Space research and mini-satellites in secondary high school

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Abstract— ***Space research, the universe and satellites are three fascinating questions for which students have no possible answers in the regular school curriculum. Therefore, every opportunity to bring these topics into school activities and closer to students' interest is welcomed. Few years ago I found the European Cansat competition held by ESA (European Space Agency), which presented itself as one solution for fulfilling this demand.***

Cansat is a mini-satellite that can be fit into a Coca-Cola soda can (330ml) and it is released from 1km altitude. This mini device is based on Arduino- microcontroller and it performs certain scientific missions like measuring air pressure, temperature, humidity, dust pollution, radiation level, location, telemetry, etc.

This competition and the preparation period are very useful for students as they offer a special opportunity to learn about sensors, microcontrollers, radio communication, space research missions, project management. Furthermore they aid the development of technical skills and applications of the acquired theories.

Keywords: cansat, satellite, Arduino, education

I. WHAT IS A CANSAT?

The CanSats (can-soda-satellite) are mini satellites fit into standard soft-drink cans (330ml, 115mm height and 66mm diameter) which simulate the work of a real scientific satellite. The CanSat is required to have a mass between 300-350grams, it must work continuously for at least 4 hours, and it should have a safe recovery system and an easily accessible power switch, maximum flight time being recommended between 120-190 seconds with a descent rate between 4,6m/s-11 m/s. Also, the unit must be able to withstand an acceleration up to 20G and a pressure of 40atm. During flight, it should be in contact with the ground station permanently, transmitting measuring data. The total budget of the finished CanSat device should not exceed 500€. [3, 4]. The CanSat is released from a rocket (Intruder) or a light plane at an altitude of 1kilometre. During the fall, the mini satellite will perform a certain scientific mission and it is expected to land on ground safely. The primary scientific mission is compulsory for every participating team, and it consists of measuring the air pressure and temperature. The secondary mission is chosen by the participating teams, for instance advanced telemetry, guided landing on a target, radiation level, etc. The European CanSat competitions are held by ESA. ESA member states take turns organizing national competitions and the winners will participate at the international level. The final phase of this contest is organized at Andoya Rocket Range in Norway or Santa Cruz Air Field in Portugal. During the whole competition the students should write technical progress reports and design documents (in English) sending them regularly to the competition board.

The big challenge for the high school students (aged 15-19) is to develop a scientific mission, like designing a real satellite and filling all measuring subsystems, communication and power units into a small space, thus producing innovative scientific, technological and educational value and promoting their activity.

II. OUR CANSATS

My students participate at this fascinating competition since 2012. At the beginning, we were absolute beginners because we did not know anything about satellite-building. So we started from the basics. After a few introductive lessons about satellites and electronic sensors we built a very simple but well-functioning measuring device that includes pressure, temperature and dust sensors, a radio communication unit and a Yagi antenna. The antenna used by our team was similar to a Yagi-Uda array one. This antenna was a tuned one, at a frequency of 433MHz. We designed three parachutes for different weather conditions and we placed the device into an special home-made steel cylinder.

The main idea for the secondary mission was to improve students' knowledge about atmosphere physics by verifying the barometric pressure formula and vertical temperature gradient law, as well as to complete an air pollution chart. We chose to measure dust density since we know that our region is relatively highly polluted, as far as dust density is concerned because of the close factories. Our goal was to form a proper image of the situation and therefore increase public awareness. Firstly, we made a detailed plan of the whole process. Then, we designed and built the measurement device (hardware and shell). In the next phase, every single subsystem of the CanSat (the sensors, the radar, the GPRS module, the RF transmitter and the parachute) was tested separately. Finally, we assembled the CanSat and we tested all of the systems together. This part served as an overall simulation of the Launch Campaign.

Fig.1. The Bolyai CanSat team Andoya Rocket Range, 2012

During the launch campaign at Andoya Rocket Range we have achieved our goals:

- the CanSat worked properly;
- parachute deployed properly;
- good descent rate (7.6 m/s);
- no major damage at landing;
- continuous radio communication between CanSat and ground station;
- two sets of measuring data were collected and saved;
- there were no significant differences between values measured in a defined height interval;

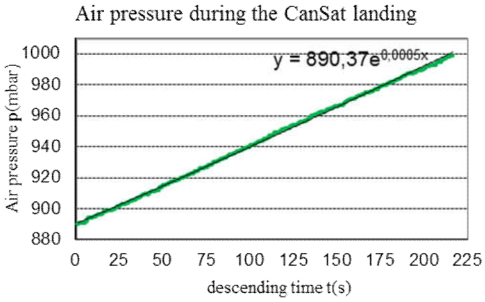

Fig.2. Air pressure during the CanSat landing

The readings from the pressure sensor obey the barometric law, which describes the change of air pressure with altitude. There is an exponential function that helped us to calculate the maximum altitude of the Cansat. According to our calculations, the maximum altitude (z) of the rocket and our Cansat was about 930meters.

$$p = p_0 e^{-z\frac{g\mu}{RT}} \qquad (1)$$

The diagram of the pressure measurements should be an exponential curve, although on our diagram it seems to be linear, the reason for this being that this is just a small part of the whole curve. (the exponential curve could be seen if the measurements took place at an altitude of at least 10 km).

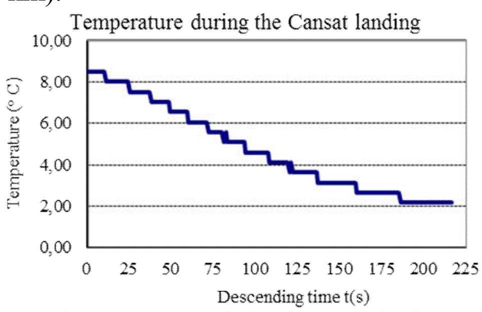

Fig.3. Temperature during the CanSat landing

The diagram (3) presents the temperature data received from the Cansat throughout the descent. Our diagram is linear and shows that the temperature decreased according to the inversed gradient law. Interestingly, the values are higher at high altitudes than near the ground. The explanation for this is the phenomenon of temperature inversion. For this to happen, several factors needed to coincide:

The night before the launch day the sky was clear, the temperature was 1°C. (22nd April, 2012). Due to this, the whole air cooled down, cooling down also the ground and the surrounding sea. In the morning of the launch day (23rd April, 2012) dense clouds appeared at a 1 km altitude which reflected the sunlight and its heat, not allowing the Earth's surface to heat up. However, the low clouds absorbed the heat.

For the 2o15 and 2o16 Cansat contest we designed more complex and complicated devices. These mini satellites complied with all the rules and standards of the CanSat competition and could perform special data analysis, by associating the data received with a 3D map, falling simulation and different dynamic and position measurements. During the descend, the unit sent measuring data to the ground with the help of a radio transmitter and uploaded the received information to a web server with a GPRS module. The collected data were analysed and processed by students and the results were presented at conferences or used at physics classes.

In 2015 for the secondary mission we choose to simulate the exploration of a newly discovered planet like a real satellite. So we divided our mission in two parts. First, we determined the quality of atmosphere measuring the air pressure, temperature, humidity, different gas concentration and dust pollution. The second task proposes to explore the surface of the planet with a small rover after the CanSat landing. This rover then would investigate soil moisture levels. Along with these we will also gather GPS data. From the acquired data we intend to compile a vertical map of humidity, temperature and UV radiation intensity and a horizontal map of soil moisture levels. We set out as a goal to get an accurate picture of the physical properties of the atmosphere and ground in order to determine whether these provide a possibility for life. We wanted to see how accurate data gathered with such measurement methods can be, and then adjust them accordingly. For this task we introduced a mini rover into the Cansat which was deployed after the landing. The rover was a semi-autonomous vehicle which is small enough to fit in our CanSat and it had a soil moisture sensor.

The rover was driven by two electric motors with two gearboxes and tracks. The rover was controlled by an Arduino unit based on the Atmel ATmega 328 microcontroller. All of the rover's components will be held together by the main chassis, which will be made of PLA (PolyLactic Acid). The ground receiver unit was entirely built by our team, based on an Atmel Atmega 328 microcontroller and the transceiver included in the CanSat kit.

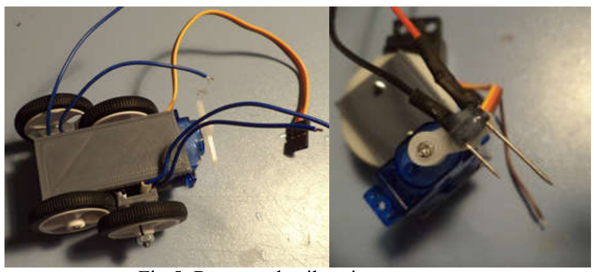
Fig.5. Rover and soil moisture sensor

Cansat15 unit used the SEN-VRM-08 humidity sensor to measure the amount of water vapour in the air. Being an analogue sensor, it measures changes in resistance as the humidity varies, emitting an analogue signal which is then processed and transmitted by the unit. We measured the humidity in a scale of 300-900 (300 indicates dry air and 900 air containing up to 95% vapour).

Being aware of the problem of the global warming, we are studying its special aspects in our region, since our town has an individual microclimate, due to which the general meteorological reports are not valid. Provided we analyse more seriously the aspects of the atmosphere, we hope that we can find signs which can confirm or confute the existence of the global warming. Last year, we designed an Arduino controlled mini meteorological ground station and now we will use the CanSat's geophysical and meteorological sensors for precise measurements at higher altitudes.

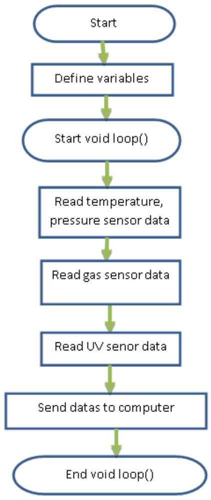

Fig.6. Flowchart for CanSat15 unit

In 2016 our secondary mission was based on different dynamics and position measurements, 3D mapping and data communication. For the dynamic position analysis we measured acceleration along the three axes (x, y, z). We also used a 3-axes compass to determine the momentary position as accurately as possible, combined with real-time GPS data. Our CanSat assigned its location to all the data it measured. This location was completed with the altitude and the tilting data in comparison with the vertical state. These three measurements were processed by a program written in javascript, which creates an animation about the movements of the CanSat. The data are a basis to our educational outreach, which is based on a 3D map of the environment around the CanSat.

One of the objectives of the secondary mission was to successfully log the data obtained from the sensors not only on a ground unit via the RF transmitter, but also on a webserver (in a MySQL database) using a built-in GPRS module. Another objective, closely connected to the latter was to draw a virtual track of the CanSat's descent. Our last technical aim was to back-up all the data on a microSD card (aboard the CanSat) with an OpenLog unit. Data uploading to the webserver was achieved using a small subsystem consisting of an Olimexino Nano Gsm data processing unit combined with a SIM800H quad-band GSM/GPRS module, that works on frequencies GSM850MHz and PCS1900MHz. SIM800H features GPRS multi-slot class 12/class 10 (optional) and supports the GPRS coding schemes CS-1, CS-2, CS-3 and CS-4. Basically, this circuit is the core item of our data processing plan, and it works in the following way: it collects the data received from the sensors and uploads it on a web page provided by us. Since this is a complete subsystem, even in case of failure will not affect other parts of the secondary mission and also it leaves more computing capacity for other tasks.

Nevertheless, during the fall, the measured data were sent with a radio transmitter to the ground, then they were uploaded to a server with the GPRS module. The server saved the received data in a MySQL database, and immediately processed them on a webpage. On the page we illustrated the line of falling in 3D based on information received from GPS, the incidence angle of CanSat from Gyro data, and the rate of fall based on accelerometer data.

We were always amazed by how the professionals at ESA and NASA create wonderful images or maps containing a lot of information from data obtained and transmitted back to a ground station by space telescopes. It still remains very interesting for us how one can map the surface of an unknown space object without having to actually land any kind of equipment on it. An orbiting unit is enough to scan the surface, and even mountains, valleys and rivers can be drawn based on the obtained data. This interest of ours determined our secondary mission to create a 3D map based on the position of the CanSat and pictures from a CMOS camera module with a resolution of 728x488 pixels.

Our data visualization was based on a 3D map of the terrain beneath our flying unit which is created in Autocad 3DSMax. On this map we presented a visualization of the measured atmospheric features as well as our position and movements. Using the data obtained from the sensors we calculated the height of the point compared to sea level. Furthermore, the exact coordinates were determined using the GPS data, the speed of the fall, acceleration of the CanSat and also data measured by the gyro sensors.

The CanSat started to collect data right at beginning of the descent. In this way we were constantly receiving data about pressure and temperature readings. From these measurements, we calculated the parameters of the weather and displayed them on the 3D map. After the CanSat landing these measurements data were processed in Wolfram Mathematica and Mathlab to create falling simulation. Our snapshots taken by a CMOS camera, due to the large quantity of data, were only saved to the SD card and were not transmitted to the ground station via the RF transmitter.

We considered designing an efficient and safe recovery system and outer shell is another part of our secondary mission. Our recovery system mainly consisted of the parachute. We made a lot of tests to define how large the surface the of parachute should be because the multitude of natural unpredictable natural factors. Finally we decided to make three chutes up from 6, 8 and 12 isosceles acute triangles, and choose the most efficient according to the weather conditions. We used a canopy material, which is adequately strong and flexible. To design the parachute the students used some simple physics principles, which they have learned at Mechanics classes: Newtonians laws, fall in gravitational field, drag, etc.

We used the following formula to determine the diameter of the parachute:

$$D = \sqrt{\frac{8 \cdot m \cdot g}{\pi \cdot \rho \cdot C_d \cdot v^2}} \quad (2)$$

Where:
m- total weight of body and parachute
g- acceleration of gravity, equal to 9.81 m/s^2
ρ- local density of the air (ρ=1.22 kg/m^3).
C_d- the drag coefficient (for the semi-spherical parachute Cd=1,5)
v- descent speed of the CanSat (the maximal speed reached during the fall is v=8m/s)

For the shell of the CanSat we tested two materials. One of our choices was the carbon-fiberglass, since it is a strong material and has a surprisingly good solidity. Moreover, it is flexible, within its breaking elongation limit, at the offload it gets back to the original shape. This feature changes depending on the change of the material's thickness. It does not absorb humidity, it is non-flammable and also heat insulator. Its only disadvantage was the price. Beside the carbon-fiberglass, we tested a PLA (polylactic-acid) plastic as possible raw material for our shell. We decided to use plastic because it is cheaper and more accessible than the carbon-fiberglass, and due to the highly customisable character of plastic we made a proper outer cover that withstands the forces appearing at the moment of impact with the ground. This year our CanSat's protection shell had two scopes. The first one was ordinary, it had to protect the main part of the electric circuits. In addition to this, we suspended on it a set of mini solar panels. We thought a lot about making it strong and light enough. Firstly we had the idea of making two different shells of which one supposed to be made of simple fiberglass and the other of vacuumed plastic. We made a 2-3 mm thick fiberglass shell, and fixed on it 4 rows of solar panels.

First we made a wood moulding which was covered with the fiberglass sheet and epoxy resins. We superpose several fiberglass slab and resins and after dried them. The surface of the template was very smooth, and the outside diameter was 3 millimetres smaller than that of the CanSat's.

The Miko-Cansat16 components:

Weather related data, mean temperature, atmospheric pressure and humidity, were measured by two different sensor units. Temperature and humidity were measured by the same unit, an HTU21D Digital Relative Humidity Sensor with Temperature Output. This sensor provided us calibrated, linearized signals in digital, I^{2}C format. Besides the low power consumption and fast response time another advantage of this sensor was that the resolution (both for RH and T) can be changed by command. Our pressure sensor, the LPS25H, was incorporated into the AltIMU-10 v4 unit. The LPS25H is an ultra-compact absolute piezoresistive pressure sensor. It includes a monolithic sensing element and an IC interface able to take the information from the sensing element and to provide a digital signal to the external world. An added advantage was that it had a high shock survivability of 10000g.

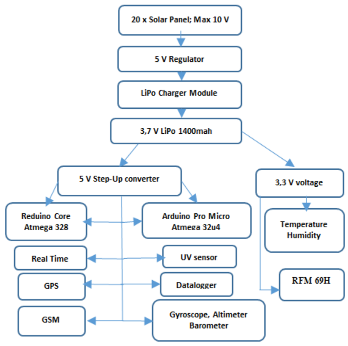

Fig. 7. The Miko-Cansat16 block diagram

The AltIMU-10 v4 unit was also equipped with a three-axis digital output gyroscope and an ultra-compact high performance e-Compass 3D accelerometer and 3D magnetometer module (LSM303D). The L3GD20H gyroscope was a low-power three-axis angular rate sensor. It included a sensing element and an IC interface able to provide the measured angular rate to the external world through digital interface (I2C/SPI). The LSM303D was a system-in-package featuring a 3D digital linear acceleration sensor and a 3D digital magnetic sensor.

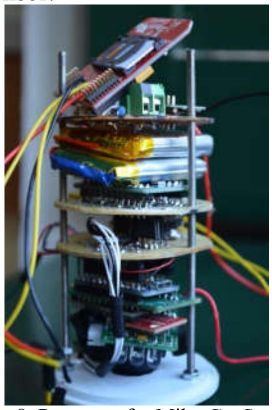

Fig.8. Prototype for Miko CanSat16

The nine independent rotation, acceleration, and magnetic readings provided all the data needed to make an altitude and heading reference system (AHRS), and readings from the absolute pressure sensor can be easily converted to altitudes, giving a total of ten independent measurements (sometimes called 10DOF). With an appropriate algorithm, the microcontroller built in device and our computer was able to use the data to calculate the orientation and height of the AltIMU board.

The device was also equipped with a piezoelectric component to detect the moment when the CanSat lands. At the moment of landing, a small electrical tension was produced in the piezo element. The piezo is an electronic device that generates a voltage when it's physically deformed by a vibration, sound wave, or mechanical strain. If the sensors output is stronger than a certain threshold, the board sends the string "Knock!" to the computer display over the serial port.

GPS data were provided by a ADH-tech sensor. The GP-735 is a slim, ultra-high performance, easy to use GPS smart antenna module designed with u-bloc's latest 7th generation single chip.

Another sensor (ML8511) measured UV intensity, which value is then weighted according to the CIE Erythemal Action Spectrum (a standardized measure of human skin's response to different wavelengths of sunlight from UVB to UVA) giving us the UV index. The UV index is a number on a linear scale from 0 to 11. We currently used the ML8511 sensor, but we were testing several other types of sensors too. Considering the low supply current (300mA in function and 0.1mA in standby mode), the current sensor guarantees a long battery life. In addition, it operates perfectly between -25°C and 75°C, which is in accordance with atmospheric measurements. The whole measuring device was driven by an Arduino microcontroller with an appropriate programme written by the students.

III. CONCLUSION

The students are very interested in this project since it is something new and exciting for them, which could help them discover the fascinating world of space science and technologies. Not only will the acquired knowledge and experiences aid them in their daily student lives (at school) but also in the future in our professional career. These contests offer a very good opportunity to improve the students' knowledge in transcurricular topics, they could combine physics and math knowledge with computer science, programming and engineering.

After every contest I try to use our achievements in the teaching process. So we built a mini meteorological station using the Cansat components and we collect air parameters every day. We created a comparative meteorological (pressure, temperature, UV radiation, wind) map for our town and Launch Campaign site and I use them during physics lessons (regarding topics such as thermodynamics, geography, biology). In the preparation phase of this project we made some 3D charts with data collected while testing at Sugás-Hill, near our town, so these data can also be used.

Our outreach activity is carried out parallel to the planning, building and testing phase of Cansat, this way we could inform the public regarding our most recent accomplishments. We hold presentations on special physics lessons at "Bod Péter" County Library, interactive workshops for primary school students (9-11 years old) during the Science Day or science camp; we keep blogs in three languages (Hungarian, Romanian and English). On these blogs we have the opportunity to publish articles presenting details for all who are interested and to share information about the whole progress of the project. In addition, we do the same on the website of our school. Furthermore, we publish articles in the school and local newspapers.

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