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PARTICULATE MATTER CONCENTRATION SENSING IN A METALWORKING WORKSHOP

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Abstract: One of the most common indoor air pollutants is particulate matter, which was measured in a metalworking workplace for three days at different operation capacities. These preliminary measurements were performed to describe the typical pollution levels of the specified workplace. Air quality limits at workplaces refer to an 8-hour average, so an on the fly calculation method was tested to predict the average concentration. Based on the measured and calculated information, a three-stage light indicated the level of air pollution. Additionally, the possibilities of reducing air pollution were defined.

Keywords: sensor, PM10, air quality

INTRODUCTION

There is an increasing interest in outdoor dust pollution [1–12], but in order to protect human health, we must not forget the importance of indoor air quality, including the workplaces [13–16]. With the spread of low-cost sensory measurement technology, it has become available to sense the air quality in our homes or workplaces. Workplace air can be loaded from several sources by gaseous and solid pollutants. The concentration measurement of particulate matter was performed for three working days in a metalworking workshop using a measuring device with a microcontroller-based particulate matter sensor. The possibility of how it can contribute to the improvement of air quality was investigated.

1. MATERIALS AND METHODS

1.1. Measuring device

A microcontroller-based measuring device containing PMS7003 low-cost sensor was utilized for indoor air pollution measurement. The general layout has already been published in another study [17]. In addition to the measurement of particulate matter, the temperature, humidity, and pressure values were measured by a BME680

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sensor. An Arduino Nano microcontroller controlled the operation of the sensors and processes the gathered data. To record time and save timestamps to an SD card, a DS3231 based real-time clock was also connected to the microcontroller. A three-stage coloured lamp indicator was added to the measuring device to indicate the concentration level of the particulate matter during the measurement. The green, yellow, and red indicator lights switched through IRF510 transistors by the microcontroller. The indicator light operated at 12 V, the Arduino, PMS7003 and microSD card reader operated at 5 V, while the BME680 and DS3231 at 3.3 V. The schematic drawing of the measuring device, including the above-mentioned components, is shown in *Figure 1*.

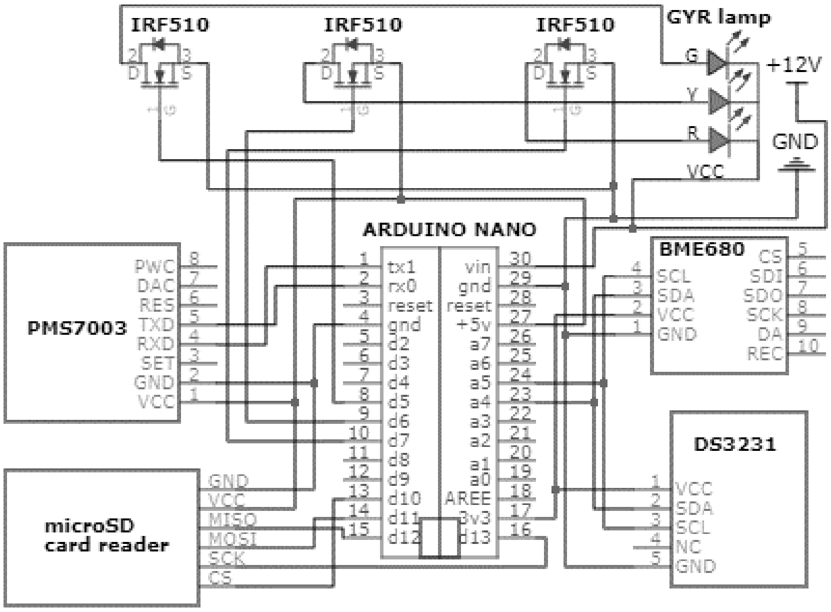

Figure 1
Schematic drawing of measuring device

The sensors were placed in lamellated housing for proper airflow and protection from direct physical impact. The lamp was placed above the lamellar layers, and the other components were placed in a lower sealed box. The box and lamella parts were printed with a 3D printer using PETG material.

1.2. Calibration method

The particulate matter sensor has been calibrated to improve the data quality and accuracy. Taking into account the study of Sayahi et al. [18], the measuring device equipped with a particulate matter sensor was placed in a climate chamber in order to control the environmental parameters. The climate chamber used in this study creates stable environmental parameters in the interior space of about 850 × 850 × 850 mm. Based on preliminary flow tests, the measuring device and the factory-calibrated TSI Dusttrack (TSI) dust aerosol monitor as a reference was placed in the upper 1/3 of the chamber, because there were the most stable temperature, humidity and flow conditions.

Soot from the combustion of isobutene gas was passed through the observation opening of the climate chamber by a fan, thus increasing the concentration of particulate matter inside. The decrease of the elevated PM_{10} (the concentration of particulate matter below 10 µm in diameter) concentration was recorded with the measuring device and the TSI reference.

Figure 2 shows the relationship between the PM_{10} concentrations measured by the PMS7003 and the TSI (circle). The calibration function determined from that can be expressed as $y = 0.58 \times x + 0.01$. The calibration result utilizing this equation is also depicted (square). At 95% the confidence interval is calculated to 2.48 µg/m³.

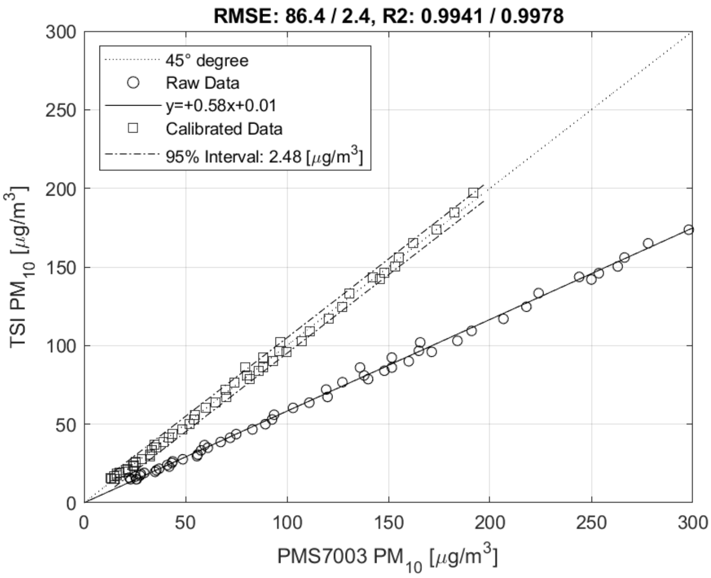

Figure 2
Results of PM_{10} calibration measurements

$PM_{2.5}$ and PM_1 calibrations were made with the same methodology as above. The calibration functions were used during the data processing of the microcontroller, so the already calibrated values were recorded in the work environment.

1.3. Measurement location and time

The measuring device, equipped with a lamp and a calibrated particulate matter sensor, was placed in a metalworking workshop. During the measurements, the main work processes were cutting, turning, and welding. The measuring unit was placed at the inspiratory height (160 cm) equally far from each workstation.

Table 1

Measurement date, duration, and dust generating work operation capacity

No.	Date	Duration	Operation capacity
#1	21. 12. 2020.	6 hour 40 minutes	full
#2	22. 12. 2020.	8 hours 5 minutes	half
#3	23. 12. 2020.	5 hours 34 minutes	zero

Measurements were performed with the installed measuring device on three working days as *Table 1* shows. On the first day, 21 December 2020, the workshop was operating at full capacity, cutting, and welding work was carried out. On the second day, 22 December 2020, they worked on semi capacity, and on the third day, 23 December 2020, no work was carried which usually generates dust. The latter is therefore a baseline and the former are a period of peak and average concentration.

1.4. Threshold concentration

The Hungarian legislation [19] determines the allowable average concentration for particulate matters. The allowable average concentration is the concentration of an air pollutant in the workplace's air which does not normally have an effect on the health of workers. Besides specified particulate matter materials (graphite powder, quartz, etc.) for the other inert powders the allowable average concentration is 10,000 $\mu g/m^3$ inhalable concentration (PM_{100}) and 6,000 $\mu g/m^3$ respirable concentration (PM_4). The calculation equivalence is the following:

$$C_{avg} = \frac{C_1 * t_1 + C_2 * t_2 + \cdots + C_n * t_n}{t_1 + t_2 + \cdots + t_n}$$

where, C_{avg} is the average concentration and C_1, C_2 … C_n are the concentration for the period t_1, t_2 … t_n, and $t_1+t_2+\ldots+t_n$ = 8 hours.

Focusing on the working processes, the allowable concentrations can be stricter. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends a TLV-TWA (Threshold Limit Value-Time Weighted Average) of 5,000 $\mu g/m^3$ for total welding fume, assuming that it contains no highly toxic components [20, 21]. Interestingly, the WHO recommends the outdoor 24-hour concentration limit value for PM_{10} as 50 $\mu g/m^3$ and for $PM_{2.5}$ as 25 $\mu g/m^3$ [22].

1.5. Data processing method

The calibrated minutely mean values of the measuring device were smoothed. The actual value was smoothed based on the weighted values of the past 10 minutes.

Predicted values were calculated using the smoothed values as the expected average concentration value over the entire 8-hour working time, assuming that the particulate matter concentration remains at the current measured value during the remaining period of the working time. Based on the Hungarian legislation calculation equivalence of the predicted average concentration (C_{pred}) is the following:

$$C_{pred} = \frac{C_{elapsed} * t_{elapsed} + C_{present} * t_{remaining}}{t_{elapsed} + t_{remaining}},$$

where $t_{elapsed} + t_{remaining} = 8$ hours.

As the predicted average concentration is calculated on the fly by the microcontroller, the indication light changed the color based on this value to show the relationship to the limit values, allowable average concentration.

2. RESULTS

Data from the three measurement days were evaluated. The first day covers 6 hours and 40 minutes, the second day covers the entire 8 hours of work, and the third day covers 5 hours and 15 minutes.

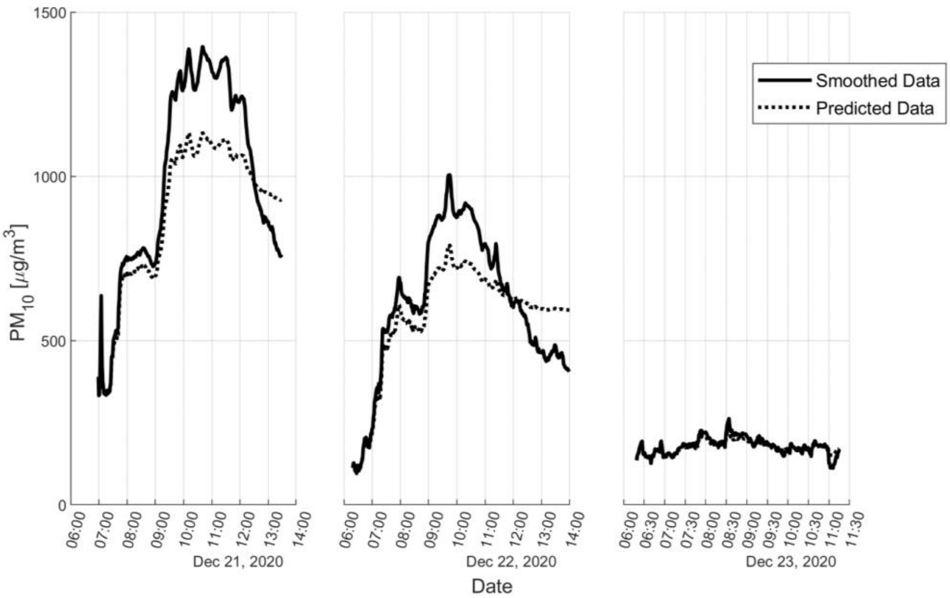

Figure 3

Results of PM_{10} calibration measurements

Figure 3 shows the smoothed and predicted PM_{10} concentrations measured on three days with different operational capacities. On the first day, we can observe that the predicted data show less than the smoothed data in the ascending sections, and then from 12:30 onwards in the decreasing section they show a higher value than the current one. The reason for this is that the predicted values take into account the earlier time intervals, i.e. in this case also the periods where higher concentrations were measured. At the end of the measurement time it indicates the average value for the whole measurement period. At the beginning of the measurement, some outliers are displayed, which may be due to some direct, nearby contamination. On the second day, the smoothed and predicted data show similar trends as the first day but in lower levels. During the third day concentrations did not increase significantly, so smoothed and predicted values show a similar trend and remain under 300 μg/m^3 throughout the investigated period.

Table 2 shows the maximum, average, and the last predicted PM_{10} concentrations of the three days. Based on the known operation capacity the levels of pollution associated with the characteristic of the shift may be defined. The basic level of pollution is under 200 μg/m^3 average concentration as the operation is zero, the medium level of pollution is under 600 μg/m^3 average concentration and the high level of pollution is over 900 μg/m^3 maximum concentration. The pollution level of an 8-hour shift above is typical just for the investigated metalworking workshop. Based on the defined pollution levels the coloured indicator lamp's operation may be determined with the on the fly calculated predicted concentration.

The average and the last predicted concentrations are different except for the second day, which covers the entire 8-hour period, which supports the correctness of the prediction.

Table 2

Maximum, average and the last predicted PM_{10} concentrations on the three days

No.	Date	C_{max} [μg/m^3]	C_{avg} [μg/m^3]	C_{pred} [μg/m^3]	Pollution level
#1	21. 12. 2020.	1,394.1	962.4	928.4	High
#2	22. 12. 2020.	1,004	586.6	586.7	Medium
#3	23. 12. 2020.	261.9	170.7	170.3	Basic

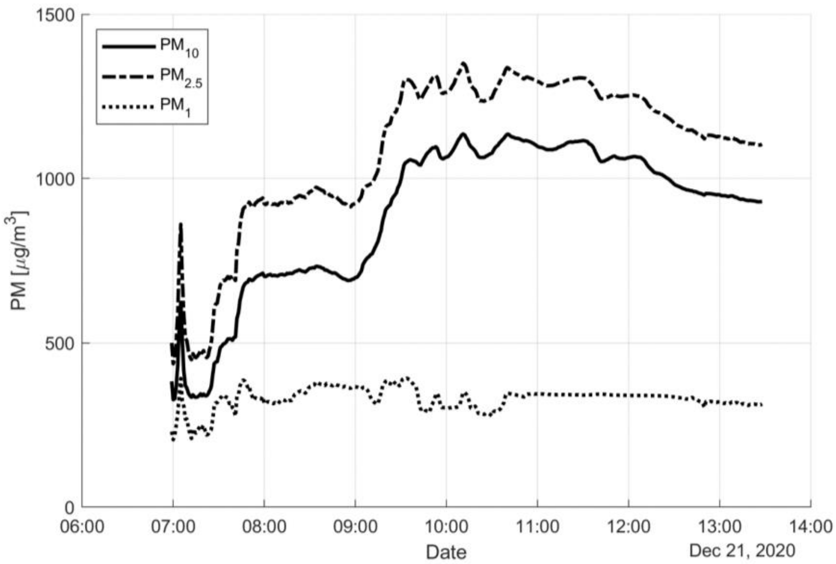

Figure 4

Predicted PM concentration on 21. 12. 2020

Figure 4 shows the predicted concentration of PM_{10}, $PM_{2,5}$ and PM_{1} on 21. 12. 2020, which was a day with a high pollution level. Due to their definition, the highest values are the PM_{10} values. The allowable average concentration level was not reached by any PM component on any day. The indicator lights can glow green, yellow or red in individual ways, depending on the concentration levels found in the workplace.

CONCLUSION

The low-cost sensor based measuring device equipped with a microcontroller and an internal clock operated without failure during the three measurement days and recorded the data with a time stamp. Measured data were smoothed and predicted on the fly. Smoothed data shows the actual concentrations. This information can be useful to control a ventilation system and allows for quick intervention to reduce the pollution level. The predicted values illustrate the expected particulate matter load over the entire working time and show the average of the actual 8 hours by the end of the day. The three different operation capacity of the days defined the three levels of pollution of the metalworking workshop. The indicator lights should be programmed based on the predicted data. If the data reache the defined pollution levels the lights can immediately show the workers the expected air load for the full-time work period. From the predicted data, the last value of the working time is recommended for long-term observations, so the 8-hour average values measured on each working day can be fed into the company's monitoring system and can be tracked by the environmental officer. A Wi-Fi module installation is recommended to solve the data transfer. Thanks to the protective housing, the measuring device can also be used in industrial environments, and the digital output of the Arduino can be connected to the ventilation controller to keep the particulate matter concentration at a lower level in the workplace.

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