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Hotspot identification with portable low-cost particulate matter sensor

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ABSTRACT

Air quality measurements were conducted at rural and urban environment with a low-cost particulate matter (PM) sensor and GPS receiver based portable device, which was developed to determine the atmospheric PM concentration and distribution. Using the PM sensors and GPS receiver data, hotspots can be identified, the air quality characteristics of crawled areas and routes can be determined. Suggestions was made to improve the accuracy of the measurement.

Keywords:
Sensor, Particulate matter, Air quality, Hotspot, Raspberry Pi

1. Introduction

The most significant indicator of ambient air quality is PM concentration due to its impact on human health [1], visibility [2] and climate [3-5]. Negative health effects of elevated PM concentrations include arrhythmia, heart disease, lung cancer and mortality [6-9]. Visibility has an effect for transport, aviation and even mood. Regarding to the complex influence of PM, the ambient concentrations of PM_{10} and $PM_{2.5}$ are regulated by The United States Environmental Protection Agency (US EPA [10]), the European Union (Air Quality Directive 2008/50/EC, AQD [11]) but the World Health Organization (WHO [12]) also makes recommendations to that. Compliance with the regulations is checked by the environmental authorities in accordance with the Federal Reference Methods (FRM [13]) or the Air Quality Directive (AQD [11]). According to the standards, the appropriate size of dust is collected by pre-separating and filtering, and the daily and annual average concentrations of PM are calculated by gravimetric method. Beside FRM, there are so-called Federal-Equivalent Methods (FEM [13]) approved by EPA, which can provide hourly, quarter hourly and even minutely data for measuring PM concentration [14]. FEM-specific methods operate according to a measurement principle different from the gravimetric method of the FRM, such as optical detection [15], beta-ray absorption [16] or Tapered Element Oscillating Microbalance (TEOM) [17]), complying with strict requirements. FEM devices cost almost the same as the FRM devices, but they are easier to handle and more practical for continuous monitoring. On the market are laboratory calibrated desktop and handheld devices (Calibrated Portable Devices) which are suitable for detecting PM, and the price is one order of magnitude lower than the FEMs, but the results are not accepted in official procedures. Low Cost Sensors are available with significantly lower price (<$30), some of which are calibrated, but their calibration is not well documented and unreliable. Fig. 1 shows the classification of PM measurement devices.

Fig. 1. Classification of PM measurement devices

AQD gives the opportunity to use complementary techniques such as air quality models and indicative measurements. Low-cost dust sensors may be suitable for such indicative measurements. Over the last decade, sensor-based air pollution monitoring systems have become more prominent, thanks for their low cost, small dimensions, high spatial resolution and they can provide detailed data on air pollution in cities. Several low-

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cost sensor air pollution measurement systems can be found worldwide from Barcelona, through Nowy Sącz and Oslo till California or Hong Kong [18-25]. Due to their small size, the sensors are easy to install on fix point or mobilize, and thus become accessible to the public for air quality monitoring [26-29]. In this context, we are currently experiencing a paradigm shift in how and who observes air quality [30-32]. This paper aims to summarize the experimental basics of a mobile PM measurement with GPS receiver based on Raspberry PI 3 B+ (RasPI) microcontroller.

2. Material and methods

During the experiments, the operation of the sensors, querying and recording of the data was made by RasPI type microcontroller. The microcontroller was equipped with temperature, humidity, pressure, PM sensor and GPS receiver as Fig. 2 shows. Temperature and humidity values were provided by a DHT22 (AM2302 chip) digital heat and humidity sensor using a single-wire Dallas-compatible protocol. The HP206C chip barometer was transmitted pressure data via a synchronous two-wire data transfer system (I^2C). The GPS receiver is equipped with a SIM28 type chip, which communicates via serial port with NMEA protocol, its antenna was 15 mm x 15 mm. Winsen ZH03 type sensor was used to measure PM, which also communicates via a serial port. Like the GPS receiver, it is powered by a 5V power supply. The sensor uses a laser light scattering method to measure the number of PM in the air drawn by fan, and then calculates it as a PM concentration. As output data, the PM concentration values of less than 2.5 and 10 µm ($PM_{2.5}$ and PM_{10}) are sent in µg/m^3. According to the datasheet, the detection limit of Winsen sensor is 0.3 µm diameter PM. Two pieces of PM sensor were installed. Recording was done with a Python 2.7 based self-developed software directly to RasPIs SD card memory.

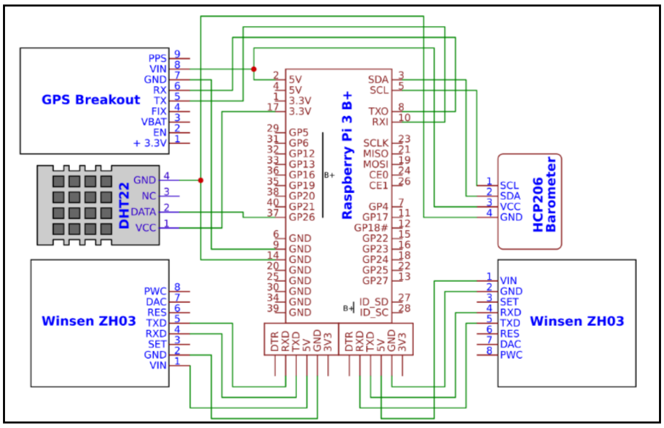

Fig. 2. Schematic diagram of the measuring device

Data were saved simultaneously with continuous reading at 0.2 Hz recording time. The RasPI was placed in a protective box on which the sensors and the GPS receiver and antenna were fixed. Zendure A3 Power Bank type 1000 mA battery was installed in the measuring box to provide power for all part of the device. A carabiner is mounted on the measuring box to secure it.

The measuring box was fixed on a backpack using the carabiner (Fig. 3). At outside location the RasPI (configured as Wi-Fi access point) was secured through Secure Shell (SSH) with an Android-based phone. As the recording software was started, it asked for the current date and time and then started the measurement and recording. In addition to the date and time, time, longitude and latitude coordinates, height values, and the number of satellites available from the GPS receiver were recorded in the output file. DHT22 and HP206C sensors with temperature (T), relative humidity (RH%), and pressure (P) values are recorded with the $PM_{2.5}$ and PM_{10} sent by the two dust sensors with 0.2 Hz intervals.

Fig. 3. The assembled measuring box and its position during the measurements

The first measurement was carried out on the Bükkszentkereszt - Libegő route (Rural measurement, Fig. 4) on February 24, between 9:42 and 10:42. Typically, it was sunny, clear winter weather, accompanied by mild air movement.

Fig. 4. Rural measurement route based on recorded GPS data (Direction of travel from green to red)

The second measurement was carried out in Miskolc on the route of the Stadium - Bulgarföld - Kilián - Diósgyőr - Berakalja - Diósgyőr (Urban measurement, Fig 5.) on March 3, between 19:32 and 21:45. The route is illustrated in Fig 4 based on the recorded GPS coordinates. The starting point is at the green end of the route and the arrival point is at the red end of the route. The weather was cold, foggy, windless and as time progressed, fog increased, visibility decreased.

Fig. 5. Urban measurement route based on recorded GPS data (Direction of travel from green to red)

During the Rural and Urban measurement, the GPS receiver was not able to determine the longitude and latitude coordinates all along the entire route, therefore the route line is not continuous at Fig. 4 and Fig 5.

3. Results and Discussion

During the Rural measurement, the temperature varied between -1.6 and 16.1 °C, and the relative humidity ranged from 38% to 62%, thus varying mild. The mean barometric pressure was 944 hPa with 2.5 hPa standard deviation (STD), as Table 1 shows. During the City measurement, the ambient temperature varied between -1.1 and -6.4 ° C, with a relative humidity ranging from 78.1% to 95.2%, thus varying in high level. These values refer well with the experienced misty weather. The average barometric pressure was 944 hPa.

Table 1. Atmospheric properties during Rural and Urban measurements

Atmospheric property	Pressure [hPa]	Humidity [%]	Temperature [°C]	$PM_{2.5}$	PM_{10}
Rural measurement					
Maximum	951.8	62.0	16.1	56	228
Minimum	936.9	38.0	-1.6	8	16
Mean	944.3	49.1	7.5	17	80
STD	2.5	4.7	3.6	20.0	5.0
Urban measurement					
Maximum	986.5	95.2	-1.1	149	296
Minimum	982.5	78.1	-6.4	47	58
Mean	985.0	91.3	-4.6	91	199
STD	0.9	3.6	1.0	19.3	34.9

The mean difference between the measured $PM_{2.5}$ values by the two Winsen sensors was 5.6 μg/m^3 and 17.4 μg/m^3 between PM_{10} concentrations. To reduce the measurement error the data of Winsen sensors were averaged for PM distribution analysis.

On the rout of the Rural measurement the mean concentration of $PM_{2.5}$ was 17 μg/m^3 and the PM_{10} concentration is 80 μg/m^3. $PM_{2.5}$ values vary between 7 and 56 μg/m^3, and PM_{10} values vary between 16 and 228 μg/m^3. Fig. 6 shows the $PM_{2.5}$ distribution along the road. Higher level $PM_{2.5}$ concentrations were recorded during the first section (red rectangle on Fig 6.), which goes through the village. Fig 7. shows a closer look to the first section. There are two easily visible red point areas in the first section (Fig. 7) of the first measurement, which show extremely high concentrations in a small area. These are called hotspots, which are suitable for identifying air pollution sources.

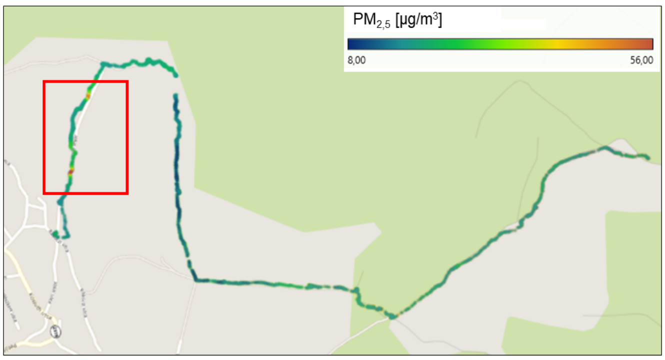

Fig. 6. Rural measurements $PM_{2.5}$ distribution

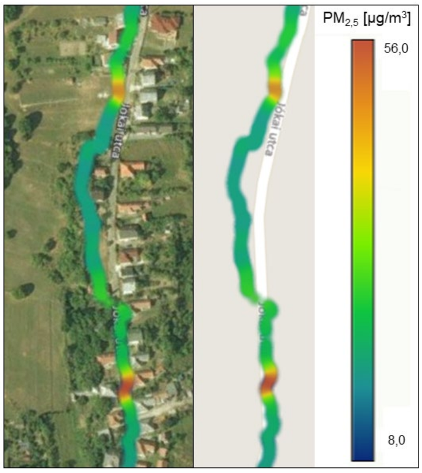

Fig. 7. Rural measurements first section with hotspots

On the route of the Urban Measurement the mean concentration of $PM_{2.5}$ is 91 μg/m^3 and the mean PM_{10} concentration was 199 μg/m^3. $PM_{2.5}$ values vary between 47 and 149 μg/m^3, and PM_{10} values vary between 58 and 296 μg/m^3. Fig. 8 shows the $PM_{2.5}$ distribution along the road.

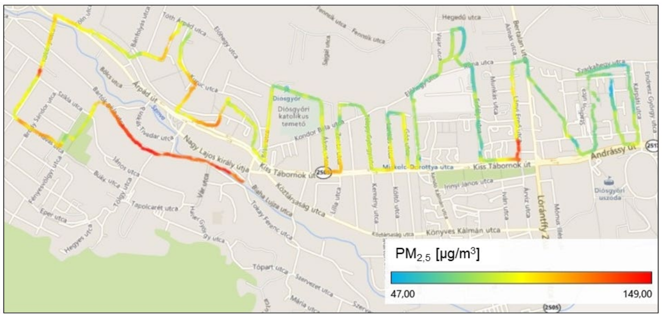

Fig. 8. Urban measurements $PM_{2.5}$ distribution

Red areas were also be observed along the Urban measurement. Some of them are pointy, others are line-shaped areas on the route. Points are like hotspots, while line-shaped sections show a typical value for a larger area, so they are not suitable for identifying the pollution sources but providing information on the ambient air quality.

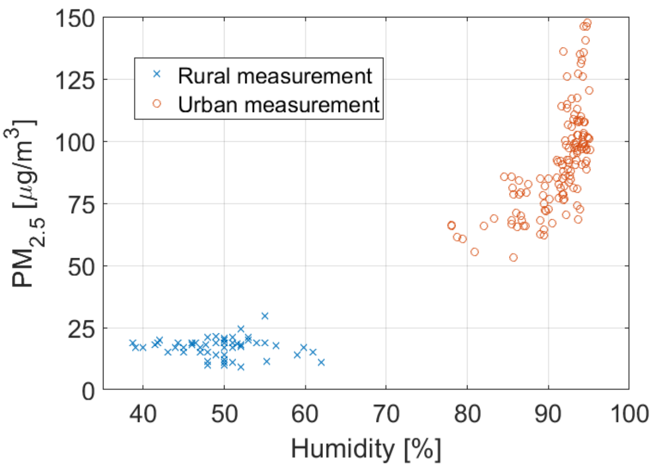

Fig. 9. Rural and Urban $PM_{2.5}$ concentrations and humidity values

The atmospheric properties are very different between the Rural and Urban measurements. Fig. 9 and Fig. 10 shows, that during the forenoon Rural measurement low $PM_{2.5}$ concentrations, low humidity and low pressure was typical. In contrast during the evening Urban measurement high PM2.5 concentration, high humidity and high pressure values were recorded.

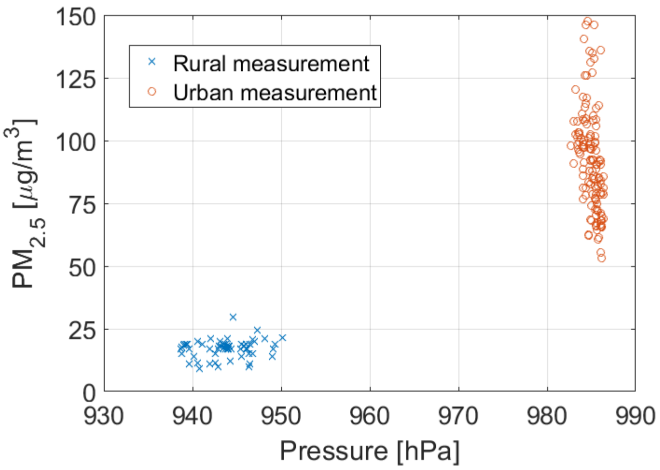

Fig. 10. Rural and Urban $PM_{2.5}$ concentrations and pressure values

As Fig. 11 shows, the Urban measurement was performed under 0 °C, but the Rural was in wide range.

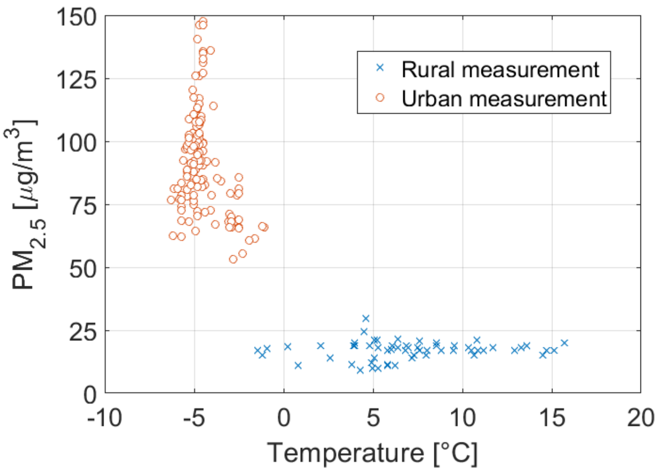

Fig. 11. Rural and Urban $PM_{2.5}$ concentrations and temperature values

The measurements give an opportunity to determine the average 1-h exposure concentration [33]. Table 2 shows the calculated concentrations.

Table 2. Exposure concentration during Rural and Urban measurements

Hour	Exposure concentration [µg/m³]			
	Rural		Urban	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
1.	109.9	20.7	172.7	66.3
2.	-	-	231.3	106.3
3.	-	-	207.1	96.2
Mean	109.9	20.7	203.7	89.6

The mean PM_{10} exposure concentration of Urban measurement was almost twice higher than the mean concentration of Rural measurement. The mean $PM_{2.5}$ exposure concentration was more than four times higher.

4. Conclusions

According to AQD, 'indicative measurements' are measurements, which correspond to a less stricter data quality objective than fixed measurements. Low cost sensors belong to the group of indicative measurement options, because according to their data tables they operate with 10-15% error limit under ideal conditions. In addition, the atmospheric parameters further increase the margin of error, but informative, indicative measurements can be carried out with them to determine hotspots and as well as to measure the pollution of selected areas and to observe trends. Low-cost sensors can be calibrated with FRM PM measuring devices and measured values can be corrected according to individual weather conditions, so more accurate concentration values can be used to determine the air quality of the surveyed areas. By utilizing the mobility of PM sensors, not only the available air quality data can be expanded, but also the accuracy of determining the personal exposure load increase. Personalized recommendation can be made by route and air quality data for outdoor recreational activities. The protection against errors caused by meteorological phenomena (gusts, precipitation and solar radiation) can be solved with a lamellar cover. Starting and controlling the measurement would be simplified by developing a mobile application. The accuracy and reliability of the GPS receiver is planned by increasing the size of the antenna.

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