

Experiments with CanSat

Mária Pető

Székely Mikó High School, Romania

Abstract

Spaces researches, satellites, speed of the light are all notions that are interesting to almost everyone but they seem to be very distant and inaccessible. However, this is just the appearance because even the 9th or 10th grade students' knowledge, curiosity, fantasy and inquisitive attitude are enough to bring these notions closer in the classroom.

This presentation is meant to show a measuring device, a measuring and a data processing technique, which allow the expansion and development of knowledge on thermodynamics and electricity on a high school level in a completely new environment with the help of a new unit called „CanSat”. The aim of the technique is to form skills and competences which allow students to solve scientific tasks, to do individual research and raises their interest in natural science.

Keywords: CanSat, speed of the light, measurement, pollution, arduino, atmosphere, outdoor activities

Introduction

Thermodynamics and electricity are part of the 10th grade physics curriculum in Romania, and they offer many opportunities to try new ways of teaching. In the course of the last school year during the activities of the Science Club together with my students I built a mini satellite called “CanSat”. With this satellite our “Bolyai”- team participated in the **2012 European CanSat** competition held by ESA (European Space Agency) and NAROM (Norwegian Centre for Space-related Education). This device is similar to a real satellite, but it must fit inside a 330 ml soda can. On the day of the launch campaign at Andoya Rocket center the CanSat was delivered by an “Intruder” rocket up to a height of 1 km and then was dropped off. During the descent we made certain measurements, like: temperature, pressure, dust and solid particle density in the atmosphere.

For me, this competition was the first step towards trying new methods in the classroom activities during thermodynamics and electricity. The results obtained and student's inquisitive attitude motivated me to continue this project with other measuring tasks, in different environment and more improved devices. In this context this school year we measured the speed of the radio waves in the air and tried to find the connection existing between the speed of propagation and atmospheric parameters.

In this paper I will present this experiments and Science Club activities.

The CanSat project

At the beginning of the project my students did not learn much (only basic concepts) about atmosphere parameters, measuring techniques of pressure, pollution, electronic circuits, etc., therefore the pre-research phase of our work consisted of mainly documentation.

After this we chose two scientific missions: to measure the pressure, air temperature, humidity and the air quality by detecting the dust particles in the proximity of our CanSat with an optical dust sensor.

We chose to measure dust density since we know that our region (being situated near Brasov city) is highly polluted, the density of dust is very concerned in the atmosphere. Our main goal was to form a proper image of the situation and therefore to increase public awareness of this issue. We proved that in our region in different meteorological conditions the air pollution is considerable. In my opinion, protecting the environment and establishing an environmental education, behaviour are possible only if we are aware how we harm it.

With our device we measured the PM10 ($< 10 \mu\text{m}$) and PM2,5 ($< 2,5 \mu\text{m}$) air pollution. The PM10 could be: cadmium, Cu, Ni, Zn, Mo, Pb, etc. The PM2,5 is very dangerous because it is not well known and viruses, fungus spores, and other toxic substances can easily attach themselves to it. According to the National Institute of Environmental Health, to the inhaled dust particles often bacteria, viruses, fungus spores, and other toxic substances are attached to the PM2,5 helping them enter the body and organism. Possible health effects are: eye conjunctivitis, irritation of the upper respiratory tract's mucous membranes; it may cause coughing, difficulties in breathing and other diseases after it is absorbed by the lungs.

We started the construction phase with developing the primary CanSat kit in such a manner that it would be able to measure air temperature and pressure, altogether with dust density (in equal periods of time). The measurement would take place after having been launched and deployed from an Intruder type rocket until the point when it touches the ground. The device is to descend at approximately 5-8 m/s from an altitude of 1km. The cansats main recovery system was planned to be a parachute, which will enable it to land safely. When designing the parachute we took into consideration all the data about the rocket, which we were provided by ESA and NAROM: gravitational influences, the forces that occur during descent and the CanSat aerodynamic characteristics. Having all these data, we made calculations and designed more parachutes so that the device would land at a proper speed. The outer shell was made of special steel, which is quite light, but resistant and also flexible enough.

The next step was to calibrate the sensors and test them, at a height of about 100-500 meters. The dust and pressure sensors have also been calibrated. We visited the local station of the National Agency for Protecting the Environment (ANPM) and there we managed to obtain the data necessary for calibrating the two sensors. This was tested and it proved to be most appropriate. We established a radio connection between the CanSat and the ground station. We stored all the received data in a text file using an appropriate programme developed by the students.

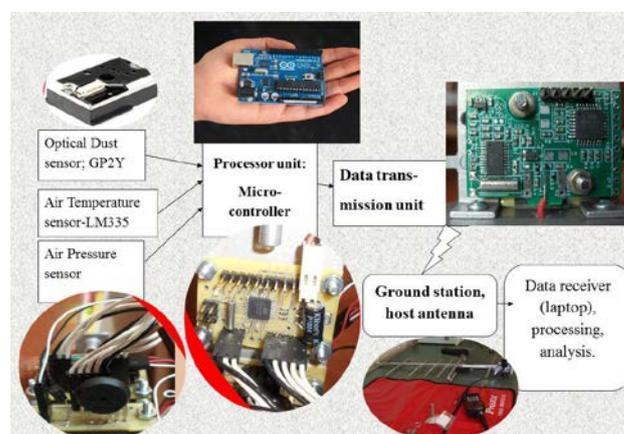


Figure 1. The block diagram of CanSat

This block diagram of device shows his parts:

- a Philips LM 335 temperature sensor; sensitivity 10mV/Celsius degree
- Optical Dust sensor type SHARP GP2Y1010AU0F. The sensor detects the amount of light reflected from particles in the air. It contains some infrared LEDs and optical lenses arranged so that the light emitted by the emitter LED irradiates the pollution particles (PM10 and PM2.5) and it is reflected to the light receiving elements.
- Pressure sensor (5V DC, sensitivity 45,9 mV/kPa);
- Battery: Type: alkaline; Voltage: 9V; Capacity: 500 mAh
- Microcontroller, Software: We used the Arduino development environment (based on Processing) and the Arduino programming language (an open-source programming framework for microcontrollers).
- Radio transmission unit, connection with the ground station by an antenna; frequency of 434.150 MHz.

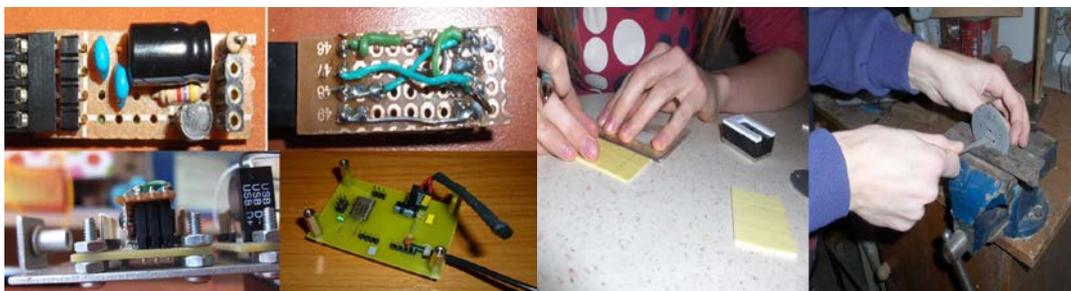


Figure 2. Build the internal circuits of CanSat

A small equipment was attached to the Arduino board in order to work with our sensors correctly. We put a filter capacitor after the stabilizer in order to smooth the pulsating DC power. This additional equipment was necessary for the optical dust sensor according to its data sheet. In order to ensure that the air will flow through the CanSat, four little holes are drilled into the top of the cover.

We created the database and we tested data import and enquiries using the measurements logged in text files, which we received during the tests. After the launch campaign we transferred all the data in our Acces database to an SQL database and created a webpage where everyone had acces to our results.

CanSat post – flight data analysis

The European CanSat2012 took place at Andoya Rocket Range (Norway 70⁰ N, 16⁰ E). On the day of the launch campaign the cansat was delivered by an “Intruder” rocket (1.5 m length, 3,3 kg weight, maximum speed 550 km/h and acceleration 11G) up to a height of 1 km and then was dropped off. At 1 km altitude the rocket deployed the cansat kit, and the devices landed on the ground with (5-8) m/s speed. During the descent we made certain measurements, like: temperature, pressure, dust and solid particle density in the atmosphere. We received all the radio packages which were sent from the cansat until the landing, and all the data we got were sensible to be able to logically explain. Due to these reasons, we consider our mission a full success, as far as temperature, air pressure and dust density data is considered. Throughout the descent we received a total of 216 readings, which were analyzed with Microsoft Access and Excel programs.

After we processed the data we got the following diagrams for temperature and pressure.

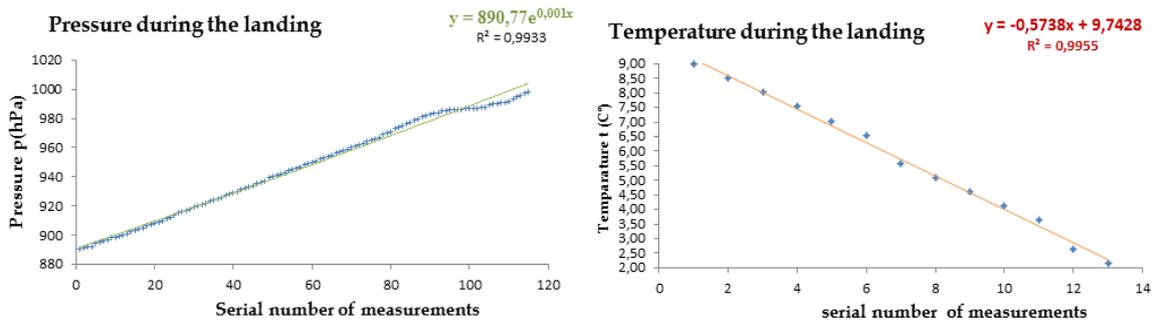


Figure 3. Pressure and temperature measured with CanSat during the landing

These values show that the **temperature decreased according to the gradient law** because the diagram is almost linear.

$$0,65 \text{ } ^\circ\text{C}/100 \text{ m}; \quad \text{grad } T \sim \text{grad}T_z = dT/dz \sim \Delta T/\Delta z \quad (1)$$

When analysing the obtained data we observed an interesting fact: the air located at the altitude of 1 km was warmer than the one near the surface of the Earth. The explanation is the phenomenon of temperature inversion. According to weather forecasts for Andoya the temperature measured near the ground (last measurements) are right, which also proves that our measurements were correct and precise.

The readings from the pressure sensor were in agreement with **barometric formula** (an exponential curve), where z stands for the altitude. We estimated the max. altitude of the rocket to be about 930 metres.

$$p = p_0 e^{-\frac{gH}{RT}} \quad (2)$$

Our secondary mission objective was to determine if there exists a certain variation pattern in the readings. Unfortunately, we couldn't detect any, but we still consider this mission succesful as well, since the data received were correct. During the cansat landing our optical sensor detected all particles in the air that reflect the infrared waves.

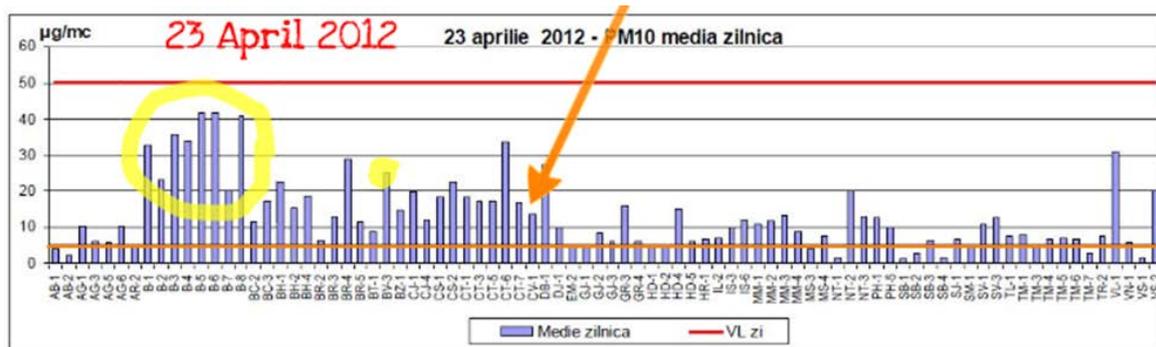


Figure 4. Air pollution in Romania at the launch day; PM10 dust pollution is concerned in the main industrial regions and big towns.

The red line marks the $50 \mu\text{g}/\text{m}^3$ air pollution limit, the orange line the average of our measurements (about $6 \mu\text{g}/\text{m}^3$). The circled readings are from Bucharest, our country's capital city, yellow dot – Brasov, whereas the arrow shows the reading for our town, Saint George.

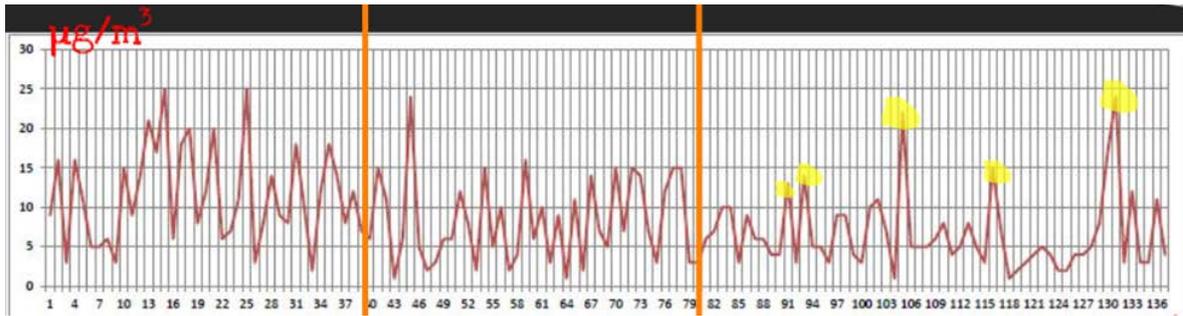


Figure 5. Air pollution at Andoya measured with the cansat PM10-2,5 ($\mu\text{g}/\text{m}^3$)

The graph above shows all our dust measurements, without any filtering. The extremely high values can be explained with our sensor's characteristics, so in order to work properly the particle density in the measuring zone should be constant for at least 5 microseconds, which in our case of course didn't happen because of the descent and the strong winds. In conclusion, we can say that Andoya is not affected by dust and solid particle pollution (is located near the sea, and has very limited car traffic).

After the European CanSat2012 contest we continued the measurements in the school yard, science lab and Science Club on several occasions. The measurement technique and data processing helped my students to understand better the basic notions of thermodynamics and air characteristics.

Measuring the speed of the light

To measure the speed of the light in the air we combine our cansat device with a handheld emitter-receptor device which is suitable for the direct estimation of the velocity of radio-waves. For this project we collaborated with the Physics Department of the Babes-Bolyai University Cluj Napoca. Our goal was to estimate the speed of the 433 MHz's frequency radio waves in the air and demonstrate the existing correlation between the air pressure, temperature, humidity and this velocity.

Romanian Physics curricula teach basic notions of special relativity in the final school year (12th grade) for students who learn at math-science classes. For this part of physics are allocated 9 hours, which include the Einstein postulates, Lorentz transformations and relativistic kinematics and dynamic. So during the normal class activity we had no time for special tasks, lab experiments, etc. Our measurements which could also be performed in the school yard, were able to help students understand better the scientific measuring method and the fact that the value of speed of the light is independent from reference frame hold. Due to this fact the value of this speed is extremely large ($c=3 \cdot 10^8$ m/s), it is quite difficult to measure directly because the reaction time of electronic devices is very slow in comparison with this value. So it needs to fit the measuring device for this condition but for learning value also it is very important that the device could be made by students with low budget in the school lab.

Our device is a simple walkie-talkie system which is appropriate for obtaining the speed of electromagnetic waves in air by the flight of time method for a direct estimation combined with the cansat to measuring the atmosphere parameters (pressure, temperature, humidity).



Figure 6. Measuring device for the speed of the light

Two simple emitter-receiver (ER) devices were built based on transceiver chips. The basic component of the ERs is a cheap integrated circuit, type RFM12BP. This element is perfect for being used in simple experiments for direct time measurement, and it is suitable both for sending and receiving data. So the same circuit is fitted for ER1 and ER2. ER1 is connected to the computers (we used two laptops) USB port, these send continuously the measured time-lag data on the frequencies: 433 MHz. [1].

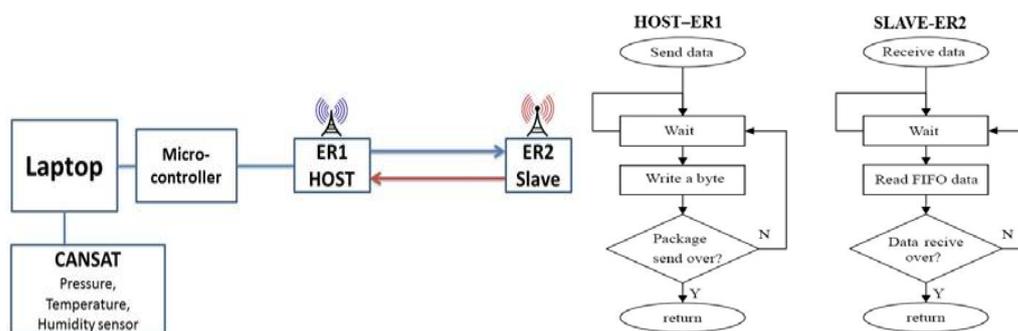


Figure 7. Block diagram of the measuring system. Emitter/Receiver protocol [5,6]

The ER1 (which is connected to the computer, named host) sends successive packages to the other, like ER2 (named slave). After ER2 detects the first package coming from ER1, it responds with another 1 byte length signal data package. If the first response package returns to ER1, it records the time elapsed between the original package and the response with a $1/8 \mu\text{s}$ accuracy. The received and recorded time is sent than to the laptop, where it is registered. If the ER1 doesn't detect the first response package, it will emit a second signal package. With the settings of the microcontroller we could define the functions of the ERs, which is the host – emitter and which is the slave-receiver.

The ERs are running a program written in C++, which commands their communication. The algorithmic representation of their communication is sketched below in Figure 7.

This is a simple operation protocol: ER1 sends a signal, and starts the clock. If this signal reaches ER2, then ER2 responds with another 1 byte length signal. When the response signal reaches to ER1, this stops the clock, writes the elapsed time to a file on the attached computer, and sends another signal, starting the clock again. During every 20 minute measurement, for a fixed position of ER2, we recorded continuously 35-40000 flight time

data. To improve the speed results we measured many flight times for fixed positions of slave ER, on different places near our town and analyzed them statistically.

Experiment

We started our measurements in the school yard. With this measurement we wanted to calibrate the device. We put the two ERs at 100-110 meter distance, installed the microcontrollers, cansat sensors and power suppliers. For the first setting we collected data 30 minutes, after than we moved closer the ER2 and restarted the flight time measurements again for 30 minutes. We repeat this procedure for 4 different positions of ERs.

The second and the third measurement days were in open-air, at a camp near our town. The team was divided in two groups. The first group determined the position of ER2, installed the power supply for this unit. During the measurement this unit would be moved to different positions regard the ER1. The other group would install the sensor, microcontroller, Arduino – board, run the data collector programmes. For the first measurement the distance between ER1 and ER2 were nearly 1 km, after 20 minutes we moved closer the ER2. So, we recorded data from 5 different distances for more than 100 minutes, this means more than two hundred thousand data.



Figure 8. The Science Club team measuring the speed of the light

We processed roughly 30000 different measuring results for each particular distance. The challenge was to separate the real, finite spread-time of the electromagnetic waves from the electronic delay of the ER device. Assuming that the average delay on the ERs is same every time (we compared numerous graphs plotted with the recorded data), differences between the real flight times help us determine the velocity of the radio waves from the different distance measurement.

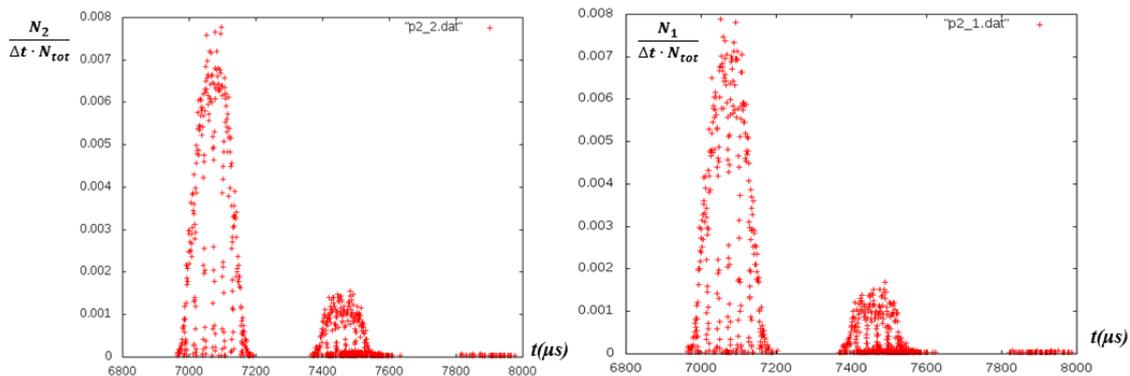


Figure 9. Histograms of the recorded flight times for a fixed position of ER2

The distributions of the light flight time for one fixed location of the ER don't show a normal distribution around the mean (real) value. We got two, very well separated peaks on the distribution – graph, the second peaks are shifted with a constant time-set. [Figure 9.] We used a statistical function for this data processing. For our graphs we eliminated the data that did not fit the first peak of the distribution function and the rare events data. By this we eliminated the influence of the digital components. For this data we calculated the characteristic mean-flight time. We plotted the mean-flight time for each measurement as function the distance between ER-s.

Table 1. Flight time measurement data

Day2/measurement	1	2	3	4	Day1/measurement	1	2	3	4
d-distance between ERs (m)	680	725	785	825	d-distance between ERs (m)	696	726	885	928
mean time (μs)	7087,047	7101,316	7142,055	7134,75	mean time (μs)	7103,847	7118,826	7160,875	7192,725
a (10 ⁻² μs/m)-day2	0,38215	0,36851	0,32987	Average- C	a (10 ⁻² μs/m)-day1	0,346197	0,318833	0,35081	average- c
c *(10 ⁸ m/s)	2,616776	2,713630566	3,031497256	2,7873014	c *(10 ⁸ m/s)	2,888531	3,136438198	2,85054588	2,9585049

Considering the linear regression on these points, the tangent of the slope will give the invers value of the velocity of the radio waves in air. [Figure 10].

$$a = \frac{t_2 - t_1}{d_2 - d_1} = \frac{1}{c} \quad f(x) = ax + b$$

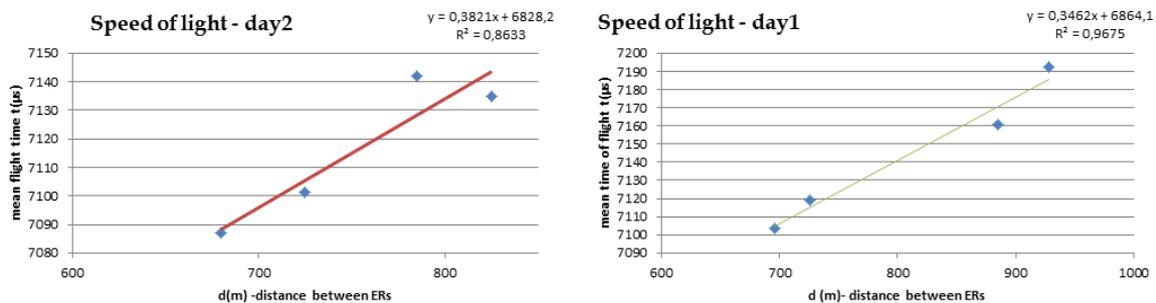


Figure 10. Average flight times as a function the distance between the two ERs. The obtained trend could be approximated with a linear fit.

The correlation between the speed of the light and air humidity was determined in collaboration with the Babes-Bolyai University Team (Benedek Elek-Zalán measurements, Sipos Lehel programming) during January. The team collected data continuously for 72 hours at distance 800-500 m, in winter on a hillside. Some series of measurements shows a connection between the velocity and air humidity, atmospheric parameters. Our sensor registered the pollution and humidity of the air. This measurement is not finished; we will continue this autumn and winter with more and improved sensors.

Conclusions

Our CanSat worked properly both at home and at Andoya during the launch campaign. We verified the barometric pressure formula, the temperature gradient from the ground to 1 km altitude. The pollution, dust measurement were good enough, we could compare the air pollution level at Andoya and Romania for the launch day. Our measurements prove that in

Brasov, due to it's being an industrial town, and in the surrounding area, thus our town as well, air pollution reaches significant levels, which is in connection with the weather conditions.

We could determine the speed of light with this experimental device. The next step of our project will be to improve the quality and accuracy of the measurement, write proper PC programs for data analyzing. We got more than 25 000 packages of data every 20 minutes, but that the distribution of the flight times for one fixed location does not show a simple normal distribution around a mean value. Instead of one peak we get other well-separable and much smaller peaks which are shifted with a constant offset. In the autumn and winter we will make long time determination, measuring continuously for 48-72 hours. We hope this data will help us find a connection between the value of electromagnetic wave speed and atmospheric parameters, particularly refractive index.

This project was successful, because my students enjoy these measuring and gladly take part in planning, programming, data processing or building phases of the project. With this work we realized a connection between different school tasks like mechanics, thermodynamics, electromagnetism, computer programming, IT.

This measuring device, measuring method and a data processing technique using computer software allows improving and developing the knowledge on thermodynamics and electromagnetism on a high school level, in a completely new environment. The aim of this technique is to form skills and competences that allow students to solve scientific tasks, to do individual research and raises their interest in natural science or IT.

References

- [1] Dombi A., Tunyagi A., Néda Z.: Walkie-talkie measurements for the speed of radio waves in air, iopscience.iop.org/0031-9120/48/1/80.
- [2] Farkas Zs., Hebling J.: Fizikai laboratóriumi gyakorlatok, JATEpress, 2001, Fénysebesség mérése levegőben, szilárd testben és folyadékban, from: titan.physx.u-szeged.hu/~labor2/01fenysebesseg.doc
- [3] Dombi A., Tunyagi A., Néda Z.: Rádióhullámok terjedési sebességének direkt mérése, *Műszaki Szemle*, 53/2011, p (3-7).
- [4] Budó Á. - Mátrai T.: Kísérleti fizika III., Budapest, 1987, 246.§, 248.
- [5] Benedek E-Zalán, Néda Z.: A fénysebesség mérése rádióhullámok segítségével, 2013, Babes-Bolyai University, Cluj-Napoca, final examination paper.
- [6] Direct measurement of the speed of radio waves in air; online from: <http://www.phys.ubbcluj.ro/~zneda/rv>
- [7] Szász Á., Néda Z.: Hálózati ping-pong- avagy a fény sebességének számítógépes mérése, *Természet Világa*, 2007/4, p. (132-133), online from (Measuring the speed of light by computer ping): <http://www.phys.ubbcluj.ro/~zneda/ping.html>
- [8] Carl B. Boyer: Early Estimates of the Velocity of Light, *Isis*, 1941, Vol. 33, No. 1, p. (24-40).
- [9] Jean M. Rueger: Refractive Index Formulae for Radio Waves, FIG XXII International Congress, 2002/apr/19-26, http://www.fig.net/pub/fig_2002/js28/js28_rueger.pdf