FINAL REPORT

Virtual European CanSat Competition 2021

sCANSATi Team

ITIS "E. Fermi"
Modena, Italy

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1 INTRODUCTION

1.1 Team organisation and roles

The sCANSATi team consists of six students from ITIS "Enrico Fermi" in Modena (Italy), driven by the interest of putting into practice their study topics in non-conventional contexts.

The students have common interests in technical and scientific disciplines, notably electronics, computer science and astronomy. From the synergy of two of the institute's courses of study, four students from the electronics course and two from telecommunications were recruited into the team:

***Fig. 1** The team*

- *Andrea Bendin*, 18 (4th class, Electronics course): 3D structure and PCB designer, hardware tester and assembler;
- *Giulio Gabbi*, 18 (4th class, Electronics course): responsible for biological analysis, secondary mission;
- *Marco Biolchini*, 19 (5th class, Electronics course): responsible for the physics of CanSat, parachute and endurance; hardware tester and assembler;
- *Francesco Mecatti*, 18 (5th class, Telecommunications course): software developer and telecoms designer;
- *Giulio Corradini*, 19 (5th class, Telecommunications course): member of the Cavezzo (Modena) astronomical observatory, software developer and telecoms designer;
- *Only for the national competition* - *Alessandro Muratori Casali*, 19 (5th class, Electronics course): hardware tester and assembler.

The sCANSATi team is led by *Mrs. Anna Maria Prandini*, head teacher of the electronics course department, who organized several lessons to help us delve into the most challenging topics we needed to study to achieve our design goals. She also provided help and support to the team throughout the whole development of the project.

The team met weekly in the school labs or by video conferencing after school lessons and sometimes during them, thanks to the collaboration of teachers and classmates to which the project was shown during its development.

1.2 Mission objectives

Our secondary mission objectives are to analyse the particulate matter concentration, to detect the presence of bacteria in the air as well as to precisely track the CanSat position while visualizing live data from the CanSat during the flight.

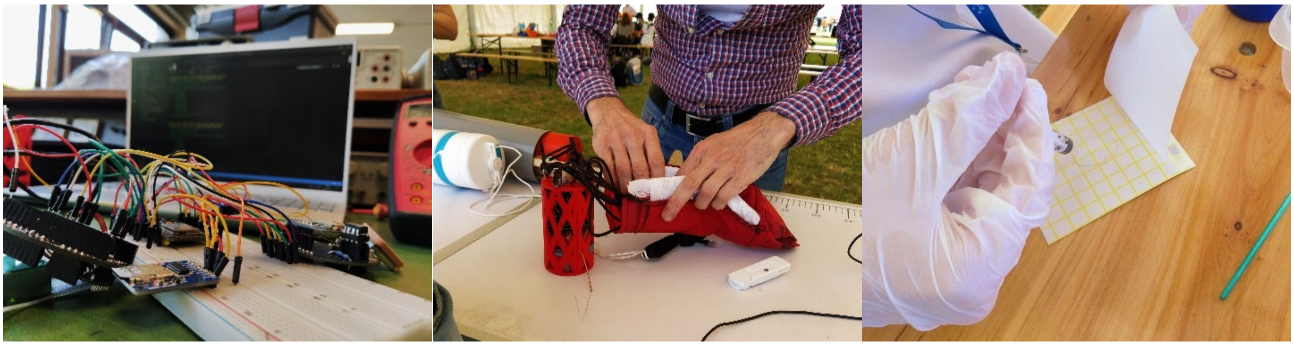
Living in one of the most polluted areas of Europe (the Po Valley, IT), analysing air is an important task, considering the impactful consequences of climate change in our times.

Furthermore, two studies published by NASA[1] and the ISME Journal[2], have highlighted the dispersion of bacteria and viruses into the atmosphere and their transmission over long distances due to aerosol particles which are carried by the wind and in turn, spread bacteria. We therefore decided to collect bacteria with the CanSat in order to carry out a bacteriological analysis. This decision was further discussed and eventually put into action as a result of the Covid-19 pandemic.

To carry out this mission, the CanSat is equipped with a particulate matter sensor that detects the PM concentration, and a sterile gauze to collect bacteria that will be grown and observed as soon as the CanSat lands.

In addition to the environmental analysis (bacteria count and PM detection), the CanSat will transmit real time measurements to the ground station. Thanks to a custom designed telemetry system, it will be possible to monitor the CanSat and its sensors on a real-time graphical interface. Data will be transmitted to the base station using the LoRa modulation, enabling long range and high-performance radio communication with the CanSat.

2 CANSAT DESCRIPTION



2.1 Mission outline

2.1.1 Advanced environmental analysis

The environmental analysis aims to collect data that describes the air in the region of the flight; our ultimate goal is to compare data acquired at different altitudes.

A Bosch BME280[3] is mounted on the CanSat; this smart sensor is capable of measuring temperature, pressure, and humidity with good accuracy thanks to integrated oversampling and filtering capabilities. To obtain an additional measurement of the temperature, a radial glass thermistor was deployed. Two sensors that adopt different technologies will make it possible to compare and validate the collected data.

A decrease in temperature of about 6.5 °C/km is expected (this is the approximate value of the vertical thermal gradient in the troposphere under standard conditions[4]); a decrease in air pressure of 119 hPa over 1000 meters, calculated by both linear and exponential Stevin's law[5] (forecasts were confirmed by the National Competition launch: 128 hPa) and therefore also a slight decrease in relative humidity, which is directly proportional to the air pressure.

The Sensirion SPS30[6] has been chosen for advanced environmental analysis. This high precision particulate matter sensor, mounted on the CanSat, provides the measurement of mass and numerical concentration of particulate matter (PM) of different sizes (namely PM1.0, PM2.5, PM4, PM10). The sensor doesn't require maintenance since it has an internal self-cleaning system that prevents the accumulation of dust on sensitive parts. It works with a laser technology which, compared to the LED one of cheaper sensors, allows higher precision measurements up to 0.3 µm.

Our particular goal is to analyse PM2.5 and PM10 levels at different altitudes and compare them with the Air Quality Index values established by the EPA[7] (**Table 1**).

Table 1 *Air quality (due to PM concentrations)*

PM2.5 24-hour avg. (ug/m3)	PM10 24-hour avg. (ug/m3)	Air Quality Index	Air Pollution Level
0.0 - 12.0	0 - 54	0 - 50	*Good*
12.1 - 35.4	55 - 154	51 - 100	*Moderate*
35.5 - 55.4	155 - 254	101 - 150	*Unhealthy for sensitive groups*
55.5 - 150.4	255 - 354	151 - 200	*Unhealthy*
150.5 - 250.4	355 - 424	201 - 300	*Very unhealthy*
250.5 - 500.4	425 - 604	301 - 500	*Hazardous*

Nowadays particulate matter is the sixth mortality factor in the world[8] and is included by the WHO (World Health Organisation) in the carcinogenic substances of Group 1[9]. The measured data are expected to fit into the "Good" range, as the launch will take place in a location away from cities and major roads.

2.1.2 Bacteriological analysis

Bacteria play an important role in the formation of ice crystals at high altitudes, which in turn affects weather, climate, and cloud formation. Furthermore, the transport of bacteria over long distances could contribute to the transmission of infectious diseases (*see refs. [1, 2]*).

The purpose of this mission is to verify the presence of bacteria: just before the flight, a sterile gauze will be inserted into the CanSat with the task of collecting possible bacteria from the air during flight, and then immersed in 10 ml of distilled water after landing. After 2 minutes, 6 ml of solution will be taken with a sterile syringe and deposited on the culture medium, which should already show the presence of bacterial colonies as red dots after 12-24 hours.

It wasn't possible to access standard bacteria count equipment, therefore in order to carry out the count and check for the presence of bacteria at high altitudes it was decided to grow them onto sheets of *3M™ Petrifilm™ aerobic bacteria count plates*[10]. These are portable tests that allow one to determine the presence of microorganisms with fast and accurate counts.

A sterilized environment for the gauze is fundamental; the CanSat is equipped with a removable compartment that allows quick insertion and removal of the gauze and lets the air flow through the gauze while keeping it separated from the rest of the internal components. In addition, a fan placed on the bottom of the CanSat guarantees greater aeration of the gauze. For a quicker sterilization, gloves, glasses, pliers, and the compartment itself will be soaked in alcohol before their use.

After the launch, the team will analyse the growth of bacterial colonies and compare the plate with those previously tested to make a quantitative analysis [*see paragraph 3.3.2 for the test plates*].

Since the CanSat will be launched away from big roads but still in slightly polluted air, a similar result is expected for the tests that showed no more than 5 colonies and that were carried out in town, in open air at 6 m above ground (forecasts confirmed at the National Competition).

2.1.3 Real time graph and advanced localization

The CanSat is also equipped with a GY-801 module, which integrates a 3-axis accelerometer (ADXL345[11]), a 3-axis gyroscope (L3G4200D[12]) and a 3-axis magnetometer (HMC5883L[13]), in order to estimate its precise location within a three-dimensional space. This IMU - Inertial Movement Unit - was designed to track the path of our can. In addition, the GPS module (u-blox NEO-6M[14]) provides the CanSat's rough position, which is useful for real-time tracking and after-landing recovery. By combining GPS localization and 3D path tracking the final goal is to locate the device in real-time, as well as to record acceleration uphill and downhill, in order to both recover the CanSat once it has landed and potentially recreate the 3D path.

Thanks to a high gain directive antenna and a Raspberry Pi, all received data is stored in a time-series database, InfluxDB[15], an optimized software environment for storing series of time-dependent data such as the ones collected by sensors. InfluxDB is faster than a traditional database when working with time series and it provides useful tools to monitor data in the time domain; then thanks to Chronograf[16] the stored data will be visualized in real-time graphics during flight, on a convenient web interface.

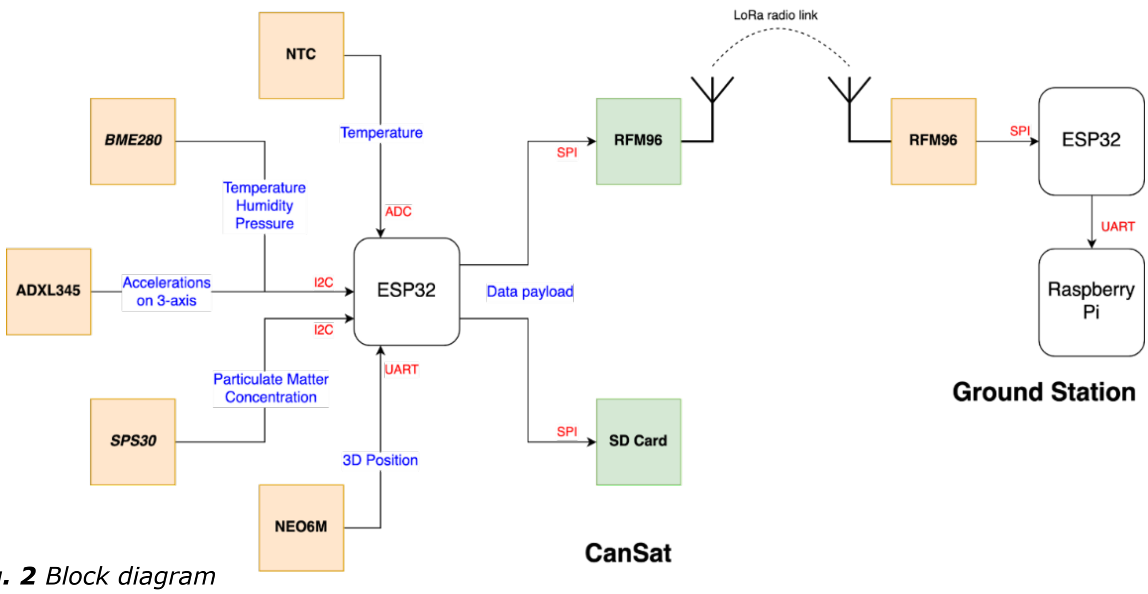


Fig. 2 *Block diagram*

2.2 Mechanical/structural design

2.2.1 Case

The CanSat features a cylindrical 3D-printed case. The structural design has been realized trying to best meet all needs in terms of functionality, resistance, rigidity, aesthetics, and accessibility (the body must be easy to mount). The shell comprises 4 parts: the upper and lower plate and the two side frames. The different parts are held together with nuts and bolts to ensure maximum tightness. A net pattern enables direct contact of the components with the external environment, therefore guaranteeing the best conditions for sampling experiments and a substantial weight reduction. The structure has been 3D printed using Red ABS, a plastic material that stands out for its lightness and impact resistance. During the printing phase printing layer orientation was fundamental in order to maximize robustness. The 3d model[17] and a video of the structural overview[18] are available online.

Fig. 3 *Case exploded view*

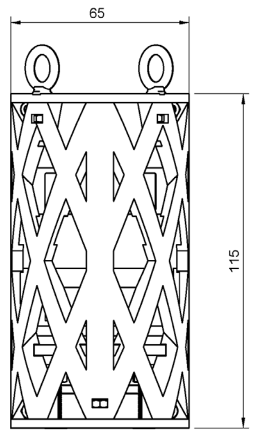


Fig. 4 *Case size*

2.2.2 Components

Components are mounted and fixed ensuring the best working conditions for every part and a uniform mass distribution inside the case.

1. Battery
2. Step-up Circuit 3.7-5V
3. Microcontroller
4. Particulate Matter Sensor
5. NTC
6. GPS Module and Antenna
7. Pressure and Humidity Sensor
8. Custom PCBs
9. Accelerometer
10. Radio Transmitter Module
11. Antenna Connector
12. Micro SD Card logger
13. Buzzer
14. Fan
15. Gauze compartment

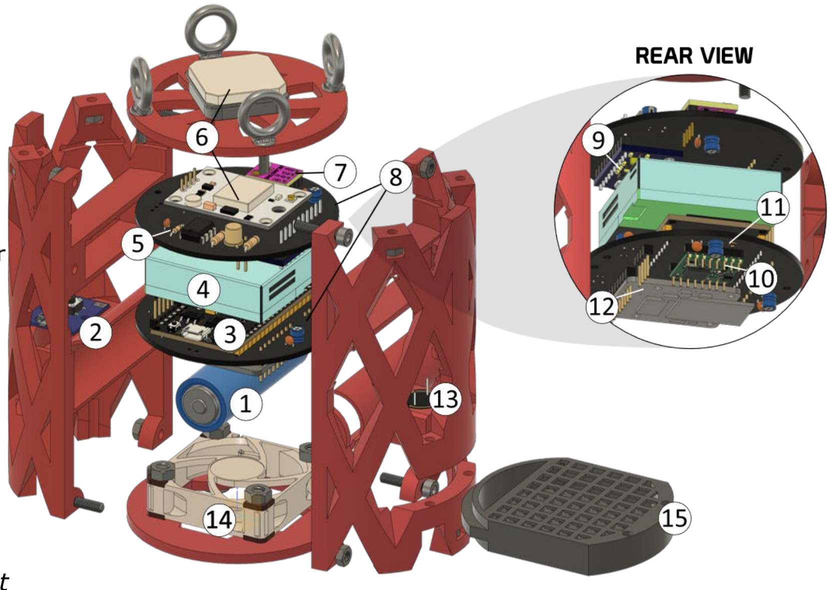


Fig. 5 *Component displacement*

2.2.3 Gauze compartment

The CanSat features a resin 3D-printed compartment to accommodate the gauze. The compartment can be quickly inserted before the launch, to minimize contamination with bacteria. Thanks to the resin material it can be sterilized without compromising its solidness.

2.3 Electrical design

The CanSat mounts two custom-designed round PCBs that connect all the components together. The choice of realizing custom PCBs was dictated by the needs of saving space. This solution has also been found to be suitable in terms of connections reliability and resistance, compared to wire-wrapped boards. The two round boards are horizontally mounted into the case. Most of the components have been soldered onto them. The electrical diagram [*see APPENDIX*] and the PCB Layout were designed using *KiCad*[19]. The two PCBs were realized using *HASL Lead Free* technology.

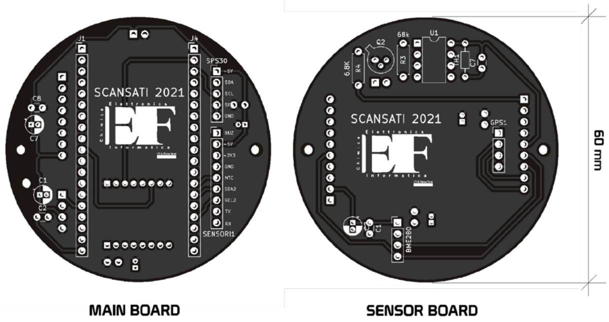


Fig. 6 *Custom PCBs*

Table 2 *Main board components*

Component	**Voltage**	**Protocol**	**Other information**
AZDelivery NodeMCU ESP32[20]	5 V		Dual-core microprocessor
Lora RFM96W Transceiver Module[21]	3.3 V	SPI	Lora Modulation, 433Mhz
Micro SD Card Breakout Board[22]	5 V	SPI	Micro SD Card reader
Particulate Matter Sensor SPS30	5 V	I2C	Measures PM concentrations
Noctua A4x10 PWM Fan[23]	5 V	PWM	RPM Measurement feedback
U.FL-R-SMT-1 Coaxial Connector[24]			Antenna connector, 50Ω
Sensor Board Connector			9 pin connector

Table 3 *Sensor board components*

Component	**Voltage**	**Protocol**	**Other information**
GPS NEO-6M-V2	3.3 V	UART	Horizontal position ±2.5 m accuracy. 1 Hz frequency update
GY801 Module	3.3 V	I2C	Integrate ADXL345 three-axis accelerometer, ±16g range measurement
BME280	3.3 V	I2C	Pressure: 300÷1100hPa ±0.25% Temperature: -40÷85°C, ±1°C Humidity: 0÷100%, ±1%
Main Board Connector			9 pin connector
Buzzer	5 V		Controlled through BJT
NTC G10K3976A1[25]	3.3 V		Fast response (<1s) and accurate glass thermistor. Working range -40÷250°C

2.3.1 Power budget

Table 4 *Power budget*

				Power consumption	
Device	**Voltage**	**Current(mA)**	**Power(mW)**	**Flight**	**Ground**
ESP32 Board	5	20	100	ON	ON
AMS1117 Voltage Regulator[26]	5[a]	69	117.3	ON	ON
LoRa RFM96 Module	3.3	28	92.4	ON	ON
GPS NEO 6M-V2	3.3	11	36.3	ON	ON
BME280	3.3	0.36	1.2	ON	ON
ADXL345 (on GY801 Module)	3.3	0.40	0.1	ON	ON
Noctua NF-A4x10 5V PWM Fan	5	40	200	ON	OFF
Active buzzer	5	30	150	OFF	ON
SPS30 PM Sensor	5	55[b]	275	ON	ON
NTC Current Mirror Circuit	3.3	0.038	0.1	ON	ON
MicroSD Card Breakout Board	3.3	30 (max)	99	ON	ON
Total Current (mA)				**184.4**	**174.4**
Total Power (mW)				**921.4**	**871.4**

[a] *Power consumption is calculated as the power dissipated by the conversion from 5V to 3.3V. Therefore, it's the flowing current times the difference of voltage between input and output (1.7 V).*
[b] *When in measurement mode*

A rechargeable lithium-ion battery was deployed on the CanSat. It provides 1100mAh at 3.7 V and it stores 4.07Wh (diameter: 17mm; length: 50mm). The CanSat consumes the most during the flight time. The battery is able to guarantee more than 4 hours of power supply to the system, even if it would remain constantly in the most power consuming conditions. The CanSat anyway should switch to a lower power consumption mode after landing, thus allowing a much longer battery life.

$$T = \frac{E_{battery}}{P_{max}} = \frac{4.07\ Wh}{0.9214\ W} = 4.42\ h = \ 4h\ \ 25min$$

2.4 Software design

An ESP32 microcontroller is the core component of our CanSat: it's the main accountable for the communication with every sensor. The microcontroller also handles the transmission, using the RFM96 LoRa radio module, and logging with the help of a micro-SD card.

Every peripheral is connected using a different media access protocol and its peculiar wire protocol, needed to deliver commands and fetch data from the device. In addition, every operation involving an external device must follow strict time constraints: as an example, a query to the temperature sensor should be handled before the next packet is sent across the wireless link with the ground station.

To meet these strict timing requirements, the firmware is based on a *real time operating system* (RTOS). Real time operating systems are suitable for mission critical applications where IO calls and system calls must be carried out in a maximum timespan, and where an error mustn't stop the system from running. During the National Campaign flight there were issues with the I2C bus of the temperature sensor and the accelerometer; those sensors couldn't communicate data for more than a minute, but the CanSat continued to transmit data from the other sensors.

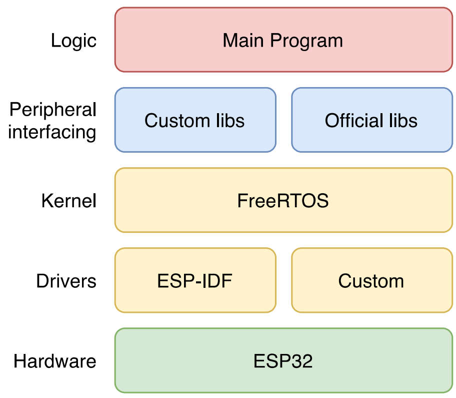


Fig. 7 *Software abstraction layers*

The official software development kit for the ESP32 comes with FreeRTOS[27], the open source de-facto standard for embedded applications (see software stack in Fig. 7).

2.4.1 Firmware architecture

Every device deployed on the CanSat has its own hardware abstraction layer: a common interface that enables to set up and query these devices in the same fashion. Each "driver" exposes a *setup function*, and enqueues available data in a temporary buffer (usually read by the main program) and is run on a separate thread.

At boot, the main thread initializes a finite state machine, and spawns a bunch of threads pertaining to the hardware drivers: one that orchestrates them and one that prepares the payload and controls the radio module.

Every driver queries its sensor once a second. When a query is accomplished, the driver notifies the main thread that data is available. The main thread is then resumed from the waiting state and starts gathering data from ready and available sensors. A semaphore is locked prior to this access.

Available data is stored in a struct, which is passed on to the *prepare_payload* task. A "packed" version of this struct is then produced and passed along to the LoRa module in order to transmit it. A packed struct has no padding bytes, whereas normal structs have aligned fields to speed up memory lookup operations. Packed structs are smaller than their unpacked counterparts and are thus suitable for data transfers. Each packet is also saved onto an SD card on a CSV-formatted log file. A *counter* field, whose value corresponds to the elapsed time from the start-up of the microcontroller, enables packet reordering.

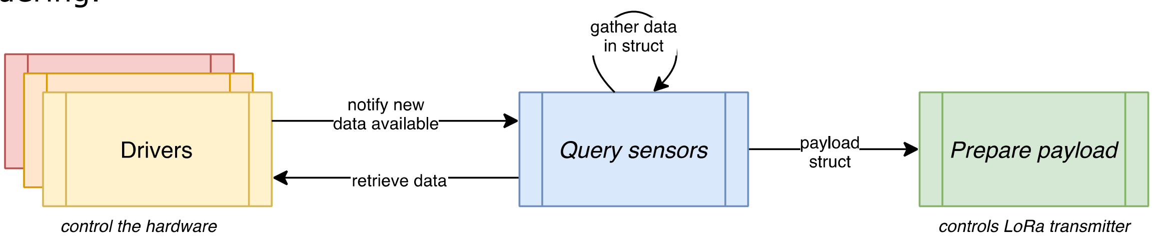


Fig. 8 *Threads interactions diagram*

2.4.2 Handling flight events

A finite state machine (FSM) is involved to determine when a certain height of the flight stadium is reached (e.g., launch, peak height, or pre-landing). On-board analysis of sensors plays a key role in the success of the flight: it is fundamental to have a reliable way to turn the fan on only when peak height is reached and only after the lateral expulsion from the rocket occurs, otherwise it could damage other CanSats in the rocket.

An FSM (Fig. 9) allows to determine different states that control how the hardware behaves during the flight based on feedback from the sensors (mainly the altimeter and the accelerometer).

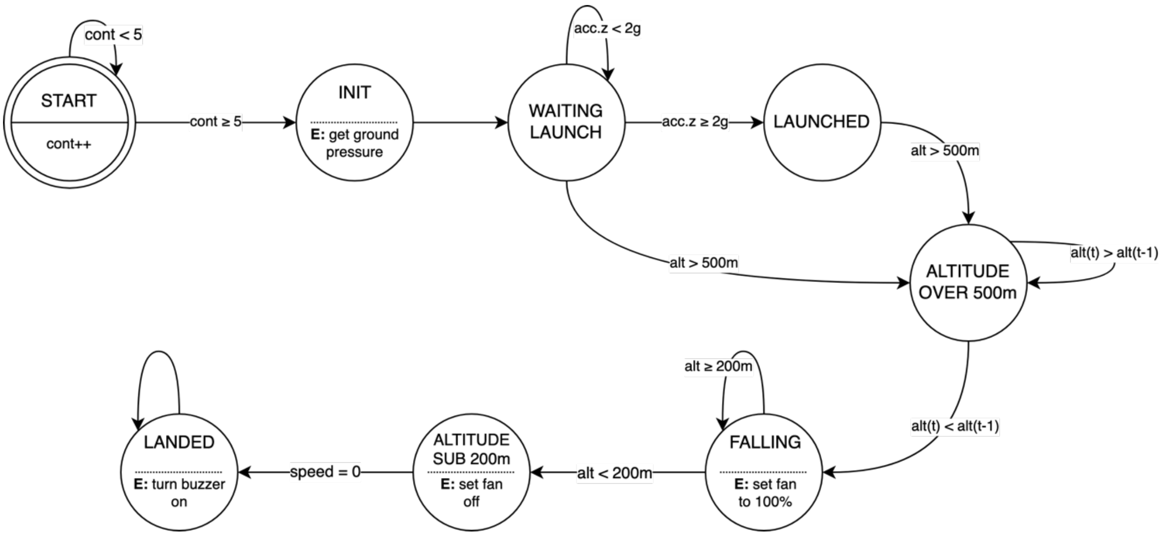


Fig. 9 *CanSat FSM state diagram. For some states an entry action is specified, and is run whenever the state is reached (even multiple times).*

2.4.3 Coding tools

The ESP32 microcontroller was programmed using the C programming language and the official Espressif IoT Development Framework[28] (ESP-IDF). The SDK, the framework and all the required tools such as the compiler are managed using PlatformIO[29] for Visual Studio Code.

Code versioning was achieved using Git: every time a new functionality is added to the code, this tool takes a snapshot of the entire codebase. If a new feature breaks the code, you can simply roll back to a previous version with a simple command.

2.5 Recovery system

Three systems were designed for CanSat recovery: a parachute slows down the descent rate and a radio beacon and buzzer help locate the CanSat once it lands.

2.5.1 Parachute

The parachute was designed to allow the CanSat to fall at a low speed (6m/s), thus maximizing the flight time, so as to carry out a meaningful bacteriological analysis (to keep the explanation simpler, the time dependency in the formulas was omitted).

A falling object in a fluid (the atmosphere) is subject to two main forces:

- weight $W = m \cdot g$ where m = 0.3003 kg and g is the gravitational acceleration
- friction $F_f = -k \cdot v^2$ (t > 0) where k is the air friction coefficient ($k = \frac{1}{2}\rho CS$) and v the velocity of the CanSat

The resulting force on the CanSat is: $F = W + F_f = mg - kv^2$

Applying the 2nd mechanic principle: $F = ma, \quad a = v' \Rightarrow \quad mv' + kv^2 = mg$

This is a Riccati differential equation and is solved as:

$$v(t) = \sqrt{\frac{mg}{k} tanh \sqrt{\frac{kg}{m}} \cdot t}$$

The terminal velocity V_t can be calculated with the limit:

$$\lim_{t\to\infty}\big(v(t)\big) = \sqrt{\frac{mg}{k}} \quad \text{because} \quad \lim_{t\to\infty}(\tanh(t)) = 1$$

The terminal velocity V_t corresponds to the CanSat maximum descent rate. It depends on its mass m, the acceleration g, and the parachute features.

Considering $k = \rho CS/2$:

$$V_t = \sqrt{\frac{2mg}{\rho CS}}$$

Therefore, the parachute area results:

$$S = \frac{2mg}{\rho C V_t^2}$$

The terms ρ is the air density: ρ = 1.225 kg/m³ (T = 15°C)[30]. The drag coefficient C depends mostly on the parachute shape. As a cross shape parachute has been chosen the coefficient is 0.6 < C< 0.85[31]. Considering a 6m/s descent rate the surface S of the cross-parachute must be between 15,7 and 22 dm². A cross-shaped parachute was made from five squares of 20 cm side. Its resulting total area is:

$$S = 5 \cdot (20 \cdot 20)cm^2 = 2000\ cm^2 = 20\ dm^2$$

Therefore, the terminal velocity will be 5.48÷6.32 m/s, guaranteeing a flight time in the interval of 158÷182 s. The parachute is attached with 4 eye bolts screwed into the CanSat case.

Fig. 10 *Parachute top view and eyebolt attachments*

Fig. 11 *Folded parachute size*

2.5.2 Buzzer

As soon as the CanSat lands, a buzzer starts emitting an intermittent loud sound, useful when searching for the CanSat in the tall grass.

2.5.3 Radio Beacon

The radio module continues transmitting data to the ground station, even when the CanSat has landed. This allows to track the CanSat using an SDR receiver[32].

An SDR - Software Defined Radio - can receive and display the spectrum of radio waves at a given frequency, and their power in the form of a waterfall diagram. Thanks to the signal power indication, it's possible to follow the signal and find its source. This is one of many recovery systems thought to find the CanSat in case of sightline loss. In addition to that, the SDR serves as a jamming detection device.

2.6 Radio transmission

2.6.1 Introduction

We chose to stick with the LoRa modulation scheme after we took part in a meeting of the *Associazione Radioamatori Italiani di Carpi*[33] in February 2020, where the radio communication of weather balloons was discussed.

We debated with the head teacher of the telecommunications course on the possibility of installing a LoRa gateway for research and educational purposes, since the latest developments in the public LoRa[34] network of Lepida[35] (a local, publicly funded ISP). We eventually installed a gateway on the rooftop of our school, and it is now publicly accessible to everyone, as we started experimenting with this technology since no teacher or student has extensively used LoRa before.

2.6.2 LoRa advantages

We designed a radio transmission system built upon LoRa, a chirp spread spectrum modulation that is perfectly suitable for IoT applications, thanks to its low energy consumption and its high sensitivity, that guarantees a long-range transmission.

2.6.3 Transmission parameters

An end-to-end transmission allows to keep the overhead as low as possible and thus decrease the BER (bit error rate). LoRa is a proprietary modulation technique. For that reason, an industrial-grade modem was necessary: the RFM96. This chip is able to transmit and receive data within the ISM band (433 Mhz, 868 Mhz, 2.4Ghz). It was eventually chosen to transmit in the 433 MHz frequency band because of its longer range compared to 868 MHz (the lower the frequency, the lower power losses due to matter interfering along the way).

***Table* 5** *Transmission parameters*

Parameter	Value
Center frequency	433 MHz
BW	250 kHz
Spreading factor	75%
Transmission power	100mW

2.6.4 Onboard antenna

A Marconi's monopole antenna ¼ wavelength was mounted on board to save space; this type of antenna takes advantage of the ground plane, which acts like a reflected dipole. The antenna has been made starting from a coaxial cable, from which the coating was removed, exposing the conductor. In order to decrease space footprint while keeping the PCB original modularity, the cable wasn't soldered directly onto it: the PCB has been equipped with an SMD IPX connector, so the antenna can be easily replaced.

2.6.5 Post-launch evaluation

Post-launch evaluation pointed up an excellent RSSI - Received Signal Strength Indication - throughout the entire fly. As a matter of fact, a packet reached the ground station every one or two seconds, depending on the distance between the ground antenna and the CanSat. Since the transmission period was about 1 second, it is possible to state that one out of two packets reached the ground station in the first phase of the fall (after the apogee), thus having a packet loss ranging (PLR) from 50% to 0%, with an average of 19%.

2.7 Ground support equipment

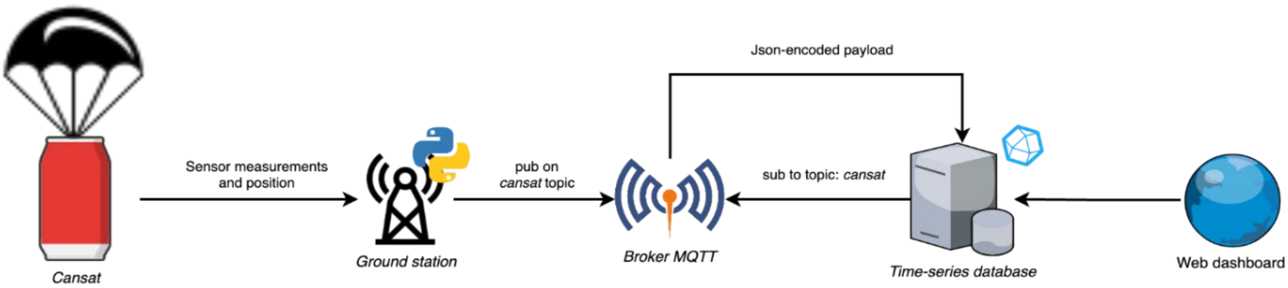


Fig. 10 *Ground data flow*

2.7.1 Introduction

The whole ground station has been put together by hand: starting from the receiver needs, we designed a custom solution that suits all the requirements (free frequency band, transmission power, noise levels) and optimizes the chance of receiving data at a good speed. It is made up of four main components: Yagi-Uda antenna (*Diamond A430S10R2*), a LoRa receiver, an ESP32 and a main computer (Raspberry Pi 3B). To ensure the best portability possible, the whole system is battery-operated.

2.7.2 Ground antenna

A Yagi antenna (dimensioned for 433MHz) was chosen - donated by the local *ARI* section to the school - because of its narrow but long-range radiation pattern (see Fig. 12). The Yagi-Uda antenna is a well-known and widespread directional antenna, which features a 45° takeoff angle; as a matter of fact, its radiation pattern resembles an ellipsoid stretched along the main axis, called the "main lobe". For that reason, it needs to be pointed towards the source of the radio signal. The antenna, controlled by hand through a joystick was made, but it wasn't fully functional, so different solutions were evaluated [*see section 3.4*].

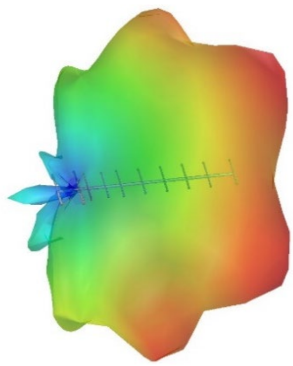


Fig. 12 *Antenna's 3D radiation pattern at 433MHz*

2.7.3 Modem

An RFM96 modem, directly connected to the antenna, is employed to demodulate LoRa proprietary protocol; the RFM96 is queried by the ESP32, on which is running a piece of software "symmetric" to the onboard ESP32. The same parameters as CanSat's have been kept for the ground station module.

2.7.4 Ground software

A custom script written in Python reads data from the serial port and sends it to a time series database (InfluxDB, running on the Raspberry Pi). Each entry is stored in a permanent way and can be shown on the interactive dashboard (served by Chronograf) anytime, and during the flight in real-time. The whole database stack allows retrieving original measurements whenever is needed.

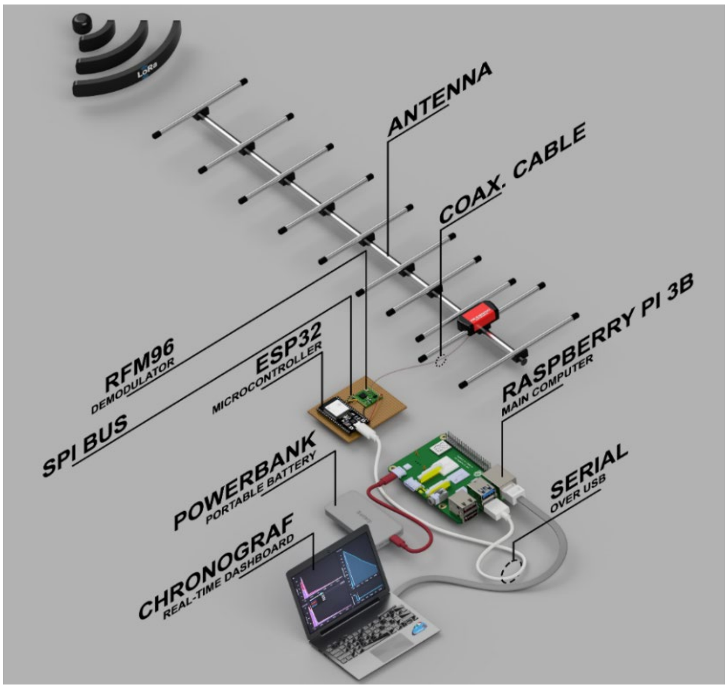


Fig. 11 *Ground station system*

3 PROJECT PLANNING

3.1 Time schedule of the CanSat preparation

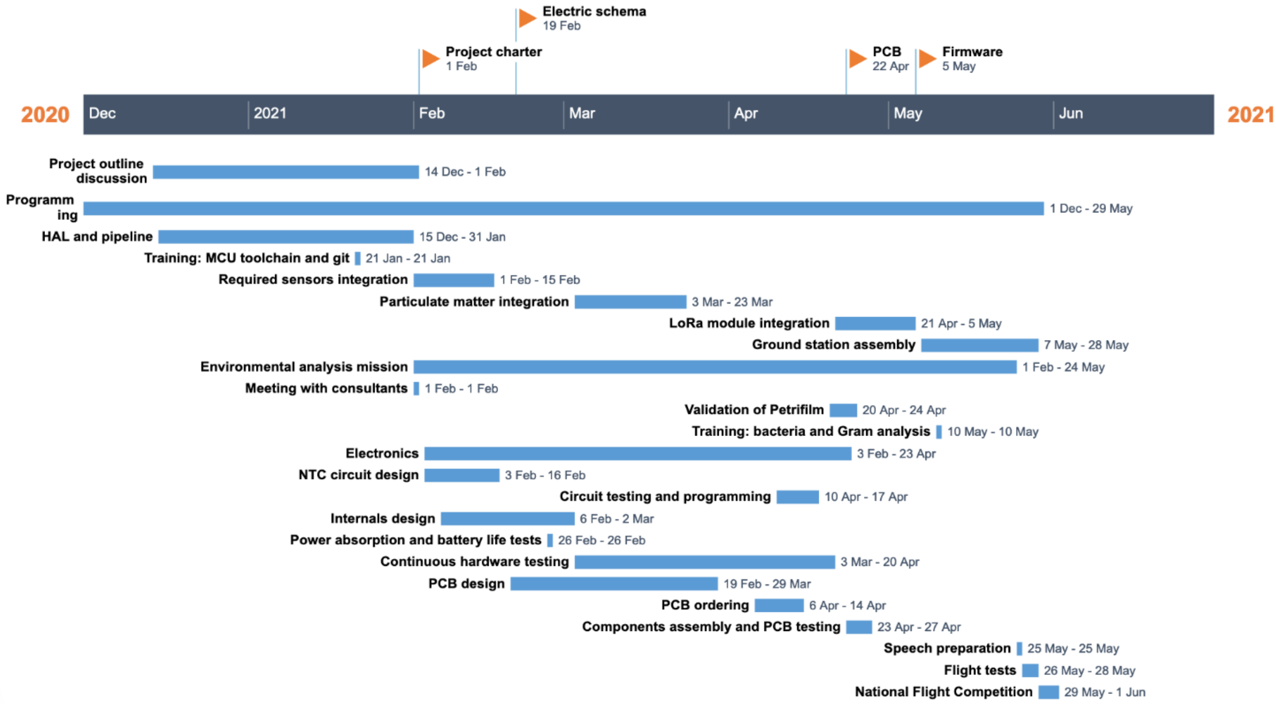


Fig. 13 *Project Timeline*

3.2 Resource estimation

3.2.1 Budget

Table 6 *Economic budget*

Item	**Price (€)**	**Item**	**Price (€)**
CanSat ESP32 Board	10.19	microSD Card Breakout Board	15.00
LoRa RFM96 Transceiver Module x2	22.74	Caps, resistors, BJT, buzzer, LM394CN	[SC] 7.00
GPS NEO 6M-V2	12.90	PCB First/Second Version	39.00
BME280	15.75	3D printed case x2	57.92
Noctua NF A4x10 PWM Fan	14.90	Li-Ion battery and power circuit	5.99
GY801 Module	[SC] 18.50	4 GB microSD Card	4.99
SPS30 PM Sensor	41.72	Parachute Material	7.00
Leads Weights	1,00	Sterile gauze	2.00
G10K3976 NTC	5.27	**Total Price**	**279,17€**

[SP] = Sponsored, [SC] = Sourced from School

3.2.2 External support

This project was funded by ITIS Enrico Fermi, AD MODUM R&D S.r.l.[36] and Graf S.p.A.[37] We are particularly grateful to our tutor *Prof. Anna Maria Prandini* and our school headmaster *Prof. Paolo Pergreffi*. We acknowledge professors *Erio Orlandi* for electronic consultation, *Ugo Malagoli*, *Lorena Marassi*, *Marco Mescoli* and *Paolo Santinelli* for their assistance; *Dr. Annalisa Del Nevo* (AD MODUM R&D) and *Dr. Elena Micossi* are acknowledged for bacteriological consultation; *Vittorio Moretti* and *Alessio Sacchi* of ARI *Modena* for radio transmission; *Matteo Budriesi* for 3D printing support; *Prof. Luca Pasquali* (University of Modena-Reggio Emilia) for useful discussion.

3.3 Testing

3.3.1 Electronics

SMD components mounted on breakout boards made it easier to test and deploy such devices on the CanSat. Each device was tested by itself on a breadboard, directly connected to the microcontroller, with the testing program shipped with it. Once all the devices' interfaces were fully functional, everything was mounted on the same breadboard and started testing the logic of our program (i.e., logic flow of data from sensors to radio link). To test the PCB connections multiple boards were ordered. First, the components were mounted using pin headers instead of directly soldering. Several connection mistakes appeared during the PCB testing phase, but they were completely fixed in Mark 2, which was fully functional and deployed on the CanSat. After the testing, all the components were soldered onto the board.

3.3.2 Bacteriological analysis equipment

To make a quantitative and comparative bacteriological analysis, ten tests with 3M™ Petrifilm™ were conducted in the days before the launch of the CanSat. Different types of sterile gauze were used (to determine the best one for the mission) in similar and different conditions to the race: gauze in contact with unwashed hands (x2), exposed to the open air on a 6-meter-high balcony (x5), exposed to the smog of a busy street (x2) and exposed to saliva (x1). Culture media were photographed each 12 hours apart, to be compared with greater precision in timing with the one of the CanSat flight (two tests after 72h in Fig.14). From the tests carried out, the best working conditions for collecting bacteria turned out to be a sterile non-woven gauze immersed in a maximum of 6 ml of distilled water.

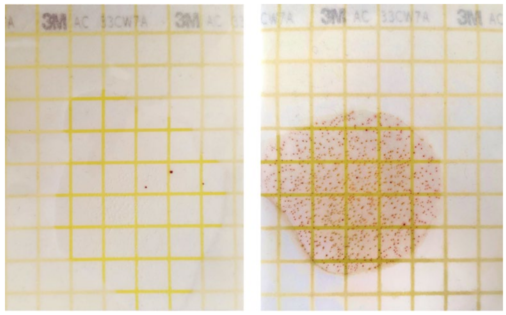


Fig. 14 *Petrifilm plate tests*

3.3.3 Radio communication

Communications trials in an urban environment (in front of our school) were conducted and half the scheduled distance was reached with a reasonable signal strength (considering the altitude and the obstacles). Several combinations of channel bandwidth were tried, spreading factor and transmission power until a fair trade off between signal strength and weather conditions resilience (background noise) was reached.

3.3.4 Drop Test

To test the parachute system and the structure's impact resistance, the CanSat has been dropped from a height of about 10 meters multiple times, no damage has ever been observed, and the parachute did its job perfectly.

3.4 Lessons learnt from the National Competition

The CanSat project, for which it was necessary to work in groups with different roles, allowed us to increase our teamwork and exhibition skills needed in presenting new ideas and sharing the results obtained.

The data collected during the national competition confirmed that the airflow was optimal due to the net structure. The temperature response over time was also rapid, and the two temperatures recorded from both the sensor and the NTC circuit were nearly equivalent. Unfortunately, due to a wrong calibration of the parameters of the FSM, the fan could not be turned on correctly on every launch and to avoid any sort of problem it was left off for the entire duration of the flight. Using data from the National Competition flight it is now possible to correctly calibrate it. Minutes before the flight we rolled back to the latest and fully functional version of the code, thanks to Git versioning. The code should never be changed at last and without proper testing.

During National Competition flight the antenna was manually driven with the support of a mechanical structure *[for context see section 2.7.2].* To achieve the initial goal of a fully motorized antenna, we came up with the idea of a fixed phased array antenna, following Vittorio Moretti's advice [*see paragraph 3.2.2*]. This type of antenna allows the radio beam to be electronically steered, sending a signal with a slightly different phase for each antenna.

The path tracking mission failed due to the lack of time to implement the onboard software needed to query the gyroscope and the compass.

4 OUTREACH PROGRAMME

The team met weekly in the school labs during and after lessons. Our classmates, teachers and other students not involved with the project were made aware of the CanSat and we showed them what we were developing. The principal pledged an area of the school website to our project, where we posted the latest developments about it.

Students' representatives helped us with an outreach by posting Instagram stories on the school's official page, about the project during its development and on the weekend of the National Competition.

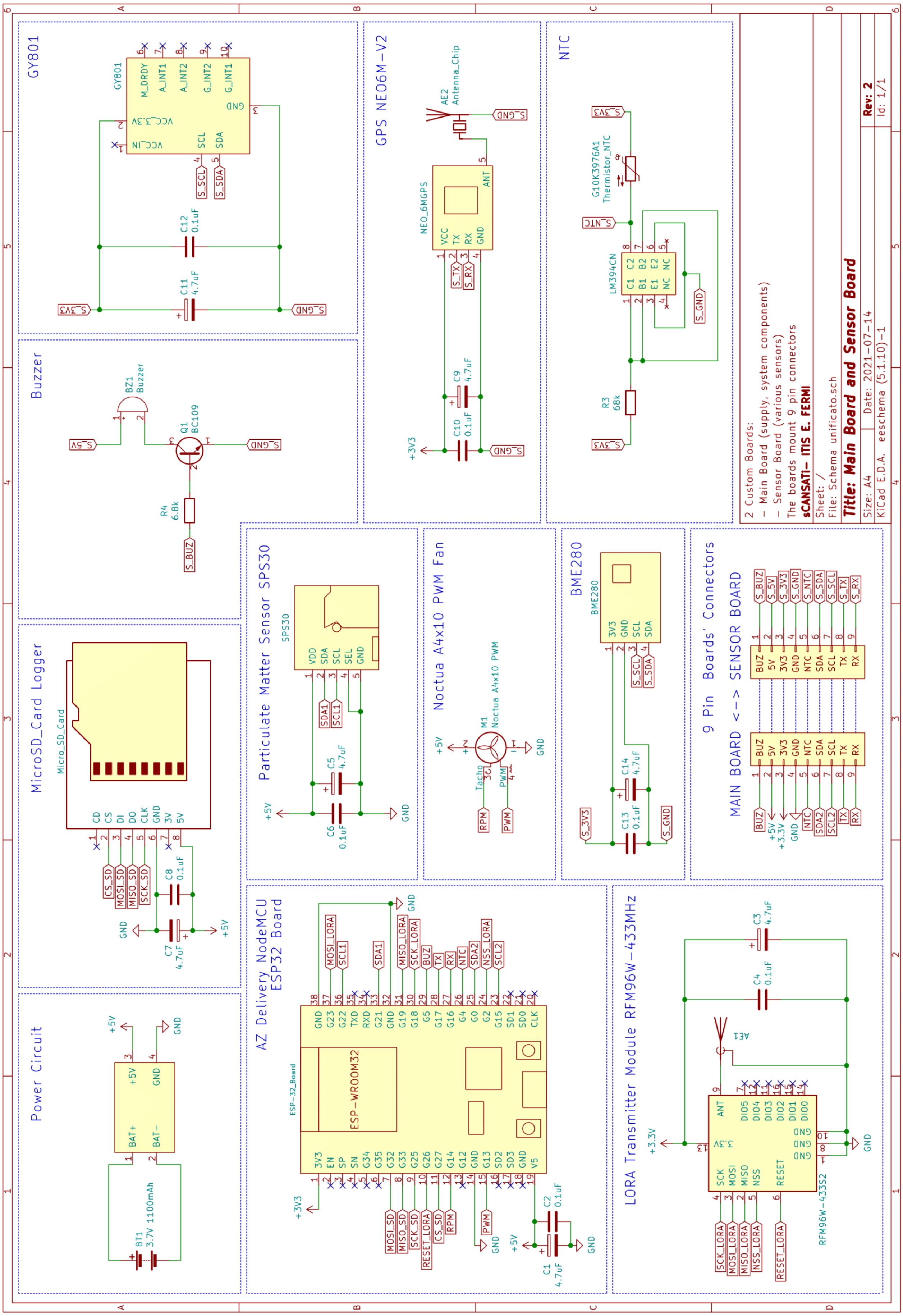
After the National Competition, we received media coverage in local newspapers; our team members took the chance to talk about the project in front of their class and during their Graduation exam.

- CanSat section on school's official website[38]
- Article on Gazzetta di Modena[39]
- Online conference for Associazione Astrofili di Cento[40]
- Instagram stories on @itisfermi page[41]
- Results presentation in class and during Graduation exams
- LinkedIn post on AD MODUM R&D page[42]
- Dedicated page on AD MODUM R&D website[43]
- YouTube video of Structural Overview: https://youtu.be/T7g9FIWCnoQ

5 REQUIREMENTS

Characteristics	**Figure (units)**
Height of the CanSat	115 mm
Mass of the CanSat	300.3 g
Diameter of the CanSat	65 mm
Additional length of external elements (along axial dimension)	40 mm
Flight time scheduled	158÷182 s
Calculated descent rate	5.48÷6.32 m/s
Radio frequency communication	433Mhz
Power consumption	0.9214 W (max)
Total cost	279,17€

APPENDIX



GY801
Buzzer
MicroSD_Card Logger
Power Circuit
GPS NEO6M-V2
NTC
Particulate Matter Sensor SPS30
Noctua A4x10 PWM Fan
BME280
9 Pin Boards' Connectors
MAIN BOARD <--> SENSOR BOARD
AZ Delivery NodeMCU ESP32 Board
LORA Transmitter Module RFM96W-433MHz
2 Custom Boards:
- Main Board (supply, system components)
- Sensor Board (various sensors)
The boards mount 9 pin connectors
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Sheet: /
File: Schema unificato.sch
Title: Main Board and Sensor Board
Size: A4 Date: 2021-07-14 Rev: 2
KiCad E.D.A. eeschema (5.1.10)-1 Id: 1/1

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On behalf of the team, I confirm that our CanSat complies with all the requirements established for the 2020 European CanSat competition in the official Guidelines

Modena (IT), 8th September 2021