Proc. XXXI International Scientific Conference Electronics - ET2022, September 13 - 15, 2022, Sozopol, Bulgaria

Mobile Low-cost Air Pollution Data Logger

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Abstract – **Air quality is one of the most important factors for human life. It is vital to monitor indoor and outdoor air parameters and to do appropriate measures. In the recent years the technology advances increasingly and that makes possible to produce many types of low-cost sensors and microcontrollers that have low power consumption. In this article the developed low-cost mobile system for air quality monitoring is presented. The results from initial measurements in eight points in the Plovdiv city center are presented and discussed.**

Keywords –**air quality, data logger, low-cost, mobile.**

I. Introduction

Global warming and air pollution are amongst the major challenges to humanity, as the population growths and cities become denser. Poor air quality is one of the key factors that contribute to low quality of life and also to number of diseases, including cardiovascular and pulmonary [1], [2]. The pollutants that contribute to poor air quality in cities are mainly from on-road vehicles and can be classified in two groups – primary and secondary. The first group are produced directly by pollution sources like gases from combustion, some of which are Nitrogen Oxides NO2, Sulfur Dioxide SO2, CO and CO2 [3], or particulate matter (PM) with various sizes, for example fine particles PM2.5. PM in atmosphere are complex mixtures of elemental carbon (EC), organic carbon (OC), mineral dust and water aerosols. Within this group are organic compounds, classified as Volatile Organic Compounds VOC [4]. Some of them are benzene, toluene, ethylbenzene, and xylenes (BTEX), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and polychlorinated dibenzo–p–dioxins and dibenzofurans (PCDD/Fs). They are mutagenic and possibly carcinogenic [5]. The other group – secondary pollutants are produced not directly but as a reaction in the atmosphere from the primary contaminates. One example is Ozone O3, which is toxic. So, it's important to monitor outdoor as well as indoor air quality in order to take appropriate measures such as frequent ventilation, managing traffic in big cities [6-8] or increasing green spaces in urban areas [5].

The aim of this paper is to present the prototype of the developed low-cost mobile air pollution monitoring system with low weight and low power consumption, and the initial results of the real life tests performed with it in the Plovdiv city center.

II. Related work

Measuring the quality of the urban air is done traditionally using fixed stations. These stations have measurement availability for a number of pollutants with high accuracy. Disadvantage is their high cost – in the range of thousands of euros, and they have also low spatial resolution because cover limited area [9]. This may cause inaccurate assessment of the air pollution over the area of study. Xie, X., et al. [9] have reviewed some of the common interpolation methods that are commonly used in the literature, namely Inverse Distance Weighting (IDW), Kriging, Data Driven Spatial Prediction, Compressed Sensing (CS), Land-Use Regression Models (LUR) and dispersion modeling, coupled with evidence of potential applications on mobile sensing campaigns. The authors conclude that combining fixed and mobile pollution data is still in its infancy and more research is needed.

With the recent development of technology there are affordable sensors in the market, namely from the metal oxide class MOx, as well as low price microcontroller modules such as the Arduino or Raspberry PI family [3]. The MOx class sensors are suitable for measuring the concentration of CO2 and the other previously mentioned pollutant gases as well as unspecific Total Volatile Compounds, known as TVOC. These sensors work using thick or thin metal oxide layer composed of tin oxide (SnO2), tungsten trioxide (WO3), zinc oxide (ZnO) or nickel oxide (NiO) [10]. The target pollutants cause changes in electron density or availability because the formation of electron depletion layer. The resistance of the sensor changes in that case and it could be measured and conditioned with the measuring device apparatus. One example of such system is proposed by G. Yurko et al. in [4] using three sensors - SGP30, BME680, and CCS811. In their paper the authors studied the real-time response of the sensors for detection of BTEX and chlorinated aliphatic hydrocarbon organic vapors using a laptop computer. In [3] an IoT developed system for monitoring indoor air quality with same class sensors – MQ-7, MQ-9, MQ-135 is presented. The results are monitored via LCD display and cloud-based platform – ThingSpeak using Wi-Fi module ESP8266. Another approach is presented in [11] – a distributed LoRa based monitoring network for CO2. The microcontroller unit that is used is the ESP32 for the measuring units and Raspberry Pi B+ as gateway for WLAN and user interface.

III. Sensors and System architecture

The proposed design is a low-cost mobile air pollution monitoring system. The components that are used are open source hardware modules from OLIMEX Ltd [12].

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A. Sensors used

The sensors that are used are from the metal oxide class (MOx) – CCS811, BME280, MQ-135. The first sensor – CCS811 is an ultra-low power sensor, which is based on micro-hotplate technology for sensing a variety of organic chemicals. It can measure air pollution in the form of total volatile organic compounds without discriminating individual types. Additionally, the sensor can measure temperature and relative humidity. These values can be used for correcting the TVOC against conditions of the environment. In the sensor are incorporated microcontroller unit with I2C interface, ADC and signal conditioning circuit. There are four modes of operation, which differ on the sampling time and power consumption – doing a measurement every 1, 10, 60 or 0.25 seconds.

The second sensor is the BME280 from Bosh Ltd. It measures temperature, relative humidity and air pressure. The parameters are corrected against the temperature. The interface can be I2C or SPI and that makes possible to connect the multiple sensors on one bus and to lower current consumption.

Fig. 1. The module with two sensors – BME280 (on the left) and CCS811 (on the bottom)

The third sensor – MQ-135 is from the MQ-x family. The sensor that is used is in the form of module – Fig. 2. It has two outputs – digital and analog. The digital output allows to be operated without microcontroller and to alarm for specific gas concentration. The second pin that is analog is used for quantifying pollutant gas in ppm units.

Fig. 2. MQ-135 gas sensor

MQ-135 can detect several gases – NH4, CO, CO2, Ethanol, Acetone, and Toluene [4]. The sensor characteristic is near linear in log plot – Fig. 3.

The specific characteristics of the sensors are presented on Table 1. All three sensors can operate with 3V power supply, which makes them suitable to be powered from two AA batteries. All three sensors are low cost and with low mass, which make them suitable to be used for mobile measurements. Properly calibrated, they could give accurate measurements. Because of their low current consumption, they can be powered from batteries.

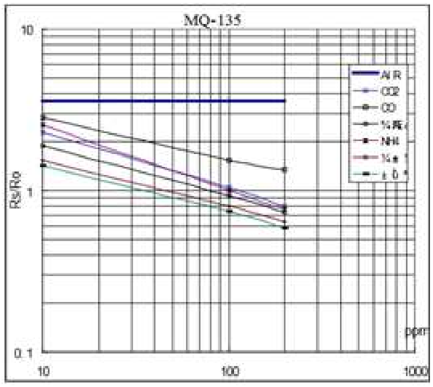

Fig. 3. MQ-135 characteristics for different gases [4].

TABLE 1. SENSORS SPECIFICATIONS

Sensor	**CCS811**	**BME280**	**MS-135**
Supply voltage, V	1.8 – 3.6	1.7 – 3.6	2.5 – 5
Current consumption, A	0.03	<0.001	0.04
Sensing parameter/gas	T(°C), RH(%), TVOC(ppb), CO2 (ppm)	T(°C), A^p(hPa)	NH_3, NO_x, alcohol, Benzene, smoke, CO_2, etc.

B. System architecture

The block diagram of the developed mobile air pollution monitoring system is presented on Fig 4. The microcontroller board is OLIMEXINO NANO. It is open source development board, based on 8-bit microcontroller ATmega32U4.

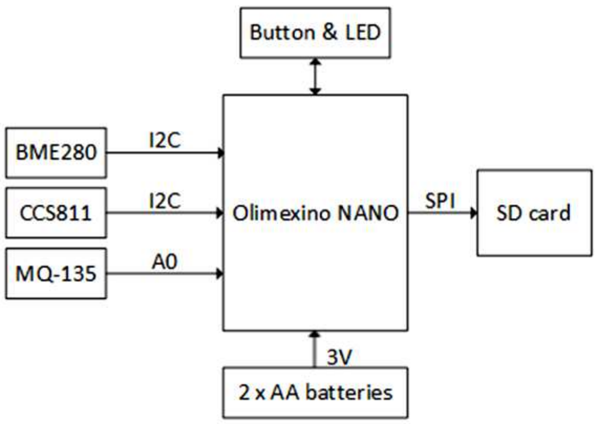

Fig. 4. System architecture

The CCS811 and BME280 sensors are connected to the MCU using I2C interface, and MQ-135 is connected through an analog line. The microcontroller processes the data from the sensors and stores the values in SD card, that is connected through SPI interface. The power supply is 3V, ensured by 2 x AA batteries. The developed prototype with mounted sensors, ready to be mounted on a drone for mobile measurements, is presented on Fig.5.

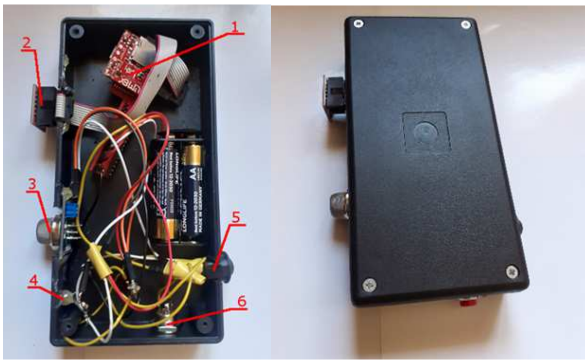

Fig. 5. Photograph of the prototype construction on the left and assembled prototype on the right.

The different components are marked with numbers as follows:

1. MCU board with SD card holder
2. Board with sensors CCS811 and BME280
3. MQ-135 sensor
4. LED
5. ON/OFF key
6. Button for start of the measurement

The prototype utilizes simple user interface – just one button and a light emitting diode (LED). At start up the LED is switched on if the initialization process ends normal. When the user presses the button, the LED blinks after 2sec for signal the start of measurement. Then after two more seconds the microcontroller starts reading the data from the sensors. It does this every second for a total of 100sec. The blinking phase at the beginning repeats a number of times for the current measurement point– for the first point – 1 time, for the second – 2 times, and so on till n times for the n-th point. This way the user could do multiple measurements, knowing the current point number. Data is stored on the SD card using CSV file format. It can be further processed and averaged offline, as well as analyzed in the time domain.

Here, the software algorithm is presented, in the form of pseudo code:

```
initialize input and outputs
if SD card present
   initialize sensors
   if sensors ready
         switch state
         case IDLE:
         turn on LED
         if button pressed
               wait for the button be released
               state = MEASUREMENT
               turn off LED
               wait 2s
               increment point
               for i = 0 to point values do
                     turn on LED
                     wait 500ms
                     turn off LED
                     wait 500ms
               end
               wait 2s
               write point variable values in SD card
         end
         case MEASUREMENT:
         turn on LED
         read sensors
         wait 200ms
         turn off LED
         wait 800ms
         increment measurement number
         if measurement number > 100
               state = IDLE
         end
```

The initial air pollution measurements have been made in the central part of Plovdiv city. As can be seen on Fig. 6, there were seven points, marked with grey dots and corresponding number, chosen for their position close to streets with heavy traffic. Also, there is one additional point in the middle of the main city park surrounded with trees, and this point is used as a reference. That is the point in the middle of the map marked as number eight.

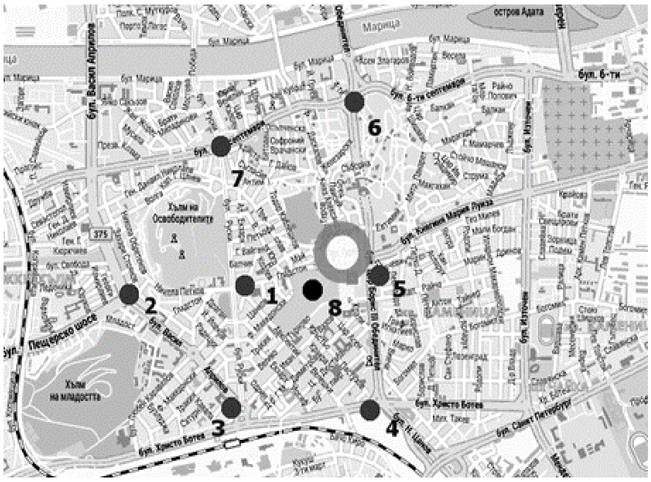

Fig. 6. Map of the central part of Plovdiv city.

Air pollution from traffic varies on the day of the week and the current hour. The measurements were done on Sunday at rush hour – between 17:00 and 18:00. Besides the traffic itself, the air pollution depends on many factors like the weather, atmospheric conditions, etc. At the time of doing measurements the temperature was around 22°C, atmospheric pressure was 1000.67 hPa and there was a light wind – 11km/h, which are typical conditions of a clear late spring day.

IV. Results

The developed air pollution measuring system was successfully used to collect data at the chosen points of the city. The average and maximal values after processing the output readings are presented on Fig. 7 and Fig. 8. The average CO_2 is raised at points 1, 5 and 6, suggesting poor air quality at these places. The maximum readings show even higher moment pollution - six points with high concentration of CO_2 and TVOC. It can be seen a correlation between the two parameters – when CO_2 is higher, then volatile organic pollution is also higher. The last 8-th point, in the middle at the central park, has the lowest pollutant readings, which quite expectedly suggests that green areas have pronounced positive effect on the air quality.

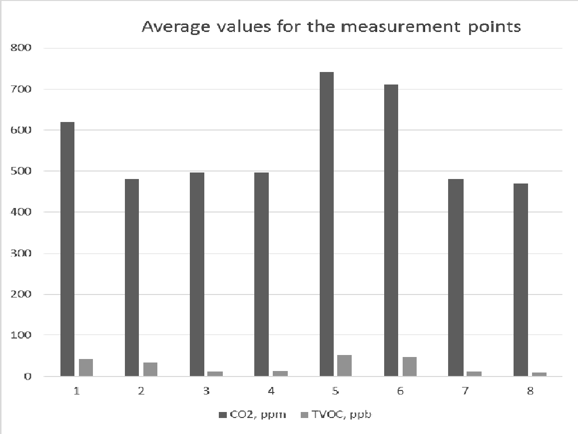

Fig. 7. Average values at the test points.

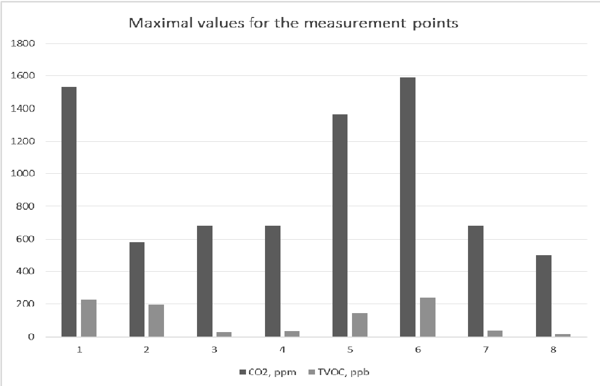

Fig. 8. Maximal values at the test points.

In Fig. 9 are presented the recorded raw values of relative CO2 and TVOC during the 100 seconds measuring period. Again, it could be seen the correlation between higher values of CO2 and organic volatile compounds in the air. The explanation of this could be that the two parameters are linked in nature as different kinds of pollution or that the sensors used are sensitive to both pollutants.

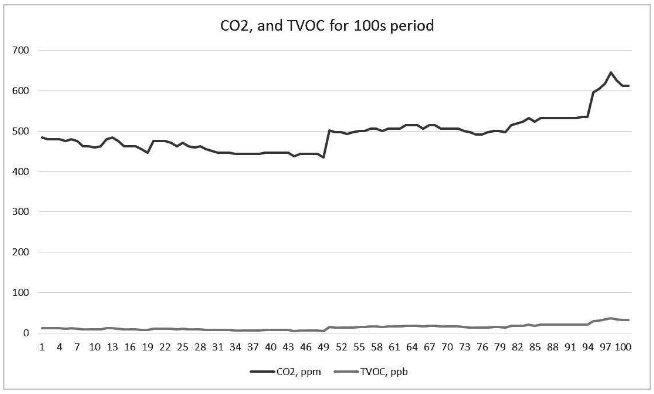

Fig. 9. Recorded values for 100sec.

V. CONCLUSION

The developed air pollution measuring system was successfully tested and used for multiple on-field measurements in Plovdiv city. The low current consumption, which is below 200mA makes it convenient to be powered from two AA batteries.

FUTURE WORK

The developed system is intended for mobile measurements. They could be done using drone in order to cover larger area with denser points of measurement and at different heights above ground. The system is suitable for this purpose, because of its low weight and low current consumption. The readings could be transmitted using wireless protocol that has long range like LoRaWAN. Furthermore, the sensors can be calibrated and licensed for official and accurate measurements of the air pollution.

ACKNOWLEDGMENT

This work has been supported by R&D Fund of the TU-Sofia, Grant **192ПД0017-19**, and also by the European Regional Development Fund within the Operational Programme "Science and Education for Smart Growth 2014 - 2020" under the Project Center of Competence "Intelligent mechatronics, eco- and energy-saving systems and technologies" BG05M2OP001-1.002-0023-C0.

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