. Two high speed steel drills spaced 18.2mm apart are used to penetrate 20 mm in depth. One drill is connected to the ground voltage level through a 10K Ohm resistor while the other one to the +3.3 V level. The former drill is connected to an analog pin of the microcontroller. Given the voltage at that pin we can specify the resistance between them and then calculate the soil moisture.

The GPS module used is the LEA-6H, which is mounted on the top of the CanSat. It sends NAV-POSLLH packages to the microcontroller via serial connection, at a frequency of 1Hz. Typical supply current is 41 mA and 47 mA during the acquisition phase and the horizontal accuracy is 2.5 m.

IV.II. Communication and Data Handling

The selected microcontroller board is the Arduino Pro Mini, using the ATmega328P, an 8-bit AVR microprocessor. It runs at 3.3 V and 8 MHz and has 14 input/output pins, 6 of them analog. The available program memory size is 32 KByte, as well as 1024 Bytes of non volatile EEPROM memory, used to make the CanSat state-aware after possible power offs. Apart from collecting and processing the measurements of the sensors the Arduino also controls the three motors through N-channel MOSFETS.

The RF module used for communication with the ground station is the XBee Pro S5 operating at 868MHz. It runs on 3.3 V consuming 60 mA at stand-by mode, 200 mA on packet emission and has a sensitivity of -112 dBm. It is used with an external antenna with 3 dBi gain which has the following radiation pattern.

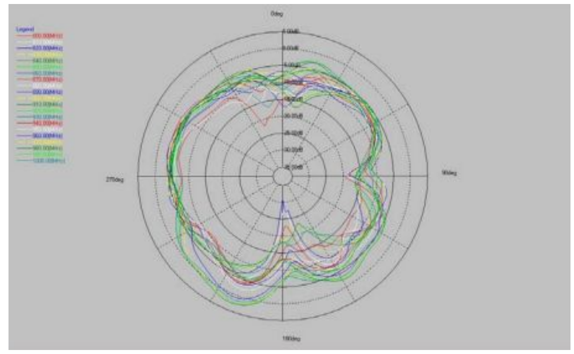

Fig. 6: Radiation pattern of the probe's antenna

The same XBee module is also used on the ground station. The two modules are programmed to operate on AT Mode with ground station's XBee being the coordinator and cansat's XBee a router. Both modules transmit at a power of 25mW which is the legal local limit at 868MHz.

IV.III. Electrical Power Subsystem

A Polymer Lithium Ion battery, charged by four solar panels, is powering the CanSat. The battery has a voltage output of 3.7 V and a capacity of 980 mAh. Four 30.5 mm by 58.5 mm solar panels connected serially are used to charge the battery through the MCP73871. Then a low-dropout regulator drops the voltage down to 3.3 V powering every piece of electronics, except for the GPS, which has an onboard regulator, and the three motors.

	Voltage (V)	Current (mA)	Power (mW)
Arduino	3.3	25	82.5
XBee	3.3	60	198
GPS	3.7	50	165
SD card	3.3	30	99
BMP sensor	3.3	1	3.3
UV sensor	3.3	0.5	1.65
Motors	3.7	350	1295

Table 1: Power budget

Through experiments the previous values of current drawn were found. We conclude that the battery selected is able to power the CanSat for the required time duration.

V. FLIGHT SOFTWARE

The flight software consists of three software states: Launching, Descent and Ground Operations. In each state, the sequence of events is:

1. Take measurements
2. Save measurements to SD Card
3. Send a telemetry package containing the last measurements to ground station
4. Process data and determine the new software state

To ensure that our mission's state is maintained through unexpected processor resets, some information regarding the current state is stored on the non-volatile memory (EEPROM) of the microcontroller, so it can be queried on processor start-up. Being able to dynamically determine our software state is vital for the success of the flight software because a simple sequential program could get stuck in the wrong software state after a sudden reset and lose control of the mission. The flight software is visualised in the flowchart of Fig. 7.

VI. GROUND CONTROL SYSTEM

The ground station consists of a personal computer, an Xbee Pro S5 and a Yagi Antenna with 8 dBi gain. The Xbee is connected via USB to the computer, and the Yagi Antenna is attached to the Xbee module with an RP-SMA connector. The data received by the computer, is parsed by a python script, checked for errors, and saved in a JSON format. Meanwhile a node.js server running locally serves a web page where the data is plotted in real-time using React.js and plotly.js.

VII. CONCLUSION

If we were to rebuild the satellite, we would have made a number of changes, both in the mechanisms and the circuits. One thing we found particularly hard was integrating all cables in the design. Lack of space along with the fact that the circuit boards were in moving parts of the cansat made this even harder. Using cable ribbons and socket connectors would give better results as well. Furthermore, a future upgrade would be the design of PCBs that host most of the electronics components, the sensors themselves and not serving as connectors between various sensor boards. Lastly, another minor enhancement would be to establish a 2-way communication with the satellite, changing the antennas' and the software accordingly, in order to be able to query the satellite for values that are typically not included in mission's telemetry packages (i.e. values stored in EEPROM), as well as have it to execute orders given from the ground station in real-time.

In conclusion, with the end of this project, our team has gained significant knowledge and experience. We believe that by constructing DrillSat we have proved our initial standing, that CanSats and CubeSats can include complex mechanisms and be used in a wide variety of space missions (such as extraterrestrial exploration) .

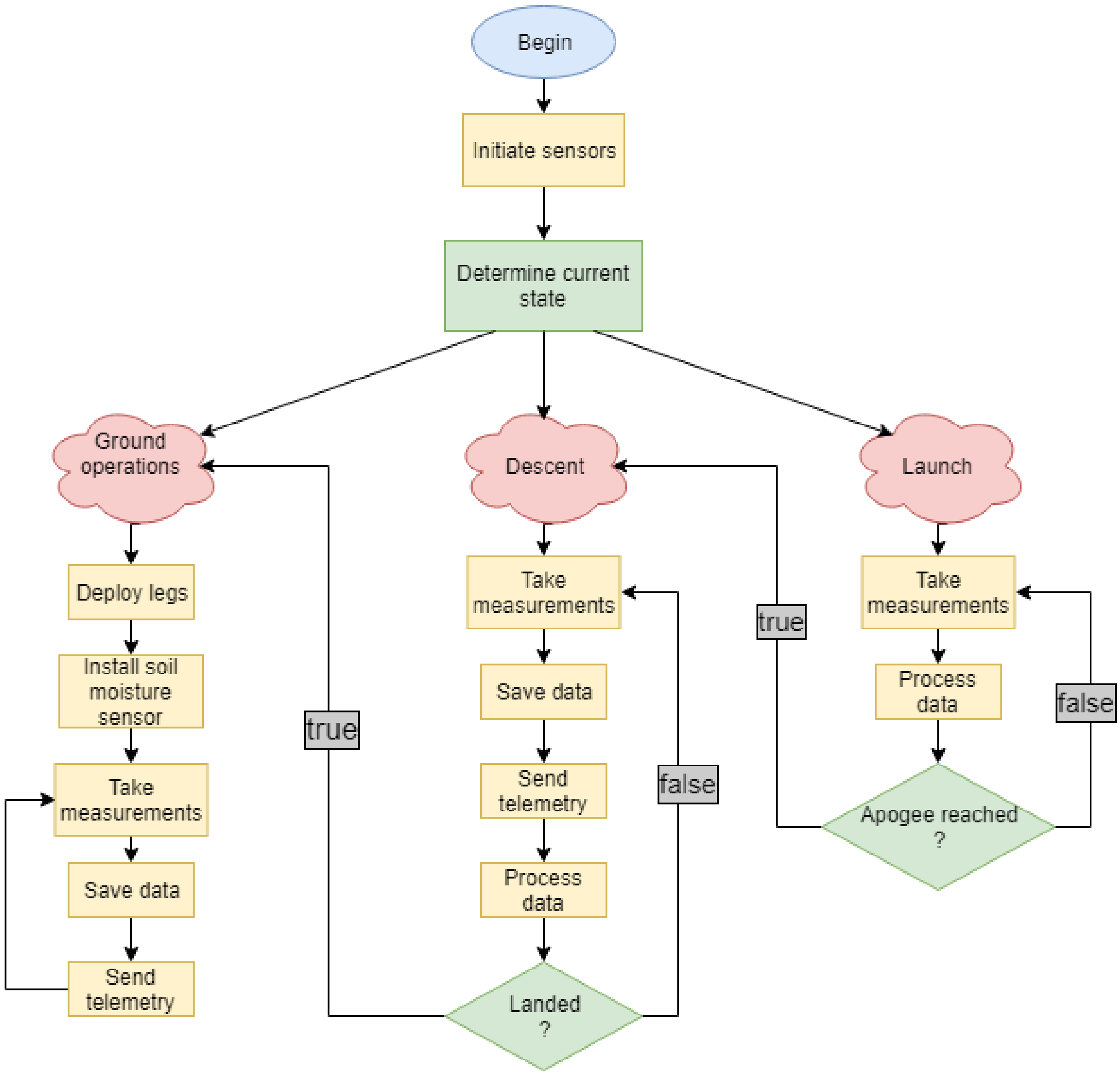

Fig. 7: Flight software flowchart

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