Development of low-cost and user-friendly sustainable portable particulate sensor

M A Fathihah1, M P Khairunnisa1, M Rashid1, J NorRuwaida1, M Dewika2, Y Ito3 and I Wuled Lenggoro3,4

1 Air Resources Research Laboratory, Malaysia Japan International Institute of Technology, 54100 Universiti Teknologi Malaysia Kuala Lumpur, Malaysia
2 Centre of American Education, Sunway University 47500 Subang Jaya, Selangor, Malaysia
3 Graduate School of Bio-Application and System Engineering Tokyo University of Agricultural and Technology, 2-24-16 Nakacho, Koganei, Tokyo 184-8588, Japan
4 Department of Chemical Engineering, Tokyo University of Agriculture and Technology, 2-24-16 Nakacho, Koganei, Tokyo 184-8588, Japan

E-mail: khairunnisa.kl@utm.my

Abstract. Particulate Matter (PM) has various effects on the quality of air, health, and environment. A newly developed on-line PM10 (particulate matter less than 10 µm) measurement using Arduino as the microcontroller which has multi-connections was able to provide real-time measurement. Shinyei dust sensor (PPD42NS) is used to measure the concentration of the particulate matter at ambient air along with temperature and humidity sensor (DHT22). The aims of the study are to build a portable and user-friendly device for the monitoring of PM10 as a low-cost and sustainable particulate sensor. The device was tested for five days to determine the particulate concentration indoor and outdoor at one site in Dungun, Terengganu. The results showed that the average of the particulate concentration at the indoor and outdoor for five days were 329 and 1587 µg/m3 respectively. The custom-made device can be treated as a low-cost measuring device for particulate matter in ambient air which will be further refined and verified.

1. Introduction

The quality of air can be determined by the concentration of particulate matter (PM) in the atmosphere. According to United Environmental Protection Agency (USEPA), the particulate matter is the mixture of all solid and liquid particles suspended in air, which are hazardous [1]. There has two categorizes of PM that considered by USEPA which are PM2.5 (with a diameter range of 2.5 - 0.1 µm) and PM10 (with a diameter range of 10 - 2.5 µm).

The microscopic solid and liquid droplets are so small that they can be inhaled and cause serious health problems to human health. The detrimental effects of respirable suspended particulate (RSP) on human health and the relationship between air pollutants and health has been widely studied. The human lung can regularly be exposed to a variety of particles including those from cigarette smoke, ceramic industry [2], burning of biomass, dust storms, mining or processing of coal [3] and mineral
oxides, agricultural work, wildfires, environmental tobacco smoke, emissions from traffic, and gas and wood stoves [4].

Not only that, particulate matter can cause atmospheric visibility impairment. It gives an impact on global climate change [5]. Haze is one of the major concern when it comes to global warming. This is because of the large amount of particulate that suspended in air exert a significant cooling effect on the earth’s climate. PM$_{2.5}$ is the major contributors to this problem. Hence, air monitoring is necessary in order to resolve these issues.

The advanced instruments such as (scanning mobility particle spectrometer (SMPS), condensation particle counter (CPC) and electric low pressure impactor (ELPI) are categorized in air monitoring research. These instruments helped the researchers to obtain the concentration of the particulate by the light scattering principle on-site in real time. The majority of these sensors work on the light scattering principle to determine the concentration of the particulate matter [6].

Advanced instruments are precise, suitable to monitor various properties of PM, and can be also used for mobile monitoring. However, these instruments cannot be applied in large monitoring networks mainly due to their high cost [7]. Currently, the low-cost sensors can measure the number of PM features and suitable for monitoring. This concern has triggered the idea that the development of the low cost and portable sensor is necessary for monitoring the air quality. Therefore, the most recent solution targeting micron-sized particulates are presented in this study.

2. Experimental methods and materials

2.1. Design and specification

2.1.1. Arduino Platform. The device is using open-source hardware platform, Arduino [8] as illustrated in Figure 1 (a) as the source to read the measurement data of the particulate concentration as well as humidity level from the sensor. According to Ali et al., the Arduino platform provides various development circuit boards, some of which utilize Atmel’s low-power CMOS 8-bit microcontrollers based on AVR enhanced RISC architecture [9]. These microcontrollers are capable of computing approximately 300,000 lines of program code per second, which is more than sufficient for most of the input and output applications required for the time scales of typical building data collection (e.g., seconds or minutes) [10]. Arduino provides an integrated development environment (IDE) that is capable of running on all major operating systems and has support for a simplified C/C++ programming language.

![Figure 1. Hardware setup of monitoring environment (a) Arduino (b) Shinyei PPD42NS (c) Humidity and Temperature DHT22 and (d) 16x2 LCD](image_url)

2.1.2. Shinyei PPD42NS. The particulate sensor unit, Shinyei PPD42NS [11] as shown in Figure 1 (b) is built based on the light scattering method. This sensor detects airborne particulate continuously after turning on. The original detection method is similar to the particle counter that can be obtained the pulse output that corresponds to concentration per unit volume [11]. The low-cost optical sensors are
counting the amount of time that particles are detected by the light receptor sensor [12]. The detectable size is more than 1.0 μm. The schematic diagram of this hardware is depicted in the Figure 2 (a) and (b). Updraft airflow is generated by heater resistor. The infrared light beam from light emitter (LED) is focused with a lens to the sensing point at the center, airborne particulate inflow into the sensor box and pass through the sensing point [13]. Light receptor (Photo IC) receives scattered light through the lens and transforms it into a pulse signal. The size of particle will be detected by the signals resulting from the detection of scattered light are passed through filtering and amplification circuitry that are externally visible on the PPD42NS, resulting in 0 – 5 V pulses of approximately 10 – 100 m in length [11].

![Figure 2. The schematic diagram of Shinyei PPD42NS (a) front view and (b) side view](image)

2.1.3. Humidity and Temperature Sensor. The temperature and humidity sensor (DHT22) was added to the Arduino platform as visualized in Figure 1 (c) to measure the temperature and the relative humidity of the ambient air. Apart from that, this sensor was used to analyse the effects of temperature and humidity on the performance PPD42NS sensor by ensuring the instruments remained undisturbed, upright and unexposed to extreme conditions. DHT22 consists of two electrodes with moisture substrate within them. As the conductivity of the substrate or resistance changes, the humidity will change. For temperature sensor, DHT22 provide the “Negative Temperature Coefficient (NTC)” sensor or known as thermistor that made by sintering of semi-conductive material such as ceramics or polymers which gave the bigger changes in resistance with small changes in temperature [14].

2.2. Study location
The investigation involved analyzing the particulate concentration as well as the relative humidity and temperature. The site was selected in Dungun area as depicted in Figure 3, which is located in the east of Malaysia. The device is exposed to indoor and outdoor for 1 hour in the morning for five days respectively. Dungun is nearer to the South China Sea, made it a suitable place to consider as having the high wind movement. The device was attempted at the end of the January (29th January 2018) until early of the February (9th February 2018).
Shinyei PPD42NS sensor can measure the PM$_{10}$ by the photodiode inside it. While passing through the sensor, particulates scatter light and the intensity of the light received by the phototransistor is directly correlated with the concentration of particulates. The indoor location was done in the house at a fixed height (61 cm) to ensure the region does not change for the investigation. For outdoor, the height is set at 44 cm outside the house due to some limitations. The data logging in COM6 port of Arduino was saved into the Excel document for further analysis.

3. Results & Discussion

3.1. Device Operating
The device is operating by using Arduino as the microcontroller to activate the sensor. The device is able to monitor the mass concentration of the particulates as shown in Figure 4 and Figure 5 for each study location. It also compatible with the feature of the humidity and temperature sensor to measure the temperature and the relative humidity of the study site as illustrated in Figure 7. The liquid crystal display (LCD) is attached to the device in order to display the particulates concentration with the humidity and temperature (Figure 1 (d)). The device was easy to operate, easy to implement and user-friendly which is considered as a green technology that can contribute towards the sustainable environment.
3.2. PM concentrations versus time

The study found that the average concentration of PM$_{10}$ value depicted lower value when tested indoor (329 µg/m$^3$) as visualized in Figure 4 as compared to outdoor (1587 µg/m$^3$) as shown in Figure 5 in the morning at consecutive five days. The particulate concentrations for PM$_{10}$ were taken for one hour in the morning (7 am-8 am) for total five days at two different locations, respectively. Figure 4 (a),(b),(c),(d),(e) visualized the PM$_{10}$ concentration sensed by the dust sensor. The mass concentration of PM$_{10}$ for five days were in ranged below than 900 µg/m$^3$. The concentration was quite high because the sensor was quite sensitive.

The study was highlighted that the low-cost optical sensors are counting the amount of time that particles are detected by the light receptor sensor instead of counting the individual particles like the high-cost sensors. As a result, the data obtained was quite noisy as compared to expensive sensors which lead to quality of near-real-time data is reduced [12]. The high PM$_{10}$ concentration in the morning also affected by the particulate that came from the outdoor because the door keep opened and closed within this period as mentioned by Diapouli et al., [15].

Figure 5 (a), (b), (c), (d), (e) depicted the particulate concentration for the outdoor area. The mass concentration of PM$_{10}$ for five days were in ranged below than 6000 µm. The concentration PM$_{10}$ was higher in the morning because the collection data was taken on a weekday which was the peak hour for people went to work as the emission from the exhaust car might be influenced by high in PM$_{10}$ concentration [16]. This phenomenon also was discussed by Lawrence et al about the particulate from exhaust vehicle might be contributed to the high concentration of PM$_{10}$ as the sensor was located in front of the car [17].
The back-trajectories analysis was done using Meteorological Data Explorer (METEX) [18] developed by Centre for Global Environment Research (CGER) in Japan to calculate the air trajectories within one week of the outdoor experiment. Figure 6 visualized the particulate trajectories for one week in Dungun site. It showed that the particulate originated came from the east region which was contributed to the high concentration of the PM$_{10}$ within that week. Malaysia experiences northeast monsoon in November to March which dominated to meteorological conditions such as wind and rainfall [19]. There were events of thick fog due to cold weather and turbulent sea coming to Dungun site during that period of time [20]. Fog was a liquid-particles aerosol formed by condensation with sizes ranging from submicrometer to about 200 µm, one of the sources that contributed to the high concentration of PM$_{10}$ [21].
3.3. Hourly temperature and relative humidity

The device was located in the living room for an indoor while, for outdoor was in front of the house’s door. The intake of temperature and humidity level was done parallel to the reading of the particulate concentration. Figure 7 depicted the mean daily temperatures tended from approximately 20 to 30 °C while the relative humidity indoor and outdoor ranged between 60-80 % levels. The humidity and temperature level was influenced by the warm and humid air in Malaysia [19]. As the temperature decrease, the air could not hold more water vapour as compared when the temperature is rise, the humidity is increase. This phenomena was explained by Nguyen et al., which was the differences in thermal preferences, levels of temperature control, socioeconomic status, and the health states of the homes’ occupants were likely contribute to this variability [22]. The result is compared with the humidity and temperature index showed from the Meteorology of Malaysia to observe the variation between the theoretical and experimental result with diurnal variations of approximately ± 5 °C and ± 1 % respectively.

4. Conclusion

The development of a low cost and custom-made particulate sensor has been tested and reported in this paper. The device has the ability to measure the mass concentration of PM$_{10}$ along with the humidity and temperature at selected sampling sites. It could be implemented as a simple and user-friendly device for monitoring daily air quality which is easy to operate in a sustainable manner.
References

[1] USEPA. *Particulate Matter (PM) Basics*. 2018 [cited 2017 11 November]; Available from: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM.

[2] Sintorini M M 2018 The impact of total suspended particulate concentration on workers’ health at ceramic industry IOP Conference Series: Earth and Environmental Science 106 012034.

[3] Petra P, Jan H and Jan B 2016 Impact of Mining Activities on the Air Quality in The Village Nearby a Coal Strip Mine IOP Conference Series: Earth and Environmental Science 44 032021.

[4] Ghio A J, Soukup J M and Dailey L A 2016 Air pollution particles and iron homeostasis *Biochimica et Biophysica Acta (BB4)* 1860 2816-2825.

[5] Tai A P K, Mickley L J and Jacob D J 2010 Correlations between fine particulate matter (PM2.5) and meteorological variables in the United States: Implications for the sensitivity of PM2.5 to climate change *Atmos. Env.* 44 3976-3984.

[6] Chiang C 2017 Design of a High-Sensitivity Ambient Particulate Matter 2.5 Particle Detector for Personal Exposure Monitoring Devices IEEE Sensors Journal 18 165-169.

[7] Gozzi F, Della G Ventura and Marcelli A 2016 Mobile monitoring of particulate matter: State of art and perspectives *Atmos. Pol. Res.* 7 228-234.

[8] Arduino. *Arduino*. 2018 [cited 2017 12 October]; Available from: https://www.arduino.cc.

[9] Ali A S, Zanzinger Z, Debose D and Stephens B 2016 Open Source Building Science Sensors (OSBSS): A low-cost Arduino-based platform for long-term indoor environmental data collection. *Building and Environment* 100 114-126.

[10] Ferdoush S and Li X 2014 Wireless Sensor Network System Design Using Raspberry Pi and Arduino for Env. Mon. App. Pro. Comp. Sci. 34 103-110.

[11] Shinyei. *PPD42NJ Particle Sensor Unit Detects airborne particles | Shinyei Technology*. 2017 [cited 2017 October 20]; Available from: http://www.shinyei.co.jp/stc/eng/optical/main_ppd42.html.

[12] The World Air Quality Index. *The Shinyei experiment*. 2017 [cited 2018 10 February]; Available from: http://aqicn.org/sensor/shinyei/.

[13] Liu D, Zhang Q, Jiang J and Chen D R 2017 Performance calibration of low-cost and portable particulate matter (PM) sensors *Journal of Aerosol Science* 112 1-10.

[14] Bogdan M 2016 How to Use the DHT22 Sensor for Measuring Temperature and Humidity with the Arduino Board *ACTA Universitatis Cibiniensis* 68 22.

[15] Diapouli E, Chaloulakou A and Spyrellis N 2008 Indoor and Outdoor PM Concentrations at a Residential Environment Athens Area *Global Nest Journal* 10 201-208.

[16] Giechaskiel B, Maricq M, Ntziachristos L, Dardiotis C, Wang X, Axmann H, Bergmann A and Schindler W 2014 Review of motor vehicle particulate emissions sampling and measurement: From smoke and filter mass to particle number *J. of Aer. Sci.* 67 48-86.
[17] Lawrence S, Sokhi R and Ravindra K 2016 Quantification of vehicle fleet PM10 particulate matter emission factors from exhaust and non-exhaust sources using tunnel measurement techniques Env. Pol. 210 419-428.

[18] Research Centre for Global Environment. CGER METEX. Global Environmental Database 2018 [cited 2018 10 April]; Available from: http://db.cger.nies.go.jp/metex/index.html.

[19] Satari S Z, Zubairi Y Z, Hassan S F and Hussin A G 2015 Some statistical characteristic of malaysian wind direction recorded at maximum wind speed: 1999-2008 Sains Malaysiana 44 1521-1530.

[20] Bernama, MetMalaysia: Cold weather phenomenon in East Coast could recur - Nation | The Star Online, in The Star. 2018, @staronline: Kuala Lumpur.

[21] Hinds W C 1999 Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles, 2nd Edition 504

[22] Nguyen J L, Schwartz J and Dockery D W 2014 The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity Indoor air 24 103-112.