Computer sensor networks application for air quality events real time identification

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***Abstract**: The problem of air pollution with fine particulate matter and aerosols is more than topical and extremely serious. There is a need to develop and build reliable geographically distributed air quality monitoring networks to enable real-time data collection. The analysis of such data would help identify the origin of the particles and timely operational measures by the authorities. The research aims at the development of a mobile modular station with autonomous power supply and the experimental feasibility study and as a first step in the construction of a complete network.*

***Keywords**:* AIR POLLUTION, AIR QUALITY MONITORING SENSORS, PARTICULATE MATTER, SENSOR NETWORK, REALTIME DATA COLLECTION

1. Introduction

The problem of ambient air pollution, even more so in the light of the European Commission's latest decision to condemn Bulgaria, is extremely serious. The quality of ambient air is determined by the impurities present in it and is regulated in the first place by Directive 2008/50/EC, which is implemented in our normative documents. The concentration of fine particulate matter (PM) is one of the main problems in many major cities in Bulgaria. One of the issues essential for solving the problem is related to the origin of the particles and another – to the frequency of measurement and spatial resolution of measuring their concentration [1, 2].

The number of EEA monitoring points on the territory of Sofia meets the requirements of the Directive, but for detailed analysis the data from these stations is extremely insufficient, since the publicly available data has a 24-hour average and is obtained upon request to the agency. This means that real-time data analysis is impossible. Due to their high cost and the need for complex technical support, their number cannot be increased easily and quickly. In addition, the addition of functionality for measuring additional pollutants is also associated with high costs.

On the other hand, the widespread and rapidly growing public network of the Luftdaten.info project (AirSofia) represents a good opportunity to complement the monitoring of ambient air quality. The shortcomings of their sensors for outdoor use, in wide ranges of temperature and relative humidity are widely known and commented, so that data from the public network must be interpreted extremely carefully, especially with regard to the absolute values of the measured indicators reported by the network [3, 4].

This study aims to test the possibility of constructing a low-cost modular mobile station with autonomous power supply as an advanced complement to stations on the public network and its application for recording real-time indoor air pollution events. The combined analysis of data from specific sensors in real time or offline could answer the question of the origin of the particles for each point in the sensor network. This would be an extremely important tool in the preparation of operational measures and an adequate response of the authorities to reduce air pollution.

2. Design and development of the mobile station

The mobile station was developed on a modular basis with microcontrollers Atmega328P and ESP8266, as such its structure allows reconfiguration for specific tasks – local data collection on an SD card, data collection with close distance transmission, data collection with transmission over a mobile or computer network; measurement, collection and primary processing of data on meteorological parameters – air temperature, relative air humidity, atmospheric pressure, wind speed and direction, amount of precipitation, parameters of sunshine – UV index, UV/IR/visible light; measurement, collection and primary processing of data on air pollutants – eCO_2, TVOC, NO_2, SO_2, CO and others.

2.1. Principle scheme

The principle scheme is shown in Fig. 1 and includes the following main components: solar panel, solar controller, battery/battery pack; lowering PWM DC/DC to power microcontrollers; atmega328P microcontroller; and optional microcontroller ESP8266; meteorological measuring sensors; pollutant sensors; SD card module for local data storage; communication modules.

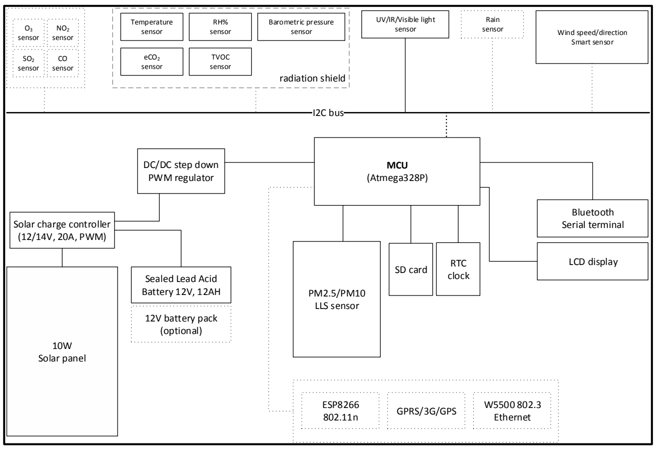

***Fig. 1** Principle scheme of mobile station*

Table**Грешка! Източникът на препратката не е намерен.** input/output interfaces and rails according to the needs of the specific research task (e.g. sensors for measuring the concentration of SO_2, NO_2, O_3 and CO in the air, which are common pollutants according to Directive 2008/50/EU).

Autonomous power supply from a solar power source (panel) or a chemical power source (Pb or LiIon batteries) provides the ability to operate in specific locations located far from the electricity grid. Depending on the configuration of sensors, the modular station has different power consumption on the one hand and on the other hand, according to the autonomy requirements of the specific application, an appropriate set of solar panels with a certain power and battery or battery pack is selected. For each of the modules, the necessary code has been developed. Raw data needs to be pre-processed, and here is one of the algorithms used – smoothing with exponentially weighted moving average.

***Table 1** Modular station components*

№	Kind of component	Function	Model
1	microcontroller	system management	Atmel328P (Arduino UNO R3)
2	Power supply	solar power source	10W solar panel of polycrystalline silicon
3	Power supply	solar power supply, battery charge, power supply to consumers	Solar Charge Controller 12/24V, 20A, PWM
4	Power supply	lowering the supply voltage	DC/DC lowering PWM module with input voltage 10-60V and stabilized output voltage 7.5V
5	Power supply	chemical energy source	battery 12V, 7-12AH or rechargeable package
6	service module	real-time clock	DS3231 temperature stabilized clock
7	service module	graphical display	LCD 16x2 display for local measurement visualization
8	service module	local data storage	SD/SDHC card module for local storage of data in CSV-formatted file on SD card
9	communication module	wireless communication connection	ESP8266EX 32-bit microcontroller with WiFi 802.11n and TCP/IP network stack
10	communication module	wireless communication connection	Bluetooth HM12 module supported by 4.1+EDR and BLE
11	communication module	cable communication connection	W5100 IEEE 802.3 Ethernet connection module according to standard 100Base-TX on twisted pair cables
12	meteorological module	measurement of meteorological parameters	Bosh BME280 for measuring temperature, relative humidity and atmospheric pressure
13	meteorological module	measurement of meteorological parameters	Silicon Laboratories SI1145 UV index, IR/UV intensity/visible light
14	meteorological module	measurement of meteorological parameters	La Crosse Technology TX20 wired digital anemometer for measuring wind direction (16 rumbas) and wind speed (0-51.1 m/s)
15	meteorological module	measurement of meteorological parameters	Technoline Mobile Alerts MA10650
16	measuring module	measurement of the content of pollutants in the air	Nova PM SDS011 LLS two-channel digital sensor for measuring of $PM_{2.5}$ and PM_{10}
17	measuring module	measurement of the content of pollutants in the air	Adafruit CCS811 MOX-plate sensor for measuring of eCO_2 and TVOC

2.2. *Implementation of Exponential Moving Average (EMA) Algorithm*

Smoothing the input data read at high frequency by the measuring sensors allows the elimination of high-frequency signal interference. They may be due to external interference or to the algorithms for converting voltage into digital equivalent in the 10-bit ADC of the microcontroller.

The algorithm using exponential moving average (EMA) to calculate the smoothed input signal value S_{i} at input signal values Y_i:

$$t = 1, \; S_1 = Y_1$$
$$t > 1, \qquad S_t = \alpha * Y_t + (1 - \alpha) * S_{t-1}$$

Where the S_t is the calculated signal from the EMA time algorithm t, α is a factor in the interval [0; 1] that determines the severity of the previous calculated signal values. A higher value of α results in a faster response to a change in input signal, but uses less raw input data than the sensor.

Since, according to manufacturers, most of the sensors used for the development of the mobile modular station are applicable to indoor or shelter conditions and have not been tested outdoors, and even more so in winter conditions – low temperatures, high humidity, snowfall, fog, etc., it is undoubtedly necessary to conduct tests on the behavior of the apparatus in real adverse weather conditions.

For this purpose, a time period is selected from 28.12.2019 to 4.1.2020. Including. The station is located at an altitude of 902 m. in the village of Bistritsa – Sofia Municipality, at a point with geographical coordinates 42.58791N and 23.36016E, in a residential area. The place is characterized by complex topography, which determines local wind speeds, as well as local microclimate. The area is residential, without heavy traffic. The population is heated with the predominant use of solid fuel installations. There are no industrial or sources of wind erosion nearby. This makes it possible to clearly identify the type of source of pollution when registering pm pollution peaks after combined analysis of data from different sensors.

In parallel, a sampling of glass fiber filters with standard apparatus for gravimetric determination of PM_{10} was carried out directly next to the mobile station for the purpose of possible correction or development of a new internal model for converting the raw data from the LLS particle counter into a mass concentration [5, 6].

To compare the suitability, influence of the microclimate and the type of polluting activities, a comparative analysis of the data from the experimental mobile modular station, in particular the temperature, humidity and PM sensors, was carried out with those of the public network of the Luftdaten.info project (known as AirSofia or AirTube), as well as data from an air monitoring point of the Executive Environmental Agency (EEA) – "AIS Kopitoto" using a reference monitoring method (beta absorption).

3. *Geographical location of monitoring stations*

***Fig. 2** Location of AAQ monitoring stations*

The location of the selected ambient air quality monitoring stations is presented to Fig. 2. As shown by it, the AIS Kopitoto is located in a rural area near the city of Sofia and is classified as a background rural near city monitoring station for AAQ.

It is characteristic of the recording of background PM_{10} concentrations and the data from the station are used to verify the conclusions of the analysis of data from the sensor stations.
Sensor station "Pavlovo #11877" is part of the project Luftdaten.info (AirSofia) and is located near two large thoroughfares – "Tsar Boris III" Blvd. and „Ovcha kupel“ Blvd. It is therefore assumed that it takes into account mainly the impact of $PM_{2.5}$ and PM_{10} emissions formed by transportation on both avenues. The $PM_{2.5}/PM_{10}$ ratio is also expected to be different from in the background points. The Bistrica No 6394 sensor station is also part of the Lufdaten.info (AirSofia) project and is located about 150 meters from the location of the experimental mobile station subject to the study.

It was chosen because of the close location to the site of the experiment on one hand and, on the other hand, it is located at the end of the residential area, at the foot of the mountain, where relatively constant vertical currents are characteristic. All sensor stations included in the Luftdaten.info project collect data every approximately 2:30 minutes, while the mobile modular station is configured to measure and record results for air quality indicators and weather data every 15 seconds (4 measurements per minute). due to fast-moving transient events (sudden pollution)

4. *Summary of experimental results from the mobile station*

Table 2 presents the summarized results of the operation of the mobile measuring station for the period from 28.12.2019 until 04.01.2020 (8 days). Samples with n=23831 values of parameters T (air temperature, °C), AP (atmospheric pressure, hPa), RH (relative humidity), DP (calculated dew point, °C), UV (UV index), eCO2 (concentration of equivalent CO2, ppm), TVOC (total volatile organic compounds, ppb) have been collected. For parameters $PM_{2.5}$ and PM_{10}, $\mu g/m^3$ samples were reduced by 2706 values to n=21125 due to sensor fan freezing by condensed water drops and a drop down of temperature below -8.8°C. The program algorithm was adjusted with changing the timing diagram for blow-in/collect mode before/after measurements to fix the problem.

Table 2 *Mobile modular station operation results*

Parameter	Unit	N	N*	Avg	Min	Max	StDev
T	°C	23831	0	0.62	-8.87	17.62	4.79
AP	hPa	23831	0	922.15	914.92	926.89	3.18
RH	%	23830	0	60.25	20.63	79.45	12.60
DP	°C	23830	0	-6.64	-13.06	-2.16	1.95
UV	index	23831	0	0.6	0.0	9.0	1.89
PM2.5	$\mu g/m^3$	21125	2706	33.63	0.40	876.20	52.34
PM10	$\mu g/m^3$	21125	2706	84.83	0.90	1893.10	131.82
eCO2	ppm	23831	0	861.80	0.00	7992.00	676.99
TVOC	ppb	23831	0	69.86	0.00	1156.00	103.14

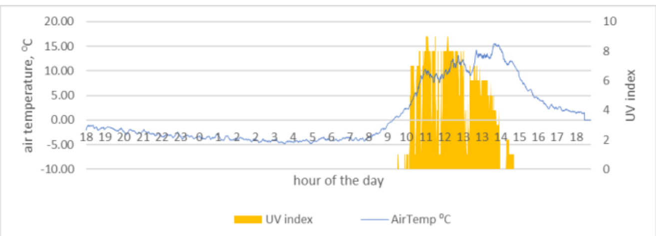

Fig. 3 *Air temperature and UV index (02.01.2020)*

For the period from 01.01.2020 to 04.01.2020 between 10 to 15 o’clock the air temperature was in the range from 5 to 15 °C, which is an unusually high temperature for this time of year. This is particularly evident in the graph of Fig. 3, which shows the daily temperature change and measured UV index for 02.01.2020, and lower emissions as a result of heating combustion processes should be expected from here.

On Fig. 4 is shown measured relative air humidity RH in % for the period of the experiment. It is easy to notice the decrease in relative humidity in periods with a higher temperature.

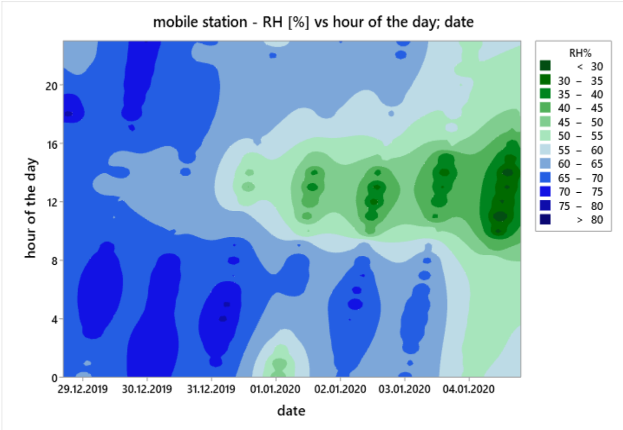

Fig. 4 *Measured relative humidity [%] by day and hours*

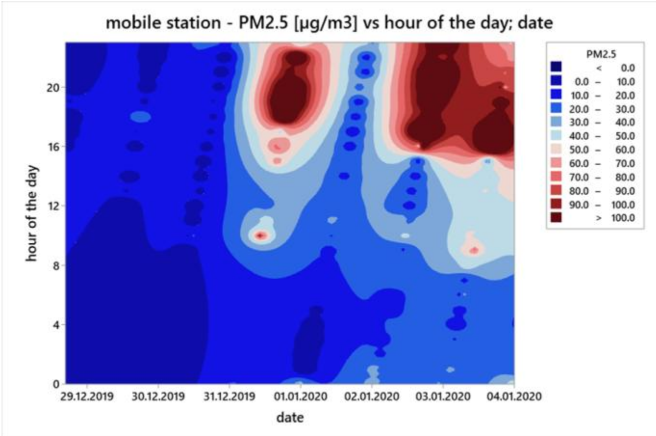

Fig. 3 *Measured $PM_{2.5}$ concentration [$\mu g/m^3$] by day and hour*

Fig. 5 **Грешка! Източникът на препратката не е намерен.**contour plot of the values of $PM_{2.5}$ measured with the mobile station, depending on the day and time of the day. The areas with red contours are in the hours typical for igniting solid fuel heaters (in mornings between 8 am and 9 am). The larger areas enclosed by red color are obtained for the evening hours (after 16:30), which correspond to the drop in the daily temperature and the associated intensive heating. The process is kept stable for several hours, with an almost constant emission.

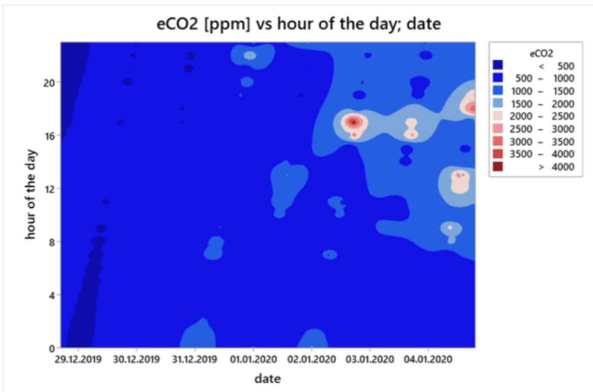

Fig. 6 *Measured eCO_2 concentration [ppm] by day and hour*

The amounts of the larger PM fraction are greater when the particles are generated when burning solid fuel for heating, which can be noticed by the red contour of the graph, which is significantly large in area and value.

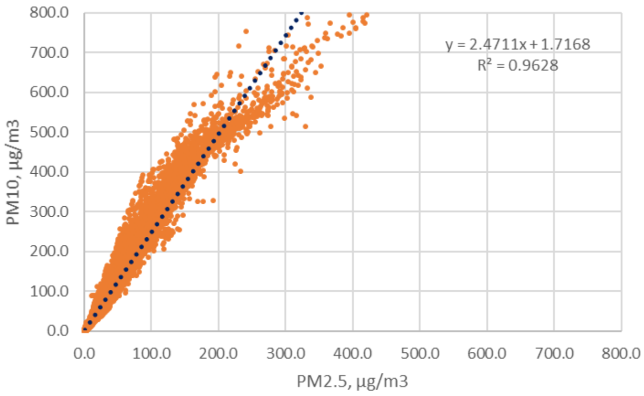

Fig. 7 *$PM_{10}/PM_{2.5}$ ratio model, obtained from measured data*

Fig. 7 presents a regression model of the ratio between PM**Грешка! Източникът на препратката не е намерен.**$_{2.5}$ and PM_{10} concentrations with a high value of the coefficient of detergent.

Areas with short-term peak concentration values are visible every morning between 8 and 9 hours, which is explained by the start times of the heating installations. since it is a clear signal for identifying an event and type of polluting activity, especially in combination with data from the other two sensors for eCO_2 and TVOC. Graphs clearly show the variation in concentration and thus the PM emission, on daily basis and as function of ambient temperature, which is essential for obtaining adequate and accurate variation coefficients used in defining the emission for the purposes of the assessment of AAQ modelling.

It is clearly noted that at the high concentration values of the two particle fractions, a distinct non-linearity of the ratio occurs, consisting in an increase in the proportion of the fraction to 2.5 µm. This could be due to the miscalculation by the LLS method, influenced by the condensation nuclei at high relative humidity (above the manufacturer's recommended upper limit of 75%).

On the other hand, the linear regression model does not take significant computational resources and time, therefore it can be used in a floating time window to analyze the change in coefficients b_0 and b_1, which are an additional indicator of the type of pollution source and its location in combination with the measured wind direction and speed values.

Fig. 6 presents the change in the measured concentration of eCO_2 by day and hours from the mobile station for the period from 28 December 2019 until 4 January 2020. As mentioned above, the combined analysis of $PM_{2.5}$ and PM_{10} and eCO_2 concentration data gives a clear picture of the source of pollution.

Fig. 8 shows the distribution of the concentration values of total volatile organic compounds (TVOC) in ppb measured by the mobile station. Here, areas with higher TVOC concentration values coincide on the ground with those of eCO_2, but are characterized by a longer duration due to the fact that pellets, wood and coal used for domestic heating in the settlement of the experiment have different moisture content, in need of a drying period in which VOC is released. Since wood has a higher moisture content than pellets, the width of these areas can be used as a characteristic to identify the type of heating fuel.

To this end, further experiments should be carried out to standardize the width of these areas depending on the type of fuel used and the weather conditions

The impact of wind speed and relative humidity is clearly evident in the comparison of $PM_{2.5}$ data and wind speed (Fig.5 and Fig.9). For example, on 31 December 2019 an area with a higher PM concentration of up to 2.5µm was highlighted for the hours of 14 to 22 hours. For the same day in the previous hours, the wind speed was low and the relative humidity was high, which is a prerequisite for accumulating pollutants in the ground layer of the atmosphere, despite intense sunshine. In other words, the influence of weather parameters is characterized by some delay in time. This requires that meteorological parameters be considered in combination when assessing their dependence.

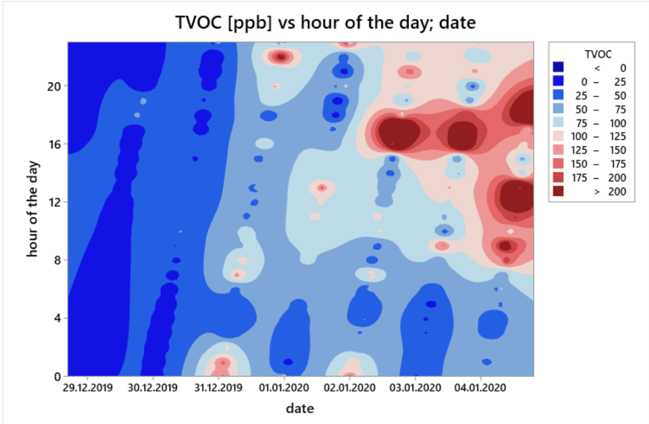

Fig. 8 *Measured TVOC concentration [ppb] by day and hour*

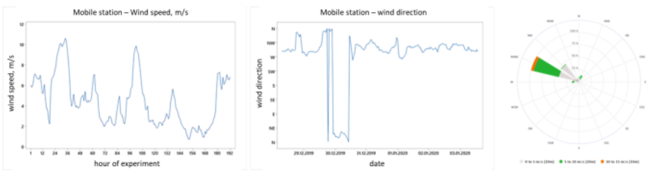

Fig. 9 *Measured wind speed and direction from the mobile station*

For comparison of the measured values of parameters - temperature, relative humidity and PM_{10} concentration, are presented in the same graphs, built according to data from the EEA's AIS "Kopitoto". Here it should be noted that the data from this monitoring station are recorded as average hourly values, therefore they are much lower in resolution than the sensor stations of the Luftdaten.info project, even more so than the mobile modular station, which makes it difficult to compare on the one hand, and makes it very difficult to identify the origin of the pollution. But there are still areas with characteristic sudden pollution, such as that on New Year's Eve on 31 December 2019 against 1 January 2020. Chronologically higher concentration values are reported in the AIS "Kopitoto" a few hours later due to the remote location of the station from the sources of pollution.

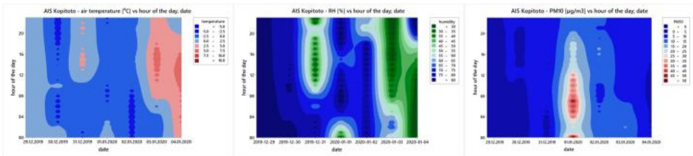

Fig. 10 *Measured air temperature, relative humidity and PM_{10} concentration from AIS "Kopitoto"*

This article aims to present a possible engineering solution using appropriate arrangement and setup of low-cost modular mobile measuring stations in a sensor network for remote sources of pollution and origin of pollutants identification in real-time.

5. CONCLUSIONS

Due to its autonomous power supply, modular stations can be placed on the so-called area sources of air pollutants, thus serving as a direct emission measurement system. Also, the presence of weather sensors makes it possible to determine and establish the conditions of occurrence of emissions depending on the peculiarities of the local microclimate.

Experiments have been carried out to verify the applicability of the developed station and its possibilities for detecting and recording events in order to identify the origin of the pollution, with the result that:

- when combining an PM level sensor with those for eCO_2 and TVOC levels, their data may be subject to a statistical analysis which clearly shows moments of high levels of specific emissions, which is relevant for the output of variation coefficients, as well as for recording events and identifying the origin of pollution;
- as a result of the comparison of station data with other sensor stations, the frequency of data collection is extremely important for the recording of short-term events characterizing charging emissions on the one hand and for characterizing the local microclimate on the other;
- it has been established that the selected hardware components operate autonomously in a wide temperature range and adverse weather conditions, while the system retains its stability and performance. The autonomous operation of the system, which is directly dependent on the energy consumption of the building modules, is extremely important as this makes it applicable for the study of emissions and/or environmental parameters in hard-to-reach areas without available electricity supply;
- network connectivity enables real-time transmission of data to a centralized system, which is essential for their subsequent processing and analysis;
- the identification of the origin of fine particulate air pollution and the reporting or visualization of such information would undoubtedly be a very useful tool in managing ambient air quality, the timely implementation of specific measures to improve AAQ, and informing the public about the origin of pollution.

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