PlasticMonkeys
CHIMP CanSat
Critical Design Review

Team Name: **Plastic Monkeys**

Country: **Poland**

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    b. presentation about CanSats for school mates during RoboTeam science club meeting
9. Project budget has been updated
10. We have changed the goals of our secondary mission - now the aim is not only to maintain two-sided communication, but also to transmit whole images to base and determine whether any targets have been spotted (see 2.2.2)

2 INTRODUCTION

2.1 Team organisation and roles

At school we can gain knowledge in the fields of maths, physics, IT and biology that is crucial when constructing our CanSat. Not all issues are directly connected with ours, but we estimate that 2 hours of schoolwork per week are linked with the project. Moreover, we meet once a week, discuss the work progress and make plans for further growth, that's additional 3 hours. To work on our tasks, after school we dedicate approximately 5 hours of contribution weekly per person. It wraps around 10 hours weekly per person.

Our team comprises the following members:

Patryk Gałczyński - Project Manager, Tech-lead, Supervisor

Patryk is a fifth year Computer Science (major in Systems Modelling and Data Analysis) student at the AGH University of Science and Technology. He founded and runs RoboTeam science club in our high school, where we know him from. He made a couple of autonomous mobile robots called mini-sumo and line-followers. He works as PaaS layer cloud platform developer in Dreamlab, which means lots of DevOps challenges and writing tons of code in Python **Tasks:** Patryk is acting as our project manager, tech-lead and supervisor. That means, he provides us with tools to work efficiently (like Trello or Git repository), organises our work by planning meetings, and pushing us to work hard every day. He also is our inexhaustible source of knowledge about electronics, Unix systems and software engineering and a helping hand when it comes to tough architectural decisions.

Jakub Podolak- Team Leader, Lead Software developer

Kuba - second year student of V High School in Cracow, member of school RoboTeam. Experienced in building different robots such as mini sumo, robotic arms and drones. In his free time he also codes in C++ and Python - mainly programmes for Arduino and Raspberry Pi. He is familiar with power tools, PCB making, soldering and 3D printing, participant of many robotic competitions such as Robotic Arena, Robomaticon. Besides he is sociable, likes meeting new people and taking on new challenges . Also skilled in vlog making and promoting. Enthusiastic about every new task, having great fun while working in team.

Tasks: Kuba's enthusiasm and charisma is going to spread in the whole team and keep it motivated - he is ready to be the team leader, help each member in case of any trouble. Kuba will also be responsible for YouTube worklogs and vlogs (promotion of

CanSat). With his experience in programming, Unix systems, electronics and mechanics he is a versatile executor of tasks and problem solver.

Grzegorz Żmija - Lead Physicist

Grzesiek is in second grade at V High School in Cracow. He is mainly interested in physics and maths, but he has various hobbies including music, chemistry, martial arts and origami. He is familiar with soldering iron and other hardware tools. He also likes working under pressure and has experience in dealing with hopeless situations. His greatest successes in robotics were second place in Line Follower category at uBot (cooperation with Bartek) and some other minor robots. He is sociable, likes meeting new people, especially with similar interests, and taking on new challenges.

Tasks: His physics knowledge and hardware skills will definitely come in useful in the creation of a reliable CanSat. He will also be responsible for physical calculations during the project. On top of that, he is ready to give the team a hand in making hardware. His cold blood and ability to quick solve unexpected problems might be useful if something goes horribly wrong. He also hopes to learn some software design principles from his more experienced colleagues.

Julia Jakieła - Lead Outreach Officer

Julka is in second grade at V High School in Cracow. Although she attends biology and chemistry class, she is interested in electronics and programming and this is why she decided to broaden her knowledge in these areas. As the result, she learnt the basics of Python and Java, made some Arduino projects and built few simple robots. In love with different types of manual work - she pays great attention to details what is useful when soldering, drilling or making PCB. She is a kind of perfectionist with the belief that hard work is a key to success. Ready for all challenges and new dose of knowledge.**Tasks:** Her social skills would be useful in order to increase public interest in our project. Julka will be responsible for outreach and promotion. She will also contribute in areas such as electronics and mechanics. On standby for cooperating with other members of the team to realize all our plans before deadlines. She also hopes to share some essential information in the field of biology while accomplishing our secondary mission.

Bartek Słupik - Lead Data Processing Engineer

Bartek is a student in his second year of high school. In his free time, except for various forms of physical exercise, he undertakes diverse Arduino projects. He has some substantial experience with Python and possesses essential electrical skills and knowledge. He prefers hands-on doings over pure theory, which was the deciding factor for him to participate in the Cansat project.

Tasks: Bartek's experience with microcontrollers makes it possible for him to develop basic software efficiently. He is also ready to give the team a hand in the area of data analysis and processing and all kinds of necessary research. Moreover, due to the fact, that one of his hobbies is hiking in remote areas, he is well versed in rescue technology and equipment - his task will also be to see to it, that the Cansat fulfills the guidelines of the mission.

Jan Derlatka- Lead Mechanical Designer

Jan is participating in CanSat for the second time. He attends third grade at High School No. 5 in Cracow, learning Physics, maths and computer science on extended level. Physics Olympiad has developed his problem solving skills, along with a creative approach to problems. Jan has also proven his management skills by organising "uBot", a robotic festival. He loves applying his knowledge in practice, which is his main motivation for participating in CanSat, but also pushed him to assemble a 3D printer. He is an active 3D graphic designer, which makes him familiar with computer design. In his spare time he learns to become a glider pilot, trains triathlon in summer and skis in winter.

Tasks: Jan's design experience will enable him to provide excellent solutions to the mechanical design of our CanSat. His knowledge of numerical algorithms may be helpful during simulations and calculations. He hopes to make a good use of his Physics knowledge while solving encountered issues.

2.2 Mission objectives

2.2.1 Primary mission

Our primary mission is to take measurements of temperature outside of cansat casing and atmospheric pressure, then transmit them to base station at least once a second. All the gathered data will be both logged to the memory of the Sat and saved at the base station after being received via LoRa link. Furthermore, all data will be uploaded to an online time-series database. This won't just enable full data recovery in case of a radio communication failure, but also allow us to analyze data during the descent. Basing on the recordings, the data analysis will be conducted and the correlation between the measurements will be presented.

2.2.2 Secondary mission

Our original idea for the secondary mission was finding people who got lost in the mountains. This was to be achieved by combining thermal images and regular images with GPS recordings, thereby enabling the rescue team to get the exact location of the target. By dropping many of such devices during a helicopter flight, the rescue team would be able to find the injured person faster. In order to ensure that we are making something really useful (not only in theory), we consulted our idea with the experts from Mountain Rescue Service (GOPR/TOPR). They indicated some drawbacks: 1) In high mountains people use down jackets to keep the heat - that would unable our thermal camera to identify them, 2) Helicopters aren't used as frequently as we thought so there could be a problem while scattering CanSats, 3) Such devices should be: numerous, produced at a low cost, prepared for different weather conditions.

So we came to the conclusion that we should modify our secondary mission. Although it might not be the best suit for mountain areas, we think that our developed solution may be useful in other cases, hence we'd like to adapt our CanSat to prepare it for different emergencies. To accomplish that, the CanSat will consist of one basic module that will ensure two-sided communication between the victim and a rescue team. The injured person will communicate with base station by pressing buttons in answer to questions displayed on a small screen. The main unit is extendable with additional modules attached at its bottom by defined hardware platform interface. This allows the Cansat to be adapted to the purposes of a particular operation or its environment. The following list contains several module ideas proposed by us, although this spare room could be used in numerous other ways:

- When an earthquake occurs – an earthquake sensor could be used to measure seismic activity after landing - providing real on-site data,
- When there is a tsunami – adding to set mentioned above waterproof casing that could even drift on water,
- During volcanic exhalation - gas sensors would give some information about the eruption,
- In each situation the rescue team could deliver necessary things (like pills, a syringe of insulin, etc.) to victims using a transport module;
- Scanning the terrain in order to find lost or injured people - comparing the images from a camera and IR array we would be able to define the victim's localization
- After a disaster in hard-to-reach places - heart rate sensor and oximeter would be helpful in defining preliminarily whether vital signs are stable or not,

On the grounds that the last two of the depicted modules are the most versatile ones and their application is closely bound to saving people's lives, we decided to embed one or both of these into our CanSat.

Both thermal and color images will be sent to base to enable immediate investigation of the area of flight. The analysis of those can aid in determination of victim's localisation and save precious minutes during a rescue action.

For their part, heart rate sensor and oximeter enable us to gain substantial information about victim's health status. But these data isn't sufficient. For this reason we will send some questions that will be displayed on a can's OLED. In that way we will complete initial medical interview which, alongside the measurements form sensors, will be helpful for rescuers and doctors. Planning a full interview in advance is really hindered due to the fact that human body is an incredibly complicated mechanism and there are numbers of different cases of being injured. Though, we have prepared a scheme (attachment #1) showing how we will conduct the interview, allowing the victim to reply only by pressing YES/NO buttons (we consider inserting "I DON'T KNOW" button, too). Depending on the answers, some questions will be displayed automatically, and the others will be sent manually from base station.

The main idea emerged because by carrying out our project we want to succor rescue actions. Maybe it will contribute to minimize the number of deaths in emergencies. Such mission would tackle the real problem.

2.2.3 Objectives

We will consider the CanSat launch as successful under the following conditions:

- measuring all parameters and transmitting them to base to accomplish the primary mission
- after the descent, successful transmission of requested photos from different moments of flight (rocket drop)
- after the descent successful reading of victims vitals (drone drop)
- reaching stable two-sided radio communication
- building an additional module (because of the limited space in a rocket probably only one module will be attached on board) - our aim is to receive all essential data from the module.
- No structural damage or electronic failure after landing
- No trouble with localisation of the CanSat after landing due to provided gps readings and attention drawing elements
- cansat will remain operational for at least 5 hours

2.2.4 Measurements

During our missions the sensors will be used to:

- measure temperature, pressure and humidity

- GPS tracking
- measure altitude
- measure victim's pulse and oxygen saturation (drone drop)
- display questions on the screen and enable to answer them by pressing buttons (drone drop)
- save thermal photos (rocket drop)
- save color photos (rocket drop)

2.2.5 Expectations

In our research we want to evaluate how our "CHIMP" (pun intended), equipped with adequate sensors, works as a rescue device and make sure that it would be a real help for rescue teams in the future. First and foremost, we can provide victim location to the rescue team in no time. What is more, thanks to the short interview with the victim that we can gather, we are able to receive some essential information about the victim's health status which will be for sure significant for rescuers and then, doctors. Moreover, we want to show that the idea of exchangeable modules is realisable concluding in reusability in different environments. To prove that the concept of designing different modules is innovative, we are planning to use both modules that we are creating on finals day - the vital signs measurement one during the drone drop, and the camera module while scattering CanSats from the rocket. This is also due to the fact, that on the rocket flight no interaction with the device is allowed, which is definitely not the case during the camera module operation. The results will emphasise that our CanSat can be adjusted to various environmental conditions, and the modules are easy to change and customize. We hope the performance during finals will show that our CanSat is ready to accomplish real-life challenges.

3 CANSAT DESCRIPTION

3.1 Mission overview

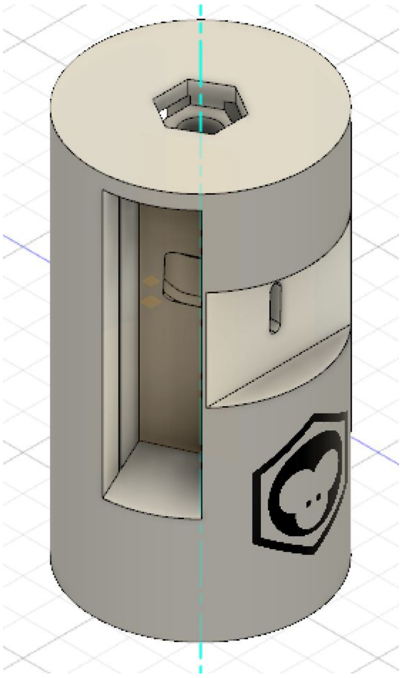
3.1.1 Overview

Before the launch, we will set onboard electronics to standby mode to decrease power consumption, then pack the parachute and prepare base station. Having reached the altitude of about 3 km, the parachute will unfold after the cansats will have been scattered. Its parameters are estimated to make our Sat achieve the target velocity of 9m/s during descent. In the time of the flight various measurements will be conducted: temperature, pressure, position. All the data will be both transmitted to base station and stored on onboard microSD card. Furthermore, every second, color images and thermal camera readings will be taken. These pictures will be stored in relevant directories on the SD Card, and be ready for transmission to the base station after a request. This will also happen once during the flight as after touchdown in rough terrain the radio link may break. To catch attention, we will use a buzzer and a LED that will blink every several seconds. Methods mentioned above will enable a potential victim to find the CanSat. After being found, our Chimp will be used to measure the heart rate and oxygen saturation of the person who puts their finger on the sensor. Moreover, we will send rescue-related questions and some recommendations based on the victim's situation. After receiving our CanSat, we will check its condition and analyze saved data.

3.1.2 Key elements

Onboard electronics includes: main computer, thermometer, barometer, an IMU unit, GPS, radio transceiver with its antenna, an OLED screen with buttons, high-power LED, buzzer and a kill switch. Additionally, the secondary mission modules: heart rate and oxygen saturation sensor in the first one, thermal sensor array and a camera in the other one. Casing and parachute are essential mechanical elements. For detailed iconographic please refer to attachment #5.

3.2 Mechanical/structural design



3.2.1 Body

The internal body of our CanSat is made out of 3D printed PLA. We have designed our own 3D model (available in our github repo, attachment #2) providing compartments for all sensors and electronic components. It also features place for a threaded rod, which is placed in the center and provides mounting point for parachute. Also, the monolithic structure seems durable - more about that in tests section. Internal electronic components are mainly soldered to the motherboard, which is screwed to the body. Temperature sensor, OLED display, buttons and a LED driver will be soldered to the second PCB board, that will be screwed in place as well. External casing in the form of flexible skin will be cast from TPU/silicone in a form of elastic tube, that our CanSat will tightly fit in. This makes our Sat more shockproof, and dust/waterproof. We will provide a special cutout in it for the display and buttons. Also, our project assumes creating interchangeable modules - we will print them in 3D and mount them to the main body using screws at the bottom of the device. With such skin our CanSat's overall mass should be between 310-350 grams (mass budget calculation can be found in attachment #3).

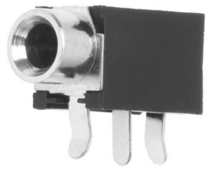
3.2.2 Safety pin

One of main CanSat requirements is having main kill switch accessible and easy to use. We are considering two approaches which are yet to be tested.

1. Normally closed push button with screw terminal with two nuts to prevent self loosening. It would be connected between main power source and power supply circuit. Nuts, when removed, releases the button and make the current flow. However, button might became single point of failure. We also do not know how it's going to act in large vibrations environment.
2. Two 2.5mm audio jacks (one for each power converter) which, when inserted, switches dc-dc power converter to sleep mode

(shorts shdn pin to ground). This approach takes advantage of

jack sockets not having any moving parts at all, which excludes vibration concerns. However, it any conducting material will get into the socket it will turn the power converter off. Waterproofing cap seems reasonable to cover the socket in this case.



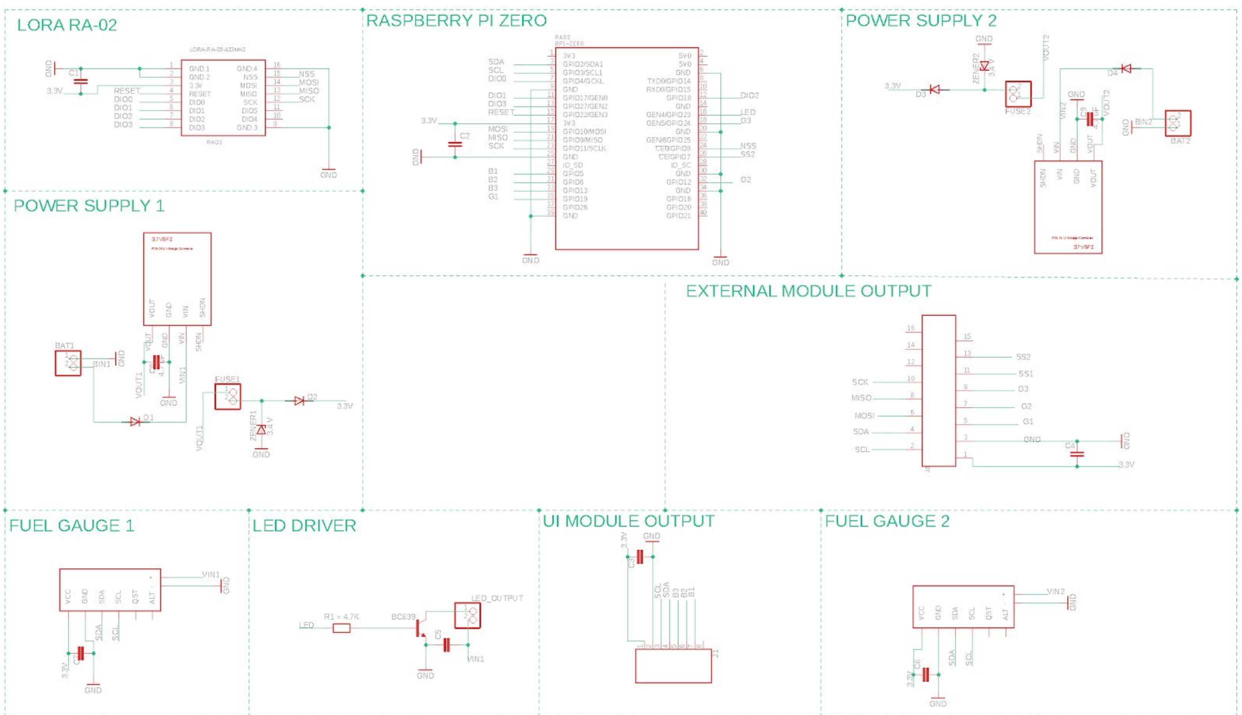
3.2.3 Battery placement

We have designed our CanSat internal body to meet the requirement of easy battery replacement on demand. It features two single 18650 battery holders exposed on two opposing sides of our can pointing upright. They will be covered by TPU external casing, which can be easily removed when needed.

3.3 Electrical design

3.3.1 General architecture

As the heart of our CanSat, we have chosen a Raspberry Pi 0W - it combines its small size with a powerful CPU which offers us multithreading, relatively huge amounts of memory (in comparison to microcontrollers) and possibility to record videos. It will be soldered to one PCB (motherboard) with GPS, accelerometer, gyroscope, barometer (BerryGPS-IMU), a transistor to drive LED and Buzzer, which are located in the additional module, two voltage regulators, place for fuses and a LoRa module. Everything is connected with Raspberry Pi over I2C, UART and SPI protocols and GPIO pins. The second PCB board with a temperature and pressure sensor, display/buttons



interface is connected to the motherboard using an unpluggable (zif) ribbon cable as well. Also, we provide data connection and power supply through a ribbon cable to the external module. Everything is powered by two 3.7V Li-Ion cells in parallel through step-down voltage regulators (one for each), fuses and a kill switch.
All Connections and the general idea of our electronic design is presented on a block diagram on the previous page. (for full page render, please find it under attachment #4)

3.3.2 Primary mission devices

The Pi is going to be topped with a BerryGPS-IMU shield designed to fit Pi zero pinout. This board has both temperature and barometric sensors embedded into it. The BMP280 (which is part of BerryGPS-IMU) offers a satisfying accuracy of +/- 1 hPa in a broad spectrum of pressure and ambient temperature, which makes it a superb candidate for missions conducted in harsh environments.

Due to the fact that the temperature is to be measured outside the CanSat, we are not able to use the sensor within the said shield. Instead, a BME680 sensor, mounted to the second PCB, is going to be used. It’s upsides are its small size and the ability to measure not only temperature but also humidity and pressure, what will allow us to compare readings from outside and inside of CanSat and make use of the backup sensor in case of failure of one of them.

The gathered data will be serialised and then sent to base via LoRa radio. A couple of modules have been considered, although all of them used either a SX1278 or a RFM98 chip. The specifications of these do not depict any considerable differences though, so the general criterion of choice was in this case the breakout board. We decided to opt for an Ai-Thinker Ra-02 module, which was the most compact of the available ones.

3.3.3 Secondary mission devices

BerryGPS-IMU

A Raspberry Pi Zero shield featuring various sensors which will help us realise the secondary mission:

- GPS - In cooperation with the cameras enables locating of the target
- Accelerometer, Gyroscope, Magnetometer - All three are going to be used to determine vertical axis roll, which is necessary to interpret images correctly. They will also determine the moment of landing.

Pimoroni MLX90640 Thermal Camera

After reaching an appropriate height a series of images of the ground will be taken. An on-board algorithm will pick the photos that may be interesting (those with warm objects) and send them to us marked with timestamp and altitude reading. The goal is to determine whether any possible targets are in the area. It is a part of our first external module.

Raspberry Pi Camera - picamera

Classic Raspberry Pi Camera module recording in HD resolution - after descending we can send a request for a photo from certain moment to our CanSat. It will pick a photo that we want and send it to us. It can be used to analyze the area from any altitude, which can be used to identify the potential victim(s).

Star LED and 12mm Buzzer

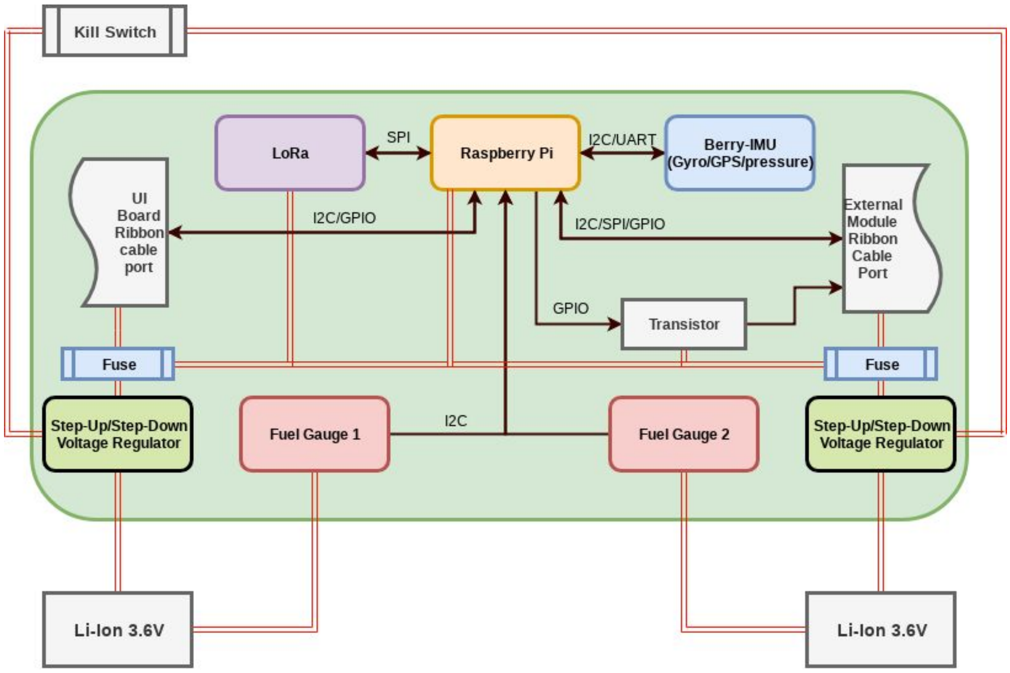
These are to catch the attention of potential targets after landing. Due to the fact that the LED requires a lot of power (300 mA), it will blink for the duration of 0.5s every 5s. Both buzzer and LED will be ran by a BC639 Transistor, which combines its small size with the ability to control 1A drag.

MAX30100 Heart rate & O2 saturation sensor

This is to measure the vitals of the target. Basing on this data the rescue team could be able to prepare themselves appropriately in advance. It is a part of our first external module.

SSD1306 OLED Display

The screen will be used to print questions requested by base and to ensure an easy-to-use two way communication user interface. Its resolution and size are big enough to fit simple sentences.



Main Board

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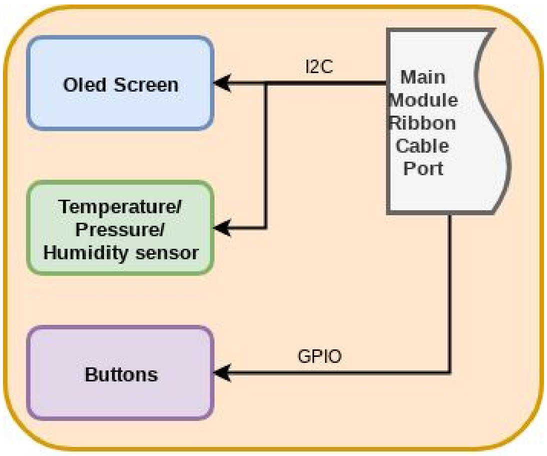

UI Module

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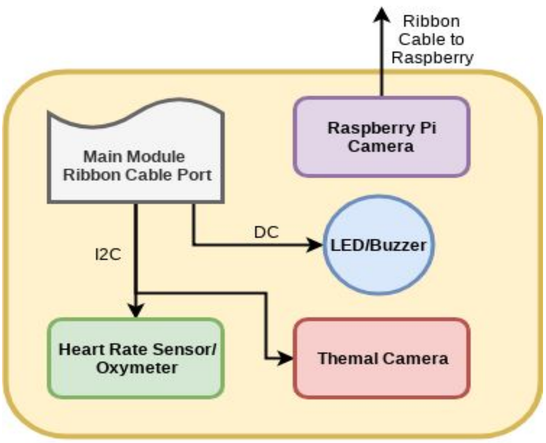
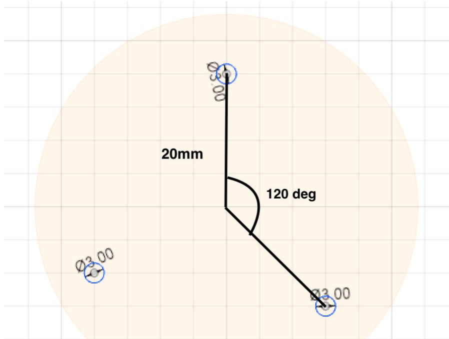


External Module 1

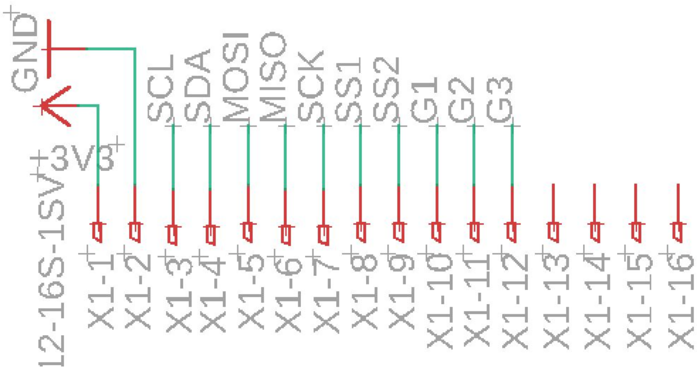
Plastic Monkeys 2019

3.3.4 Hardware Platform Interface



Our solution offers generic way of hooking up different modules to our can, which is guaranteed to work if it meets the following specification:

- 16 pin 1mm ZIF connector, both sides
- may use i2c, spi with two chip selects, 3 gpio
- its average current draw does not exceed 300mA
- provides 3x3mm mounting holes in place depicted below
- does not exceed 20mm height
- does not exceed 60mm in diameter



3.3.5 Power supply

An approximation of power budget has been made in order to derive how many energy sources of which capacity need to be taken into account. It is depicted in the following table.

Component	**Max. Current consumption [mA]**	**Typical current consumption [mA]**	**Remarks**
BerryIMU GPS	31	25	
DS18B20 Temperature Sensor	1,5	1,5	
MAX30100 HR+SpO2 Sensor	1,2	1,2	
BMP680 Temp, pressure, humidity	12	7	
MLX-90640 Thermal Camera	4,5	4,5	Although this seems impossible for a camera, it is proven in the datasheet. It has been confirmed in the test campaign
Raspberry Pi Camera	250	200	Will be turned off after landing
Raspberry Pi Zero W	230	230	
LoRa SX1278	120	30	Max Value is pure TX. The two chips share their current consumption specs. Typical value based on tests.
SSD1306 OLED screen	15	10	
FY248 Buzzer	12	4	Typical for 1s beep every 5s.
Power LED Star	310	60	Typical for 0.5s blink every 5s.
Total	**987,2**	**573,2 (343,2)**	**(after landing)**

Based on these results, a set of possible solutions has been presented. It is shown in the next table. When deriving uptimes, an 80% efficiency factor of the voltage regulator has been taken into consideration.

Solution	Total Capacity [mAh]	Uptime @Max. Consumption	Uptime @Typical Consumption
Panasonic 18650 3,6V	3400	2:49:00	7:25:00
2x Panasonic 18650 3,6V in parallel	6800	5:38:00	15:39:00
Prologium Li-Cer 3.7V	To match a single 18650 (3400mAh), a 32x32cm sheet is required		
	To match two 18650s (6800mAh), a 42x42cm sheet is required		

The considered solutions feature two standard 18650 sets as well as a pioneer bendable solid state Lithium-ceramic battery provided by ProLogium. Although these are cut-proof, bendable and safe on the whole, a hefty 32x32cm sheet would be necessary to match its alternatives, which was the reason of excluding this solution. Over fifteen hours of uptime is a satisfying amount, nevertheless this result does not consider voltage falloff and ambient temperature (which is proven to drastically influence battery life) and therefore is surely overestimated. On these grounds the decision has been made to opt for a **double 3400mAh Panasonic 18650 set**. It provides voltages ranging from 4,2V to even 3,1V when nearly exhausted, so a step-up/down voltage converter (Pololu S7V8F3 3.3V 1A) is necessary to ensure stable power supply for the sensors and Raspberry Pi (3,3V). This setup has been thoroughly tested (see 4.5)

3.3.6 Communication system

The mission assumes two-way communication between the Base and the CanSat. To achieve this, one could set up synchronized clocks on both devices and assign specific time intervals for each station. Nevertheless such configurations tend to desynchronize, which would lead to global communication failure. To overcome this problem, we propose the following master-slave protocol:

The principle is that the slave listens most of the time and the master may transmit at any time. Slave transmissions are only allowed as response to the messages received from the master. After transmitting a message, the master listens for the slave for a predefined time window.

Let CanSat be the master node, and the base - the slave. The reason for this is that the slave always needs to be listening for packets - thus using energy. Furthermore, more data will be sent from CanSat to Base than the other way, which enables the Slave TX Interval to be shorter.

The Frame (the period of two way communication) looks as follows:
First, the Master sends one packet of data. After the slave receives it, an ACK (acknowledgement) is sent back to the Master. It is then followed by a brief time period of specified length, when the Slave transmits their data.

As said before, we decided to embed an AI-Thinker Ra-02 LoRa module into the Cansat. It will be equipped with a 17,3 cm long (quarter wavelength) flexible antenna. The base station will be equipped with a TTGO board which features LoRa transceiver topped with an Arduino-like board and an OLED screen. This could be useful to monitor the performance of the radio link in real time. It will use a Yagi type directional antenna with gain of 15dB.

3.3.7 Failsafe and failover mechanisms

Power

We are aware, that errors occur all the time during such complicated system development, hence we are preparing our hardware for such circumstances. We have implemented redundant power supply systems, with two step-up step-down voltage converters operating totally independent. Moreover, both voltage converters are protected from battery reverse voltage with schottky diodes. Next, we have incorporated over voltage protection at voltage converter output with zener diode and resettable fuses. Last but not least, we position both circuits on two opposite sides of the board, to make it impossible to short both of them with the same wire.

Sensors

For our sat primary mission we have incorporated redundant sensors, bme280 and bme680 which can overrides one another in case of emergency. We are also considering having small arduino connected to i2c bus monitoring its activity and gather basic telemetry in case of raspberry pi failure.

3.4 Software design

Linux-based operating systems available for Raspberry Pi, which we are using in our Sat, support multithreading, so we can apply distributed software. We will call each program in our design a “block”. Each sensor is going to have its own individual block and individual log file. Merge-Block will merge obtained data with attached timestamp and send it to the main buffer, which will be regularly (partly) emptied by LoRa transmitter block. Buffer will mainly work in prioritet FIFO manner, if not else specified. Priority specification gives us option to request some specific data (photos for example). Distributed software structure provides special redundancy - if one sensor stops working, or one program crashes, the rest will work uninterrupted. What is more, Raspbian provides us with daemons and systemd units that should keep our blocks up and running. Flow diagram of our software can be found at the end of Software Design part.

Communication between all blocks is based on writing and reading from log files. Each block will write to its own log file creating a stack of data, from which Merge-Block can easily obtain most recent readings (most recent line). This solution has many advantages over direct data transmission between two blocks - different scripts aren't connected in any way, a crash of one of them does not affect others, Merge-Block doesn't have to ask for a reading and wait for it (all tasks are done asynchronously) - the data in the log file is always ready to take. Furthermore, if we want to launch another block, that has turned off before, it doesn't have to look for a connection to the Merge-Block, it just writes to one specified file as if nothing happened. Also, each log file with raw data can be used as a second, redundant source of data after a mission. The only thing that is going to run in a slightly different way is Camera Block. We need to precisely synchronize footage with readings like GPS position, rotation, attitude etc. To achieve that, our camera will take photos all the time and save them in one folder, and when a Merge Block creates a new packet with data it assigns it a number, copies the most recent photo, changes its name to this number and stores it in a second folder. As the result - if we want a photo, which shows us a situation according to a certain packet - it's ready to take and send.

Due to the usage of Raspberry Pi, and experience of our members in this language, we decided to write our code in Python with additional various Bash scripts.

To calculate the storage that will be used by all logs we came up with a formula:
Used storage = ((size of one reading (S) * number of sensors (N) * read frequency (f1)) + (color image size (I) + thermal image size (T)) * imaging frequency (f2)) * operation time (t) The result can be seen here:

S [B]	N	f1 [Hz]	I [B]	T [B]	f2 [Hz]	t [s]
40	10	4	300000	12000	1	25200
Total:	**7902,2 MB**					

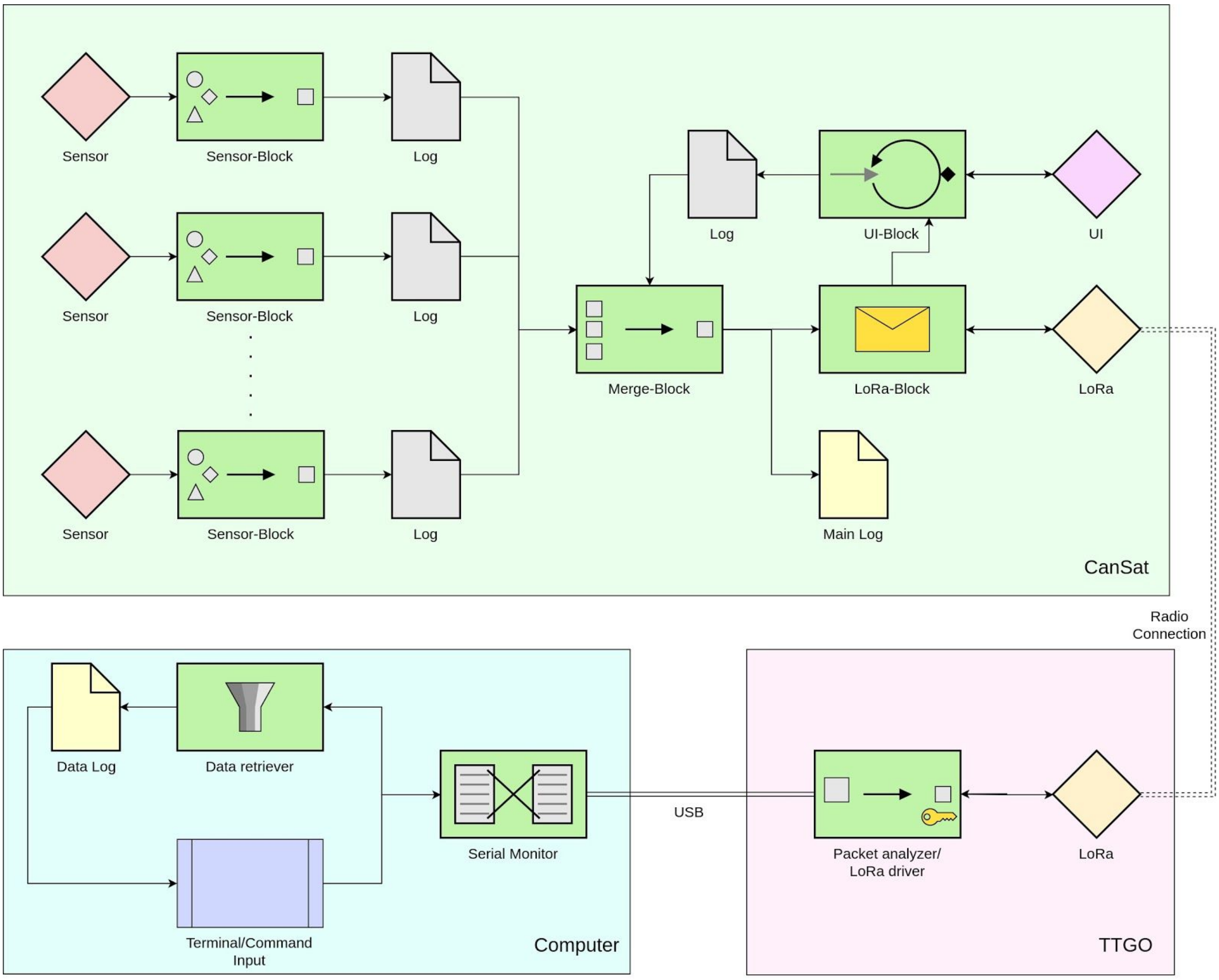
We can see that all logs from 10 sensors and photos from two cameras (thermal and regular) during a 7-hour mission will need less than 8GB. Our Raspberry Pi supports micro-sd cards that have much more free space than that. We can add to it 5GB occupied by the Raspbian system and our scripts, 2GB of an optional camera recording to see that 16GB SD card would provide more than enough space for our mission. However, for our safety, ability to add any features later or double or triple the photo/reading rate, we are going to use a 32GB card.

Our base station setup has to be written in two languages and for two devices - TTGO LoRa module and notebook with Linux. TTGO, programmed in Arduino C, will have 2 different modes: listening and sending. In the listening mode, it will receive data from LoRa, check their correctness, display them on built-in OLED screen and send them to a computer via USB, where Python script will retrieve serial data and save them on computer's hard drive. Furthermore, all readings will be automatically sent to our own Graphite database using python scripting. This gives us even more redundancy and ability to plot data live using Grafana Software. In sending mode TTGO will listen for a command from PC, which will be inputted manually, and send it to CanSat using LoRa.

To send the data via LoRa, we decided to use MessagePack. It is a binary serialization format thanks to which we will be able to pack the sensors' readings. Small integers are encoded into a single byte, and typical short strings require only one extra byte in addition to the strings themselves. We have also considered JSON but we came to the conclusion that MessagePack is smaller and faster so we opt for it.

LoRa link efficiency estimation has proven that at minimal Spreading Factor and Coding Rate necessary for the transceivers to stay in touch it is possible to send about 1500 bits of pure payload per second. To make maximum use of this low bitrate, the data is compressed and serialized in an appropriate way. For instance, the readings from the temperature sensor could undergo the following process:

- The raw value is a float in range of around (-40, 40 degrees)
- If we assume the boundary range of (-63,5, 63,5) and decrease the accuracy to 0,5 degrees, we can use the following operations to fit the value into one byte:
- (Raw temperature value) * 2 + 127 converts the range into (0, 254)



BeaCan Software

Plastic Monkeys 2018

3.5 Recovery System

We are going to use a parachute to land safely, however at the first stage of planning we evaluated the idea of landing using spherical airbag, but it turned out to be way too risky and time-consuming. Our calculations estimated optimal perpendicular surface of parachute’s canopy to be 0,28m^2 (assuming optimal velocity as something close to 10 (more precisely 10,3)) meters per second, (calculated from classical drag force equation). Assuming that we would fall from 3000m and CanSat motion is close to uniform motion estimated flight time is 290 s. Parachute mounting is done by binding all its strings to hole in threaded rod in internal casing. Several test drops have been conducted (see 4.3)

3.6 Ground support Equipment

Our ground station consists of one notebook equipped with Linux distribution as OS, and TTGO - an arduino compatible development board, with built-in LoRa module and OLED screen (for live data preview) and suitable antenna. It will be paired with our radio module in CanSat, and constantly listen for packets from it. Packets will be sent to the computer through USB-cable where they are going to be aggregated, arranged, analyzed and stored. Also, we want to send commands and text to our sat - they will be loaded on laptop, sent to our board through USB Serial and then released to Sat.

4 4. TEST CAMPAIGN

4.1 Mechanics

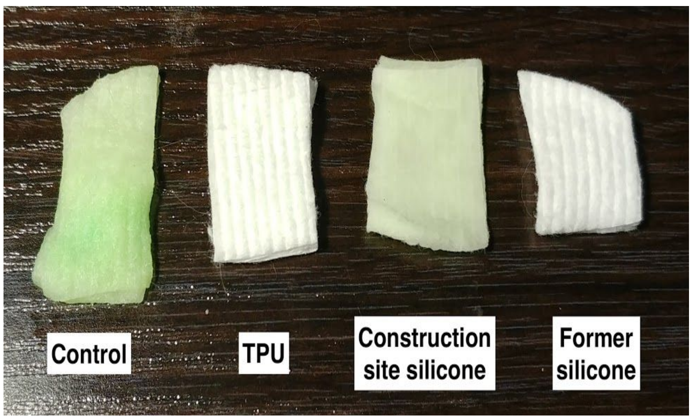
4.1.1 Hardware alignment

We consider space saving a very important factor of our design, since less space taken by necessary components leaves more space for modules. To align our hardware optimally we are going to model each component in a 3D software and move them around. Having the design done, we are going to begin prototyping by assembling our CanSat according to the design and by performing tests on the prototype. The tests are going to check: probability of short circuiting, each sensor working, mechanical durability and telecommunications.

4.1.2 External casing

Our external casing is supposed to be made out of silicon or similar material. We expect it to provide water-resistance, absorb part of energy released at impact. We have made 3 different outer shell prototypes to test their durability and water resistance. They were made from:

- Former silicone (easy to make good forms, not so easy to work with)
- Construction site silicone (easy to get, not so easy to model)
- 3d printed TPU (easy to model, not so easy to print)

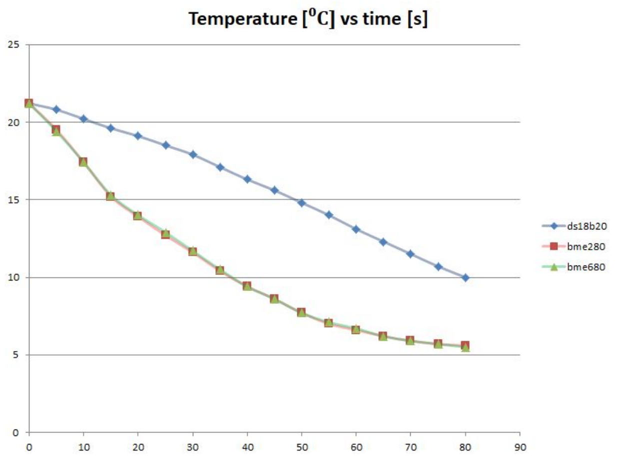


We carried out water resistance test by placing tissue between shell and internal casing, and partially submerging them in mixture of water and ink for 20 minutes. Construction site did not pass this test due to its multiple defects. TPU and Former silicone went fine.

Conducted durability tests showed that since we can not control former silicone thickness (unlike TPU where we just set its thickness in 3d cad software) it is easily breakable. Furthermore, on TPU we can also easily write using permanent marker and stick ours and sponsors' stickers. Therefore we would opt for TPU casing.

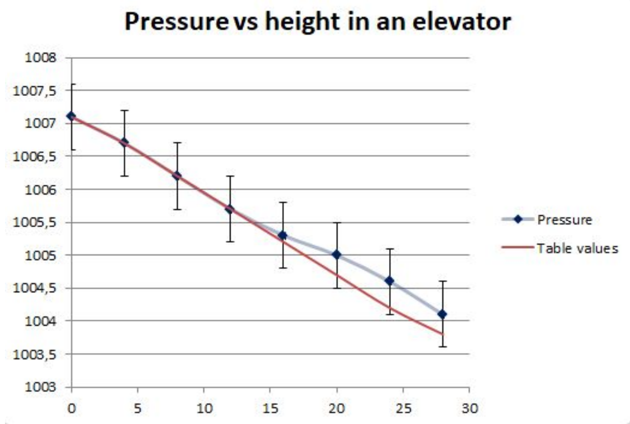
4.2 Sensors

4.2.1 Thermometer



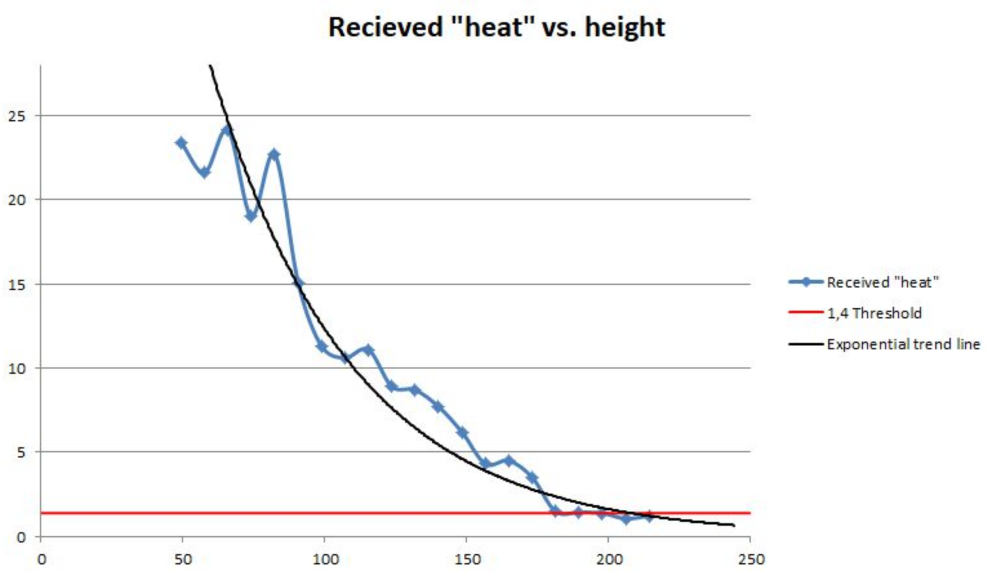
Three different thermometers (DS18B20, BMP280, BME680) have been evaluated and tested. The devices were put into a fridge (ca. 5oC measured with an alcohol thermometer). It is noteworthy, that the DS18B20 reacts to temperature changes much slower than its counterparts. Moreover, it takes over 0,5 seconds to get a sample of data. Because of that we opted for the BME680, as it is the newer version of BMP280 and has some additional features.

4.2.2 Barometer



The BMP680’s pressure sensor has also been thoroughly tested. During an elevator ascent, it has shown accurate readings which changed appropriately every floor. They have been compared to calculated table values. The sensor has also been taken to a highland region, and the read pressure has been compared with the table value for such height showing no offset. This proves its reliability and enables us to embed it into the CanSat.

4.2.3 Thermographic camera



The goal of the thermal camera test was to measure the boundary height, from which we can detect various objects using this sensor. To achieve this, a drone flight over a bonfire has been conducted. A series of images at altitudes varying between 20 and 200m have been taken and analyzed. An automatic algorithm has been used to determine important areas on the image (we don't want to transmit the whole raw readings). It works as follows: First, the average temperature of all pixels is calculated. Then all pixels, the temperature of which is greater than this average + a given threshold are returned as the result. The diagram depicts the relationship between the drone's altitude and the "received heat", which is the sum of values of the chosen pixels. During additional pre-tests an optimal threshold value of 1,4 has been determined, which successfully removes background noise and is shown by the red line.

Basing on the gathered data a conclusion is to be drawn, that from the altitude of 170 meters one can doubtlessly detect a small bonfire (40x40cm). That implies that an area of 140x140 meters on the ground can be successfully scanned for such objects. It appears that in situations where a heat-emitting object is to be found, the thermal array actually gives more data then color images, hence it is doubtlessly useful in our mission.

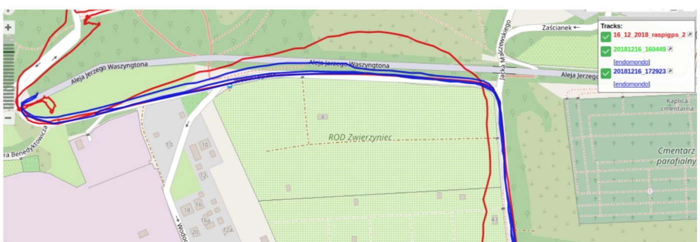
4.2.4 Raspberry Pi Camera

During the same flight the color camera has been tested. The full-quality images enabled us to find the said bonfire from about 170m, which is comparable to the possibilities of the thermal sensor array. However, in order to send them to base they need to be significantly compressed, thus losing sharpness. As the result the maximum height from where we were able to detect the 40x40cm target was about 80m. After some calculations, this implies that a 3x3m tent would be recognizable form the height 0f 340m out of a 400x300m area.

4.2.5 Pulsometer & Oxygen saturation

By far we have received only one of two considered sensors, the MAX30100. Although at the beginning the readings seemed to be accurate in comparison with a smartwatch, later we've encountered a bug which disrupted the data completely. Right now we are working on a fix and waiting for the second candidate (PulseSensor) to arrive.

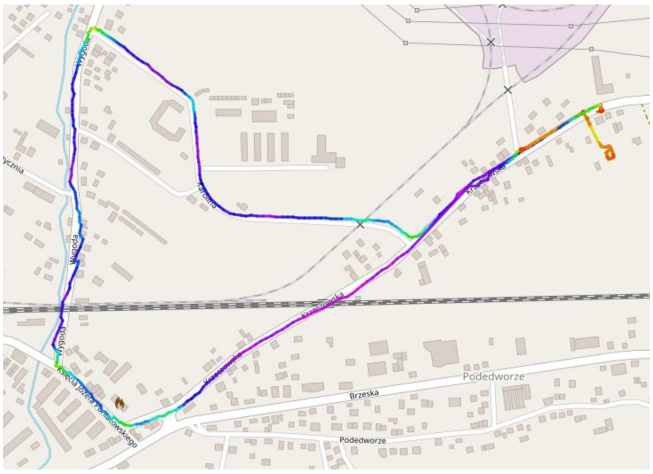
4.2.6 GPS

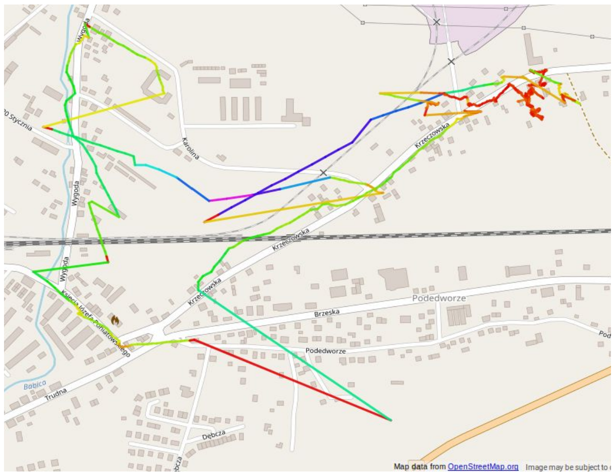


As a GPS module we are using

BerryGPS-IMU v3. We have tested its accuracy by moving with different velocity (walking and driving a car) and comparing the logs with the very precise phone's GPS. After having found GPS fix, the track designated by Berry IMU was almost the same as the track appointed by phone. But when Berry loses contact with some satellites, its readings start to differ from reality. During our test, the biggest measurement error was equal to around 50 m and it was noted when our module was inside a car and its velocity started to grow. After a while the number of available satellites increased so consequently the measurements became more precise again.
Although sometimes BerryGPS IMU has some problems with indicating the proper route, we assume that those differences aren't really significant . Taking into account all situations when we used this module and compared its readings to another source, we were always satisfied. We are thus ready to confide in BerryGPS's measurements.

We have also tested how does BerryGPS perform without external antenna. Being in a car, there were a lot of problems with obtaining a fix – measurements were really deformed. But getting out of the car didn't help much. There is only one conclusion: without external antenna the measurements are not accurate.





4.3 Tests of recovery system

During these tests we have dropped a payload, connected to the parachute with 8 strings (65cm each), from various heights. The canopy of our parachute is made of plastic-like super-soft, lightweight and tear-resistant fabric (producer does not provide exact name of this material). A bowl measuring 80 cm in diameter, with a 40 cm hole in its middle. This is to ensure a stable descent.

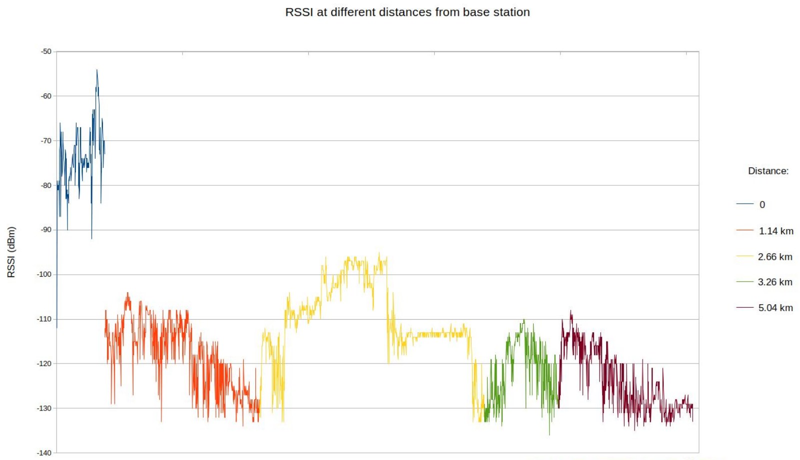
The first drop was from a 11 floor of Kapitol dormitory building (50 meters in total, 40m from 11 floor, during neglectable wind. Although the flight was stable and controlled, the descent rate was as low as 4,6 m/s (calculation based on video taken, which is available as attachment to this document). In order to reach speeds closer to the desired ones we have broadened the hole in our parachute from 40 cm to 50 cm. During the next test we have decided to use a drone to lift the payload to exact 100m. However, it had a strict mass limitation of 100g, so we didn't use the full payload. The analysis of gathered data has proven though, that even with 300g of load the speed would be about 6 m/s. Broadening the hole even more seems a bad idea since the parachute might curl out. On these grounds we have ordered a smaller parachute (55 cm in diameter), the parameters of which seem to rise the descent rate to 10m/s. We will conduct additional tests with new parachute to confirm desired descend rate.

4.4 Communication system range tests

Our first environmental radio test was conducted in Blonia Park Krakow and it focused on the measurements of throughput during an about one kilometer long walk. All further tests were conveyed with 20dBm = 100mW of power setting.

Length of the packet	Delay between sending packet (ms)	Approximate distance from base station (m)	Packets per second	Percentage of received packets	Average RSSI (dBm)
30	300	0-250	3.28	98.27%	-96
20	300	250-300	3.26	99.40%	-97
20	500	300	2.03	100%	-97
10	500	300	1.99	97.30%	-99
10	800	300	1.33	81.08%	-100
10	300	300-850	2.81	85.48%	-117

In order to measure maximum range of our radio and the link reliability, we set off to Dobczyce Lake. The base station was situated on top of a 10m observation deck. The transmitter attached to a car and driven to four measurement sites at distances of 1.14km, 2.66km, 3.26km and 5.04km from base



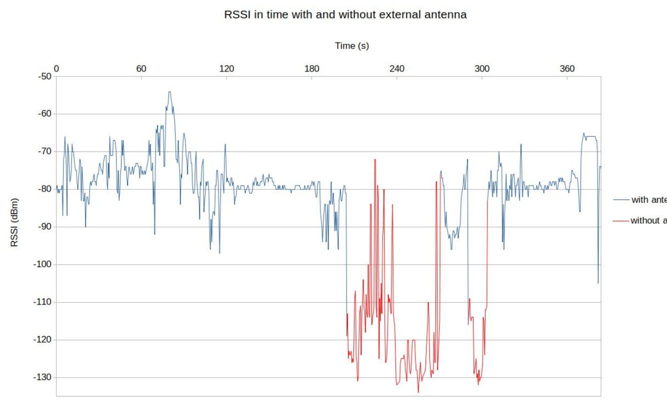
station. The results are shown in the table below:

Dist-ance	Altitude	Received packets	Packets per second	Average RSSI	Radius of the 1. Fresnel zone	Comments
1.14 km	316 m	91.25 %	1.82	-118 dBm	14.05 m	Due to the fact that the transmitter wasn't so far from the base station, we expected that the signal strength would be better. However we should take into account that when we were holding our can, we were surrounded by trees that could cause some distortions.
2.66 km	290 m	87.55 %	1.74	-110 dBm	21.46 m	Although the results were quite good, most of the lost packets were sent in the last minute of this attempt. We we were heading back to the car then so when we were in a some kind of ravine surrounded by trees, radio communication was hindered. Assuming that we take into consideration the time without last minute (so when we weren't moving through trees), the percentage of received packets is getting up to 97.35%, that gives us 1.94 packets per second!
3.26 km	338 m	72.35 %	1.44	-121 dBm	23.75 m	Low percentage of received packets was probably caused by limited amount of time we spent doing this try– all indications are that if we had stayed there longer, the results would have been better.
5.04 km	268 m	73.59 %	1.46	-124 dBm	29.53 m	Thanks to reduced amount of distortions in Fresnel zone, communication between transmitter and receiver was possible even though the distance was substantial.

The conducted ground radio tests have proven a reliable communication over distances exceeding 4 kilometers - thus ensuring uninterrupted transmission during the flight. Moreover, the link was also stable when the transmitter was moving attached to a car (over 15 m/s, which is more than the descent speed of the CanSat). In spite of heavy rain and many terrain obstacles on the way, 75% of 20-byte packets have been successfully received (the checksum matched) . It has also appeared, that settings such as Spreading Factor of 7 and Coding Rate of 4/5 are sufficient to achieve the said goal safely. This enables us to achieve 80 bytes per second per side throughput which can probably be further increased by optimising software. Such efficiency lets us transmit images of satisfying quality quickly which has been proven in several tests.

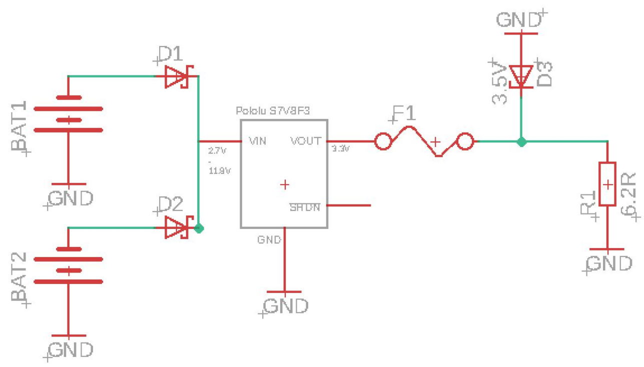
The photo on the left is a 160x120 JPG file of size of about 3kb.

It has been sent via LoRa in under a minute, and all the lost packets have been successfully retransmitted and rearranged due to our software. We estimate the minimal time of sending an image of such size to be around 25 seconds.

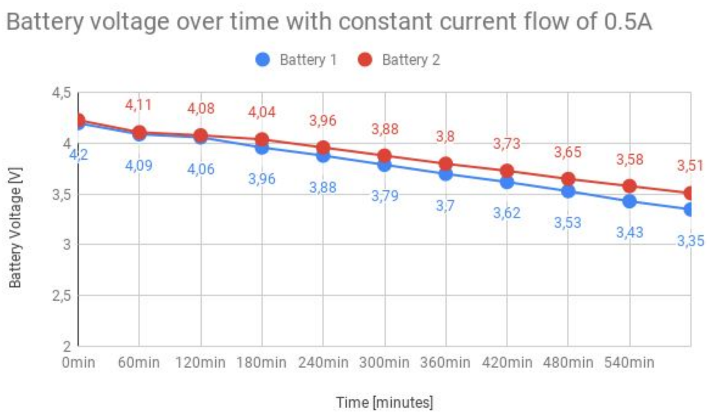


In addition to that, we conducted tests regarding available antennas. The Yagi came up trumps, as it boosted the RSSI by over 20. Several models of quarter-wavelength CanSat-side antennas have also been tested and proved a wide range of discrepancy despite their similarities. We have opted for the one which had the best signal strength. The chart below shows how RSSI was changing in time when we were changing the quarter-wavelength antennas and even though the differences are not really visible, one of them seemed to have the best signal strength.

4.5 Energy budget tests



To estimate the maximum battery uptime during the mission, the measurement of current consumption has been taken. A current of 520 mA was drawn during the usage of the camera, while 300mA were the peak values while this device was turned off. These values correspond to preliminary predictions. To confirm our calculations we carried out battery discharge tests. We took our whole power supply system (that includes two 18650 batteries, couple of schottky and zener diodes (failsafe mechanisms), fuses and 3.3 step-up/step-down power converter) for a fairly long trial (10 hours in total). We have constructed the following circuit, using 6.2 Ohm resistor resulted in constant current load of 0.5A which is a good approximation of real current consumption our sat will draw. Battery voltage drop over time can be seen at chart provided on the left. This test confirms that our sat will be able to work constantly for over 10 hours without any doubt.



5 PROJECT PLANNING

5.1 Time schedule

Following the agile framework, we are planning our workloads for every week providing valuable results in iterations, this way we deliver basic solutions first and improve them over time.

Date	**Action**	**Phase**
September, October 2018	Making decisions about missions, electronics and mechanics, evaluating ideas, testing basic key concepts, starting activity on social media that will develop along with our project	design
4 November 2018	Preliminary Design Review	Key date
8 November 2018	organisational meeting with our agile coach to draw some conclusions wha we should change before the second report to enhance our performance	organisation
15 November 2018	Preparing first external case prototype	prototyping
17 November 2018	Comparing and testing each of 3 thermometers we had	testing
22 November 2018	Creating some silicone molds	prototyping
26 November 2018	Establishing radio communication and initial test with stock antennas	testing
27 November 2018	receiving essential parts from OzzMaker	organisation
29 November 2018	Barometer tests	testing
4 December 2018	First descent - parachute test	testing
11 December 2018	Participating in PCB designing workshops	organisation
16 December 2018	Environmental radio test with yagi antenna focusing on the throughput measurements and, at the same time, GPS accuracy tests	testing
18 December 2018	Receiving new components from Pimoroni	organisation
20 December 2018	First test of the thermal camera	testing
22 December 2018	Final environmental radio test with yagi antenna focusing on the range measurements	testing
27 December 2018	Water and dust resistance of the silicone mold	testing
2 January 2019	Establishing two-way radio communication and sending first photo via LoRa module	testing
5 January 2019	First safety pin prototype	prototyping
9 January 2019	Batteries’ lifetime test	testing
11 January 2019	LED and buzzer performance	testing

12 January 2019	Final tests of IR array, picamera and parachute	testing
13 January 2019	Critical Design Review	Key date
second half of January 2019	constructing CanSat and its additional modules, providing software and mechanical solutions	constructing
February 2019	testing CanSat as a whole, making possible improvements	testing
beginning of March 2019	preparing CanSat to launch	preparation
10 March 2019	Final Design Review	Key date
March 2019	thinking how to optimize the work of CanSat, possible changes will be executed but only when supported by tests, making sure that Sat is ready to be launched	preparation, possibly constructing and testing
4-7 April 2019	Final Competition	Key date

5.2 Task list

We carry out task tracking with Trello's Kanban table, which is publicly available at https://trello.com/b/yPotoGbC/cansat-🐒 (please note that there is an emoji in the url). Since we divide our workload into many small tasks, there is no point into placing all of them here, as stated before, the full list can be found in our trello table. Every task is properly labeled according to its subject and has a team member assigned to it, hence we can track whether knowledge sharing process is taking place and if workload is evenly distributed. One thing we learned about ongoing workflow, is that that the fully agile approach is not adequate for this project since we have no way to manipulate time limits. Hence, we opted for modified Kanban approach with fixed due dates. From the day of last report, every task had its own deadline according of team members declaration. To the day of writing this report, we've done **82 tasks (41 since PDR, sic!)** with average of **20.25 tasks per member** - which still looks like **healthy collaboration**. Due to presented modification we increased number of tasks done on time. From our CDF diagram, it can be easily concluded, that we work in 1 week long sprints, with great results (steep burn-up curve).

To better build up team spirit, after PDR submission, we have organised so called retrospective meeting, with our Agile coach, to look back at our workflow from distance and propose some improvements. We came up with several conclusions, where most of them were applied during work between PDR and CDR. These are:

- doing tasks in pairs results in better quality of delivered values and keeps us motivated
- we should consult ideas with each other
- good communication between team members is a key value

- doing tasks from same category all the time decreases morale, now we do tasks with different labels for better knowledge propagation

5.3 Resource Estimation

5.3.1 Budget

Component	Raspberry Pi Zero W	Berry GPS-IMU v2	BME680 thermo meter	SX1278 LoRa Module Ra-02	PCB	IR Array Breakout MLX90640 (Qwiic)	Parachute	Power LED diode	FY248 Buzzer
Price	52 PLN	44,5 USD	22,5 USD	4,5 USD	85 PLN	34,80 USD	60 PLN	6,50 PLN	2,50 PLN
Status	✓	✓	✓	✓	ordered	✓	ordered	✓	✓

Component	Tact Switch *3	SH1106 OLED Display Module	micro SD card 32GB	Li-Ion Panasonic NCR18650 B Battery *2	Step-up/step-down voltage converter *2	Liquid rubber - silicone for external case	Filament PLA for Internal Casing	Pulse sensor	Fuel Gauge * 2	picamera
Price	3 * 2 PLN	27 PLN	19,95 USD	2 * 24,90 PLN	2 * 35 PLN	35 PLN	45 PLN	24,95 USD	2 * 10,95 USD	29,95 USD
Status	✓	✓	✓	✓	✓	✓	✓	ordered	ordered	✓

	PLN	USD
Sum	438,8	203,05
Exchange rate(13.01.2019) to EUR	0,23	0,87
Sum in EUR	100,92	176,65
Total	~280€	

5.3.2 External support

It comes out that our project is considered as pretty interesting one because of the fact that a number of organizations have decided to help us. At the moment we are collaborating with worldwide known companies such as **Pimoroni** (United Kingdom), **Sparkfun** (United States of America) and **OzzMaker** (Australia) - they sent us necessary parts. Additionally, the **Krakowski Park Technologiczny** (KPT) (Poland) which is the most complete one-stop-shop for business operating in Poland offered us financial support. Moreover, we have made contact with Farnell element14, the global high-service distributor of technology products, but we're still discussing our potential cooperation. Listing other backers we mention **DreamLab** [Ringier Axel Springer Polska sp. z o.o.] that provides us with access to their **conference rooms** and **agile coaching** when needed - **Aleksandra Kendziora**. We have consulted our ideas with professional **TOPR rescue team member** - **Jacek Bąkowski** and we also gain some **medical advice** form **Katarzyna Szpak** - befriended doctor. Thanks to **Paweł Błach** we were able to test our parachute and cameras using his drone. When it comes to substantive and methodological help, we had confronted our ideas and prototypes with multiple **Hackerspace Krk** (rapid prototyping, electronic circuit design) , **Klub** Turystyczno-**Radiowo**-Astronomiczny **Ryjek** (regarding radio uplink, antenas, two sided communication and so on) and **AGH Space Systems** (mechanical design, parachute choosing etc.) members. We have been granted with access to **3d printer in our highschool**. Last but not least, we are actively consulting our ideas and decisions with **former CanSat builder - Jan Dziedzic** - to learn from others mistakes.

6 OUTREACH PROGRAMME

Published	Post	Type	Targeting	Reach	Engagement
7.01.2019 23:28	EN: Finally - our LoRa tests! Grab your			10,9K	283 55
5.01.2019 21:45	EN: Wow guys, we've made a lot of things			217	25 22
28.12.2018 21:42	EN: Hey guys, how you doing? Have you heard			223	81 16
24.12.2018 16:44	EN: Dears, Christmas is coming! 🎄 Whole			218	66 16
19.12.2018 21:29	EN: Just look at that! A bunch of teens shivering			213	164 15

Our team is betting on various publicizing methods. Currently, Plastic Monkeys have their own simple web page (plastic-monkeys.space), Facebook and Instagram fan pages (about 370 followers in total -), where our work progress is shown to our followers. These mediums of communication are the most versatile and popular among young people, who we are targeting. Also, we have our own YouTube channel where you can find videos explaining various aspects of our project. Furthermore, we have designed our own logo, graphics, and wallpapers that are used by all team members. Our page and description of CanSat competition were spread among students and teachers in our high school using facebook school group. We have been mentioned by them on their official Facebook page.

- Our Plastic Monkeys Facebook Page: facebook.com/pmcansat
- Our Plastic Monkeys Website: plastic-monkeys.space
- Plastic Monkeys YouTube Channel: PlasticMonkeys Youtube
- Plastic Monkeys on Instagram: instagram.com/pmcansat/

We have boosted our posts on Facebook which resulted in broaden the outreach up to 10 thousands users!

In addition, we conducted a presentation regarding CanSats for our school mates during the RoboTeam science club meeting. They were very interested in whole project and gave us a lot of valuable feedback.

Also, we have got in touch with the local newspapers' editors and now we are waiting for our own article where we could describe our project. We have also scheduled a meeting with one of RMF group radios to talk about the project and maybe will be awarded with an interview.

Moreover, we have sent couple submissions to local meetups for making a presentation about our project (waiting for decision yet):

- pykonik (https://www.pykonik.org)
- PyLight Krk (http://www.pylight.org)
- SysOps/DevOps Kraków (https://www.meetup.com/pl-PL/SysOpsKrk/)

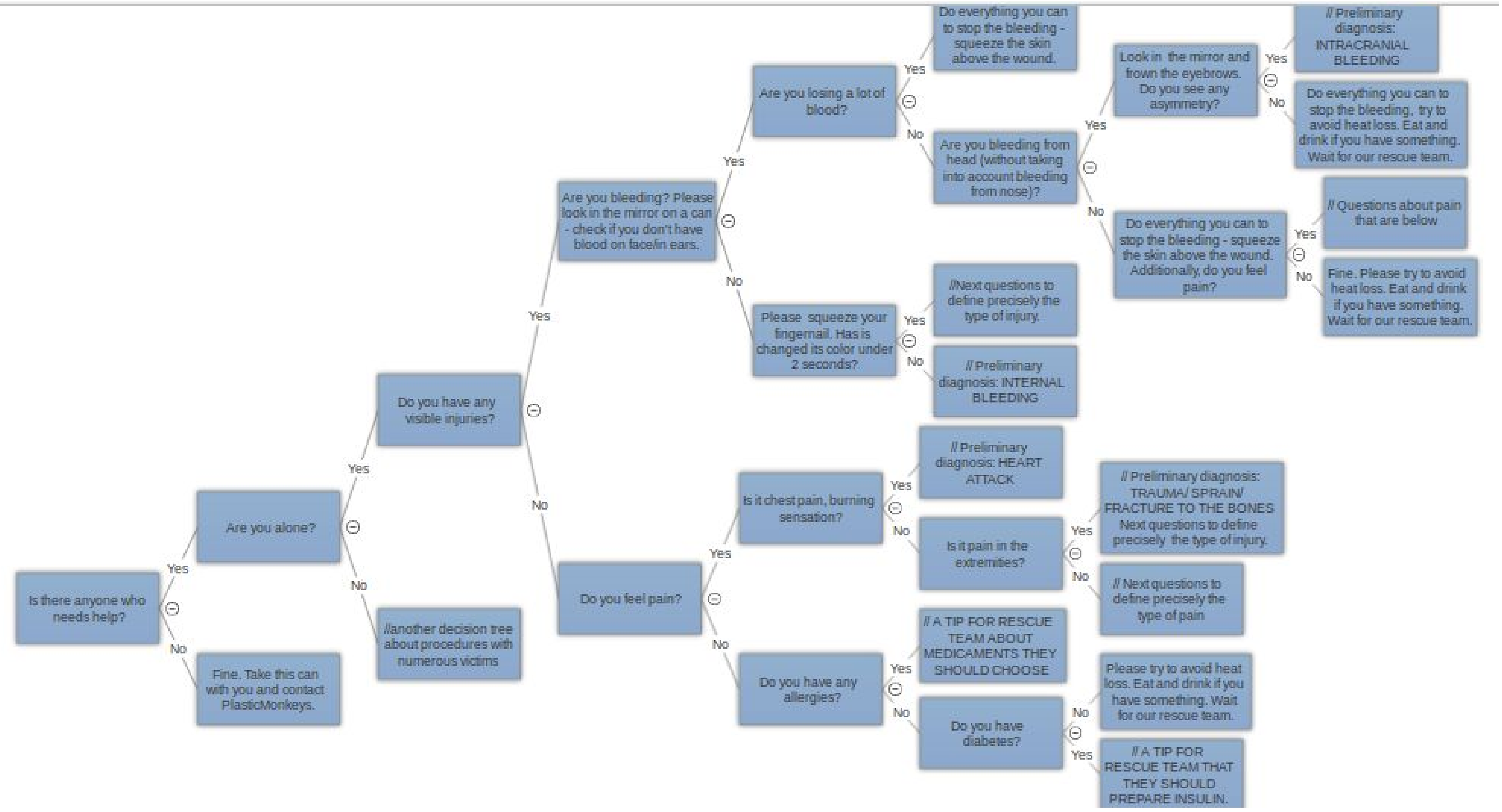
CANSAT CHARACTERISTICS

Notes: Diameter of the CanSat is bigger than the one shown on the last page because of extra silicone skin.

Characteristics	**Figure**
Height of the CanSat	112 mm
Diameter of the CanSat	65 mm
Mass of the CanSat	32
Estimated descent rate	7 m/s
Radio transmitter model and frequency band	SX1278, 410-525 MHz
Estimated time on battery	13 hours
Cost of the CanSat	~200€

Attachments:

#1 Interview scheme

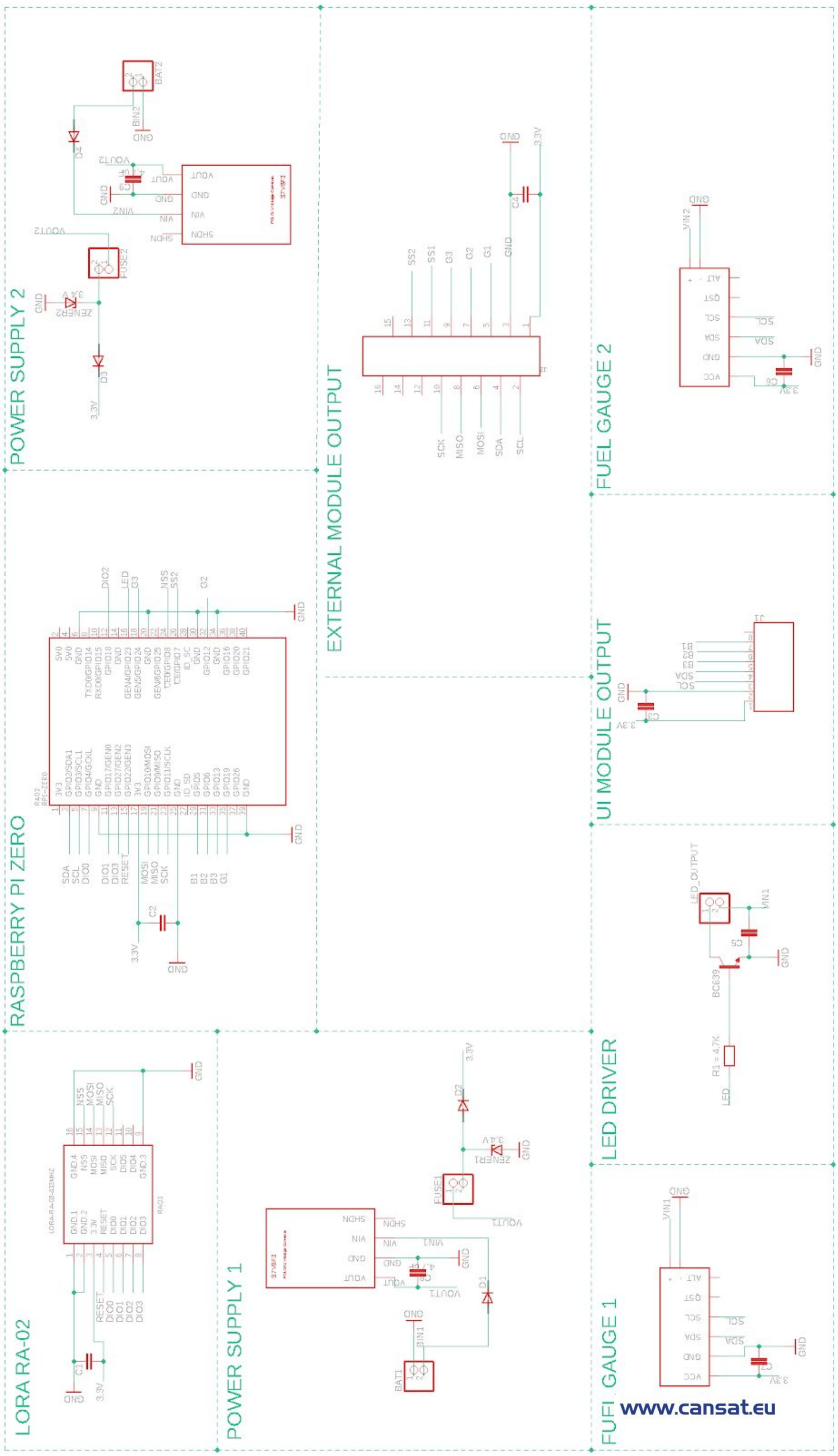


#2 github repository link: https://github.com/evemorgen/PlasticMonkeysCansat

#3 mass budget table

część	masa [g]	założona gęstość [g/cm^3]		grubość osłonki
silikonowa powłoka	40.00	1.2		0.2
obudowa z PLA	62.5	1.25		
spadochron	40			
Elektronika przewody, raspi, czujniki etc. (przeszacowane, mocno, w górę)	40			masa baterii:
baterie	96			48
mocowanie spadochronu (pręt)	40			
elementy konstrukcji i bezpiecznego uruchomienia	20			
Suma:	338.50			

#4 main board electric schematic



Attachment #5