

UNIVERSAL MEASURING PLATFORM FOR ATMOSPHERIC PARAMETERS AND AIR QUALITY MONITORING WITH THE USE OF UNMANNED AERIAL VEHICLES

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Abstract: The aim of the project was to design a universal measuring platform in the form of a compact device applied to an unmanned aerial vehicle performing air quality tests at various altitudes. The measurements included recordings of temperature, pressure, humidity, suspended particulate matter, ionizing radiation, sunlight, and ozone content. The data is recorded in relation to the actual date and time on a microSD card.

Keywords: unmanned aerial vehicles, measuring platform, air quality monitoring, atmospheric condition testing

1 INTRODUCTION

Nowadays, scientific research in the fields of aviation, unmanned aerial vehicles, as well as other scientific and technical areas, including energy efficiency audits, necessitates the provision of adequate meteorological data protection. Despite the high level of development of services provided in this area by the Institute of Meteorology and Water Management (polish national institution) and other private meteorological and synoptic centers, accurate measurement data is only available in the immediate vicinity of meteorological stations or weather radars, and forecasts for other regions are often based on imprecise mathematical models. [1] This project attempts to solve this problem by creating a lightweight aerometric platform that will enable low-cost and simple meteorological coverage for scientific research, technical inspections, and other operational activities.

Such a platform could be used both for measurements at ground level, in which case the measurement would be carried out by a person holding the device, and for higher altitudes, using unmanned aerial vehicles. The recent dynamic development of drones (according to analyses, the UAV market is expected to grow from USD 26.3 billion to USD 41.3 billion between 2021 and 2026, with an average annual growth rate of 9.4%) means that securing research with aerometric measurements up to a height of 120 m will become commonplace and easily accessible. Due to legal constraints, the devices currently available are characterized by low field accessibility (UAVs weighing more than 4 kilograms can only be flown without permits in non-urban areas) and high prices due to the exclusivity of the products and orders mainly from large entities with high investment costs in measuring equipment. An alternative to expensive mobile measuring stations for implementation on UAVs or other wheeled vehicles is to rent or build stationary measuring stations. This solution is also expensive and, in addition, does not allow for easy transfer of measurements to another location. For measurements with high repeatability in a single area, this choice makes logical sense, but it should be remembered that meteorological parameters can change significantly

even over a distance of a few kilometers, which reduces the accuracy of measurements to a level similar to that of SYNOP or METAR dispatches and weather models in third-party applications.

Due to the problems identified above with the solutions currently available on the market - their capabilities and technical and legal limitations - this project is designed to be lightweight, inexpensive, and applicable to almost any drone with suitable, albeit reduced, load-bearing parameters compared to available products. [2, 3]

2 OBJECTIVE OF THE PROJECT

The lightweight aerometric platform should be capable of measuring the following parameters:

- air temperature,
- relative humidity,
- atmospheric pressure,
- sunshine,
- ozone content in the atmosphere,
- PM10, PM2.5, and PM1 particulate matter,
- ionizing radiation.

In addition, the collected data is to be saved on a microSD card in a file with the extension *.csv (comma-separated values), which will allow for easy import of data into calculation programs (including Microsoft Excel). In order to facilitate the identification of the time and place of measurements, the device will also record the measurement time using a real-time module. Each unmanned aerial vehicle used for measurements was equipped with a satellite navigation system and the ability to export data after flight.

The main objective is to create a lightweight device that will facilitate legal flights, i.e., the maximum weight of the device with the casing and mounting elements should not exceed 300 g. The dimensions of the device should also be in line with the standard dimensions of unmanned aerial vehicles so as not to interfere with their flight characteristics. The maximum dimensions of the device have been set at 150 x 150 x 50 mm (length x width x total height).

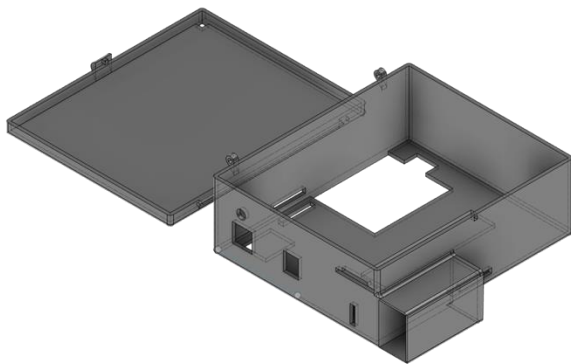


Figure 1. Unfolded housing of the aerometric measuring platform – view of the 3D model from Fusion 360 software, isometric perspective



Figure 2. Lightweight measuring platform after printing and implementing the electronic circuit – final version, using Bambu Lab PLA Aero filament and a Bambu Lab A1 3D printer.

The platform should also be able to perform measurements without the use of an unmanned aerial vehicle, which is why an independent power source in the form of a 6F22/6LR61 battery with a nominal voltage of 9 V and a capacity of 628 mAh is planned to be implemented. For faster replacement of the power source, the battery will have a separate opening in the device housing and a connection to the Arduino Uno microcontroller via a “click” connector.

The total cost of the platform (purchase of sensors and electronic circuits, filament for printing the housing, mounting elements) should not exceed EUR 250, which will significantly increase the application and prevalence of measurements.

3 DEVICE CONSTRUCTION

Various sensors, selected for both quality and cost, were used in the construction of the device. A BME280 sensor was used to measure temperature, humidity, and pressure. This is the basic sensor for the measuring platform (tab. 1). In addition, a real-time module, a microSD card data recording module, and an analog ambient light sensor were implemented. According to

the design assumptions, the platform was also to measure dust, ozone saturation, and ionizing radiation levels. These values are measured by three DFRobot sensors (SEN0463, SEN0321, SEN0460), built in such a way as to ensure adequate access to the measured medium.

Tabel 1. Technical specifications of the BME280 sensor [4]

BME280 technical specification			
Parameters	temperature	relative humidity	pressure
Range	-40 – 85 °C	10 – 100 % RH	300 – 1100 hPa
Measurement accuracy	±1 °C	±3 % RH	±1 hPa
Resolution	0,01 °C	0,008 %RH	0,18 Pa
Communication interface	I ² C, SPI		
Supply voltage	3,3 V		
Response/sampling time	0,9 s	1 s	0,9 s
Dimensions	15 × 10 mm		

The control code for the device was written in C programming language in the Arduino IDE program. Free libraries provided by sensor manufacturers containing basic functions and data reading algorithms were used to operate the sensors.

All sensors and microcontroller was built into casing printed in 3D. The material used to make the housing was selected based on an analysis of filaments available on the market for selected printers (fig. 1). The choice of the right material was made based on two key properties: low weight and resistance to external factors. The obvious choice was a filament from Bambu Lab called Bambu PLA Aero. It is the only filament widely available on the market that features technology supporting lightweight and energy-efficient flying models. The technology of foaming the filament during printing at high temperatures used in Bambu PLA Aero proved to be an irreplaceable feature that met the requirements of the measuring box model performing aerometric measurements, adapted for implementation on any drone with sufficient lift capacity thanks to the minimization of the weight and density of the finished print (tab. 2).

For comparison purposes, prior to printing the 3D model of the housing, an analysis was carried out of the standard PLA filament from Bambu Lab and the PLA Aero filament from the same manufacturer in terms of

printing parameters and print samples of the previously designed device housing model.

Tabel 2. Comparative analysis of PLA and PLA Aero filaments [5]

Parameter	PLA	PLA Aero
Printintng temperature [°C]	190 - 230	220 - 260
Printing speed [mm/s]	< 300	< 180
Material density [g/cm³]	1,24	1,21
Density of print [g/cm³]	1,21	0,55 - 1,05
Total mass of casing [g]	91	40

The housing (lower part of the cover) was assembled using a groove and hole in a specially designed and printed hinge. In addition, after assembling the parts printed using a 3D printer, they were sanded with P180 grit sandpaper to improve aesthetics and reduce material roughness.

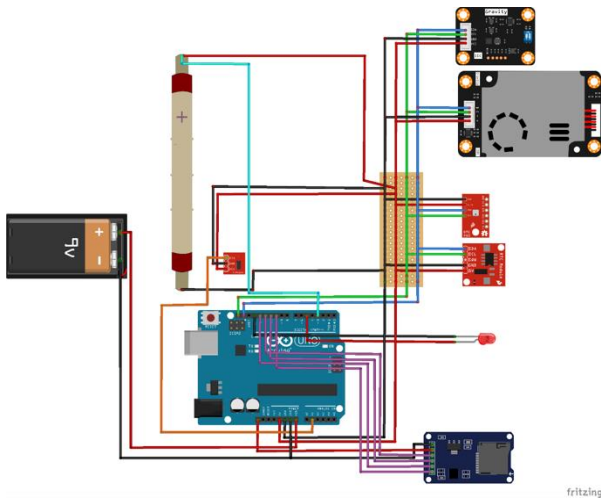


Figure 3. Graphical diagram of connections between sensors and the Arduino UNO microcontroller

The electronic part of the device was assembled using GoldPin connectors, which simplify any necessary replacements. The disadvantage of this solution is the poor mechanical resistance of the connector – even a slight pull on the wires causes the connection to come apart. In addition, a power bus (5V and GND) and data bus (SDA and SCL) for sensors with I2C data transfer were made using tin soldering on a PCB board (fig. 3, tab. 3).

Tabel 3. Electronic connections between sensors and the Arduino UNO microcontroller

PIN IN – Arduino UNO	PIN OUT – sensory
3	Geiger-Muller data
5	LED diode cathode
6	DAT RTC
7	CLK RTC
8	RST RTC
10	CS SD
11	MOSI SD
12	MISO SD
13	SCK SD
SDA	I2C bus
SCL	I2C bus
A1	light sensor - data
5V	power bus
5V	RTC (VCC)
GND	power bus
GND	LED diode anode
GND	RTC (GND)

4 RESEARCH METHODOLOGY

The final stage of the project was to perform a series of tests on the developed platform. The device was initially tested to verify the cooperation and exchange of information between the sensors and the microcontroller, the quality of data recording, and the internal battery life.

The main stage of testing involved a series of flights and checks of the accuracy, quality, and reliability of data recording in the air. Originally, it was planned to perform flights only with the DJI Phantom 3 Advanced unmanned aerial vehicle, due to its design and load-carrying capacity. Due to the lack of a class assignment and a take-off weight exceeding 250 g, flights with this drone are only possible in the OPEN A3 subcategory. This implies the need to stay at least 150 m (horizontal distance) away from residential, commercial, industrial, or recreational areas. Therefore, for flights in areas that do not meet the conditions of the OPEN A3 subcategory, another UAV was used – the DJI Matrice 4T. Due to its C2 class, this drone was used for flights in accordance with the regulations for A2 licenses – at a distance of up to 5 m from bystanders in limited speed mode. [6]

When selecting a suitable location for the research, the focus was primarily on a wide range of environmental conditions, as well as on the diversity of research locations in order to take into account the varied spatial contexts and local conditions affecting the results of the air quality analysis.

Sixteen flights were planned in four different locations:

- the center of Katowice (Sławika and Antalla Square) – dense urban development, in the vicinity of one of the main transport arteries of the agglomeration – Drogowa Trasa Średnicowa, DK79;
- park in Dolina Trzech Stawów (Valley of Three Ponds) – a recreation and leisure area located in the vicinity of dense urban development and the A4, DK86, and DK79 motorways;
- the village of Pękowice – a village located in the Krakow agglomeration, Zielonki commune;
- Mysłowice, Długa Street – farmland located in the vicinity of the A4/S1 expressway junction.

In each location, the flights were repeated four times to eliminate random errors. During the flights, data from all implemented sensors were recorded. In addition, in order to compare the results with meteorological observations, METAR and SYNOP reports were recorded for the meteorological stations: Katowice-Muchowiec, Katowice-Pyrzowice, and Kraków-Balice, as well as data from IMGW meteograms and stationary air quality stations. Collecting such a broad reference database allows for the analysis of possible errors in data recording due to:

- relatively high and low air temperatures,
- increased and decreased relative humidity,
- dynamic changes in atmospheric pressure,
- wind speed and direction,
- the presence of dust and pollutants in the air.

After the initial selection of measurement locations, they were checked in the DroneTower system (the official application of the Polish Air Navigation Services Agency, enabling the reporting of UAV flights and checking the current geographical zones for SBSP – DRA – drone area). Both locations in Katowice are in close proximity to the EPKM – Katowice-Muchowiec airport. Due to technical work on the runway of this airport, it was possible to perform flights in full scope without obtaining permission from the managing entity (ATZ EPKM was inactive during the flights). [7]

The test flights were performed between October 5 and October 10, 2025.

Analysis of the results obtained during the flights confirmed the correct operation of the design and operating procedures, and the test results indicated that the system operates reliably within the full range of anticipated operating conditions. No further design or system modifications were found to be necessary.

The results obtained during the test flights of the device were presented in tabular form and in graphs created in Microsoft Excel. Analysis of the results collected using the platform allows for numerous conclusions to be drawn and trends to be described in terms of altitude gain or in comparison to location.

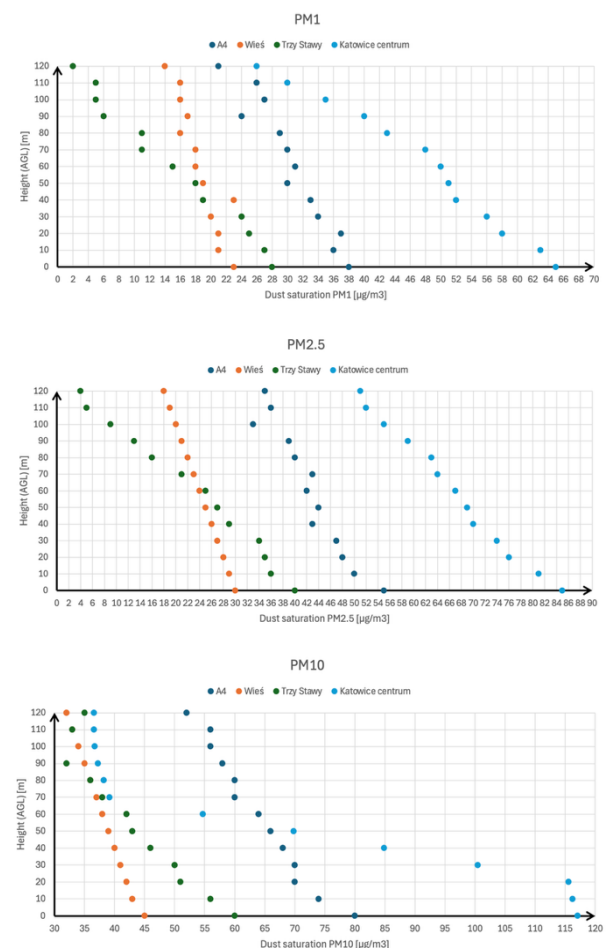


Figure 4-6. Graph showing the relationship between the average mass of particulate matter suspended in one cubic meter of air and the height and location of the measurement, for PM1, 2.5 and 10 particulate matter.

5 CONCLUSION

As a result of the design work, a functional aerometric platform was obtained, meeting the accepted assumptions, made using additive printing technology, weighing 269 g and measuring $124 \times 124 \times 30$ mm. The device can be used on most mass-produced medium and heavy drones (including the DJI Phantom, DJI Mavic 3, and DJI Matrice 4 series) and can collect environmental data in three-dimensional space up to a height of 120 m (legal restrictions), even in hard-to-reach places.

The design work carried out included both a theoretical analysis of the literature on measurement methods and solutions currently available on the market, including the creation of a database of their limitations and disadvantages, as well as the practical design and construction of the device, both in terms of electronics and additive manufacturing. A key aspect was to maximize weight reduction by selecting the right material for 3D printing (ultra-light PLA Aero) and minimizing the weight of electronic components while maintaining the capability and precision of measuring the specified parameters. Another problematic element was the platform's power supply – selecting the lightest option while maintaining the ability to operate for a

minimum of 30 minutes on a single charge and the ability to power the device.

A significant challenge of the work turned out to be the formal aspect resulting from the regulations for flying unmanned aerial vehicles without a class rating and planning such missions. Flying in accordance with applicable legal regulations resulted in the need to adjust the research methodology in terms of the locations where measurements were taken; procedures were also developed to minimize operational risk. In practice, however, due to the physical parameters of the platform, it is possible to use a drone with a class, for example C2, which will allow flights to be performed at a distance of up to 5 m from people, in the drone's limited horizontal speed mode (up to 3 m/s) – according to the regulations of the OPEN A2 subcategory.

One of the key research problems and assumptions of the work was also to construct the platform using such technology and components that the total cost would be reduced to EUR 250 gross. The total cost amounted to EUR 204,47 gross, which fully meets the assumed conditions.

In order to minimize the possible disturbances described in the theoretical chapter, advanced filtering and signal compensation should be used, which may be the direction of further research and contribute to the development of the project in the future, using a filament for additive manufacturing with protective properties against electrostatic charges by dispersing them, such as PETG – ESD or ABS-ESD, elements ensuring signal filtering and mechanically stabilizing the measuring platform.

Attention was also drawn to the possibility of making a “do-it-yourself” version of the device available in accordance with the open-source principle, with the intention of making its educational value available to the school and academic community. Users will be able to assemble the device themselves after receiving a 3D model file in *.step format, code, and instructions, using a 3D printer, Bambu Lab PLA Aero filament, and commonly available electronic components. This method will allow for the development of technical skills, learning about the operation of individual components and devices, and adapting the design to individual applications. It will also enable learning about the principles of additive printing, microcontroller programming, and the development of design skills.

The recorded temperature in all observations showed an almost linear downward trend, with a temperature gradient ranging from $-0.6\text{ }^{\circ}\text{C}/100\text{ m}$ to $-0.8\text{ }^{\circ}\text{C}/100\text{ m}$. For flight 3 in the Valley of Three Ponds, two significant deviations were recorded for relative heights of 30 and 80 m (up to 1°C). These errors are within the measurement error range declared by the sensor manufacturer.

The air quality analysis (PM1, PM2.5, and PM10 particulate matter) showed significant differences in dust levels for different areas and heights. In all measured cases, the worst results were recorded for the locations at Sławika and Antalla Squares in the center of Katowice, while the best (lowest values) were recorded for the rural area and the park in the Valley of Three

Ponds (figs. 4-6). All readings decreased with increasing altitude; in the case of measurements in the center of Katowice, PM10 dust showed a very dynamic decrease above an altitude of 20 m.

The data presented above confirm the compliance of the test flights with the adopted research methodology and their complete functional correctness in real conditions.



Figure 7. Lightweight aerometric platform mounted on a DJI Phantom 3 Advanced UAV during device testing on October 9, 2025, location - city park

In summary, all the design assumptions for a lightweight measuring platform for monitoring atmospheric parameters and air quality using an unmanned aerial vehicle have been met. As a result, it was possible to develop a device capable of providing adequate meteorological protection for scientific research, technical inspections, or other work requiring precise aerometric data while performing other measurements.

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