Development of an Atmospheric Dust Particle Sizes and Density with other Related Weather Parameters

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Abstract— The main objective of this study is to develop a measuring device to determine the dust particle size and density with some atmospheric weather parameters (temperature and relative humidity). The particulate matter (PM) was subdivided into three: the dust particle of less than 1µm in diameter is PM1.0 µm, any dust particle between 1 µm to 2.5 µm in diameter is referred to as PM2.5 µm and any dust particle greater than 2.5 µm and less than 10 µm in diameter is referred to PM10 µm. The dust instrument developed consist of a dust particle size and density sensor, temperature sensor, humidity sensor, real time clock, storage medium shield, intelligent display and a microcontroller. The dust sensor (SEN0177) utilizes the light scattering and digital Fourier analysis to determine the particle size and density levels, temperature sensor (BMP180) and relative humidity sensor (HIH-4030) were used to measure the temperature and relative humidity of the environment. The sensors were linked to arduino mega 2560 using arduino platform C program for the proper communication with all devices. Each sensor has standard output and the measured output was compared with available instruments around. The correlations of dust sensor, temperature sensor, relative humidity are 0.97, 0.99 and 0.92 respectively. Dust sizes and density has measuring range of 0.3 µm–10 µm with density of $0.0\ \mu g/m^3$to $512\ \mu g/m^3$ and resolution of $1\ \mu g/m^3$, temperature of 0.01 °C and 0.001 % of relative humidity. The possible error of dust density is $\pm 0.0015\ \mu g/m^3$.

Keywords: Dust Particle Size, Dust Particle Density, Microcontroller, Atmospheric Parameter, Air Quality

I. INTRODUCTION

The one of prima factor responsible for the continuity in the existence of human species is based on the quantity and quality of the air exchange to the environment. The mass of air surrounding a particular region (atmosphere) plays a significant role in determining the health of the people living in that region. The atmospheric gases consist by volume 78% of Nitrogen, 21% oxygen, and the remaining percentage consist of carbon dioxide, Argon, Neon, water vapour dust particles, CO, SO_2 etc. In accordance to Dermator (2011) from his finding shows that people spent about 5-6 hours outside daily. Therefore, sound health of the people and the air quality of the environment are primarily essentials.

Although, dust particles occupy a minor percentages in the composition of atmospheric gases; they contribute greatly to atmospheric pollution. Their adverse effects include poor visibility, interference with power supply system i.e. when deposited on solar panel (PVC); as well as communication signal transmission and reception causing attenuation. Dust particle are made up of microscopic solid and liquid matter suspended in the air are referred to as atmospheric particulate matters or simply particulate matters, they include suspended particulate matters (SPM), thoracic and respirable particles (Brown et al., 2013), inhalable coarse particle which are coarse particle with a diameter between 2.5 and 10 micrometers (µm) (PM_{10}), fine particles with diameter between 2.5 µm and 1 µm ($PM_{2.5}$), ultrafine particles are less than or equal to 1 µm (Li and Wu, 2013). The sources of the particulate matters are usually natural originating from volcanoes, dust storms, forest and grassland fire, living vegetation and sea spray. Human activities, such as the burning of fossil fuel in vehicles, power plants and various industrial processes; also generate significant amounts of particulates.

In general, the size of the particle is a main determinant of where in the respiratory tract the particle will come to rest when inhaled. The smaller and lighter a particle is, the longer it will stay in the air. Larger particles (greater than 10 micrometers in diameter) tend to settle to the ground by gravity in a matter of hours whereas the smallest particles (less than 1 micrometer) can stay in the atmosphere for weeks and are mostly removed by precipitation. Larger particles are generally filtered in the nose and throat via cilia and mucus, but particulate matter smaller than about 10 micrometers, can settle in the bronchi and lungs and cause health problems (EPA, 2008). Fine particulate matters with diameter that are generally 2.5 µm and smaller, tend to penetrate into the gas exchange regions of the lung (alveolus), and very small particles (< 100 nanometers) may pass through the lungs to affect other organs even gets into the bloodstream. The effects of inhaling particulate matter that have been widely studied in humans and animals include asthma, lung cancer, respiratory diseases, cardiovascular disease, premature delivery, birth defects, low birth weight, inflammation oxidative stress, impaired oxygen transport access to the placenta and premature death. Exposure to $PM_{2.5}$ has been associated with greater reductions in birth weight than exposure to PM_{10} (Nieuwenhuijsen, 2003). The World Health Organization (WHO) in 2005 estimated that "... fine particulate air pollution ($PM_{2.5}$), causes about 3% of mortality from cardiopulmonary disease, about 5% of mortality from cancer of the trachea, bronchus, and lung, and about 1% of mortality from acute respiratory infections in children fewer than 5 years of age, worldwide" (Hogan, 2010). Particulate matter has effect not only on human and animal but in vegetation where particulate matters clog stomata openings of plants and interfere with photosynthesis function (Aaron et al., 2005) in this manner high particulate matter concentrations in the atmosphere can lead to growth stunting or mortality in some plant species.

Certain country of the world notably the United States, took proactive measures against the phenomenon. In setting up the environmental protection agency (EPA) the United states of America (USA) Environmental Protection Agency (EPA)promulgated the Clean Air Act, which was last amended in 1990, requires EPA to set National Ambient Air Quality Standards (40 CFR part 50) for pollutants considered harmful to public health and the environment. The Clean Air Act identifies two types of national ambient air quality standards. Primary standards provide public health

protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. The EPA has set National Ambient Air Quality Standards for Particle pollution (PM), which is among the "criteria" air pollutants as shown on Table 1. (http://www.epa.gov/air/cri-teria.html)
Furthermore, it has an effect on energy distribution. Solar photovoltaic (PV) system uses solar cell to convert energy from sun radiation into electricity. The solar photovoltaic panel circuit converts the direct current energy received from solar panel into electric current, (Shaharin et al., 2014). The power generated from a solar panel (PV module) depends on the amount of irradiance which reaches the solar cells. Light obstructing materials mainly dust particles reduce the solar panels performance by obstructing the intensity of sun's radiation penetrating into the solar cell, (Muhammad et al., 2016). Although dust is a comparatively insignificant constituent of the atmosphere, it is very crucial to weather and climate since without dust particles, water vapour cannot condense or freeze to form fogs, clouds and precipitation from clouds. The dust particle supplies condensation nuclei for the water to condense or freeze. Particulate matter also affects the climate of the earth by changing the amount of incoming solar radiation and outgoing terrestrial long wave radiation retained in earth's system, changing the cloud formation and properties, contribution to global warming and reduced visibility, (Oke, 2018; Simone et al., 2015). Very little is known about the effect of dust storms on radio signals on slant-paths. Available data indicate that at low frequency below 30 GHz, high particle concentration and/or high moisture contents are required to produce significant propagation effects.

Pollution		Primary/Secondary	Permissible Level	Average Time
Particle Pollution (PM)	$PM_{2.5}$	Primary	12.0 µg/m^3	1 year
		Secondary	15.0 µg/m^3	1 year
		Primary/Secondary	35.0 µg/m^3	24 hours
	PM_{10}	Primary/Secondary	150.0 µg/m^3	24 hours

Table 1: USA EPA National Ambient Air Quality Standards for PM2.5 and PM10.
http://www.epa.gov/air/criteria.html

Various researchers have designed dust measuring devices in the past. Hogg, 2008; Hongli et al., 2012 and Simone et al., 2015, Anna et al., (2012), and Oke, 2018 used various techniques some of which are extremely complex, the resultant device are bulky, lacking portability. Furthermore, majority of them are used to measured dust density only lacking the capacity for measuring particle sizes, as well as cogent atmospheric parameter. This study produced a low cost, efficient and effective dust particle size and density with other related weather parameters device. In this paper a low cost effective dust particle size, density and atmospheric parameters will be measured directly and logged.

II. Methodology

A. Design Principle and Structure

The atmospheric dust sizes and particle measuring instrument mainly consist of laser dust sensor SEN0177, temperature sensor BMP180, humidity sensor HIH-4030, real time clock DS3231, microcontroller unit, liquid crystal display, SD card, power charging unit and power supply as shown in Figure 1. First, the laser dust sensor produce scattering by using laser to radiate suspending particles in the air, then collect scattering light in a certain degree, and finally obtain the curve of scattering intensity with time, it get the relationship between time domain and frequency domain and send proportional analogue signal to the microcontroller. A HIH-4030 Relative Humidity sensor uses a capacitive change when the deposited materials on the substrate absorbed the water molecule, it changes its capacitance value that will be calibrated against water molecule in the atmosphere and when the atmosphere is dry, it removes the molecule and the capacitance value appreciates again. Determining the Relative Humidity (RH %) requires knowing an accurate temperature. The semiconductor sensor BMP180 used to measure the atmospheric temperature and pressure with altitude. The proportional output signal from the three sensors transmits a proportional analogue signal to the microcontroller which will transform the proportional output signals into processed data. The processed data will be displayed on the Liquid Crystal Display and stored on the memory Secure Data Card.

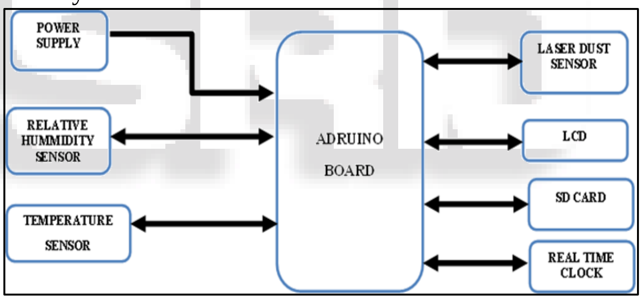

Fig. 1: Basic Block Diagram of Instrument

B. Sensors Unit: Dust, Temperature and Relative Humidity

The SEN0177 laser dust sensor is a digital universal particle concentration sensor which obtains the number of suspended particulate matter in a unit volume of air with 0.3 to 10 microns and output them in form of digital interface. The laser dust sensor has an operating voltage of 4.95 V, operating humidity range of 99% and temperature range -20°C and 50°C. The sensor can measure particulate matter of diameter 0.3 µm to 10 µm with the density range of 0 µg/$m^3$to 512 µg/m^3. The laser dust sensor utilizing laser scattering techniques as discussed in section 2.3.4, when there is scattering of laser irradiation in air by suspended particles, the sensor collect the scattered light at a specific angle to obtain the scattering intensity of laser with time curve. The microprocessor collects data and temporarily introduces the obtained signals for arithmetic conversion into power spectrum data using Fourier transform method. The form of data contains all frequency information ranging from low frequencies to high frequencies. The Fast Fourier transform method innovatively performs high-speed computations with regards to the sample whose size is a power of two. Table 2 shows the sensor pin connection with the microcontroller.

Sensor Pin	Arduino Pin	Function Description
Pin 1	VCC	Positive Power (5 V)
Pin 2	GND	Negative Power
Pin 3	SET	Mode Setting
Pin 4	RXD	Receive Serial Port
Pin 5	TXD	Transferring Serial Pin
Pin 6	RESET	Reset

Table 2: Sensor Pin Connection with the Microcontroller

The humidity sensor utilizes the capacitive sensing techniques. The sensing unit consist of an air filled capacitor, protective polymer layer, porous platinum layer (electrode), polymer layer (dielectric), platinum layer (electrode) and silicon substrate. When the moisture in the atmosphere changes, it changes the permittivity of the air filled capacitor and determine the speed the generated electric signal moves. The moisture content passes through the porous platinum layer which changes the dielectric constant of the aluminium oxide in polymer layer. When there is variation of the rate of water content, the capacitance changes. The changes in the capacitance is measured by a frequency determining oscillator, as the capacitive reactance of the capacitor decreases, the oscillating frequency across the plate increases. The proportional analog signal generated from the oscillating circuit will be inputted in the microcontroller. The microcontroller processed the received signal into the atmosphere humidity information.

The code for the relative humidity sensor written in C-language is as thus:

```
// Humidity sensor
sensor = analogRead(0); // analog pin connected A0
voltage [1] = (sensor * 2400) /4095; // convert raw sensor value to millivolts
voltage [2] = (voltage [1] – 528) * 10000; // remove offset voltage
RH = voltage [2] / 2046; // dividing by the sensitivity
```

The calculated relative humidity (RH) needs to be temperature compensated, thus

$$RH_{corrected} = \frac{RH}{1.0546 - 0.00216T}$$

where T is the temperature measured in °C by BMP180

The temperature sensor uses the piezo-resistive sensing techniques. It has a temperature and pressure semiconductor on chip. It determines the altitude of the environment and computes the value to get the pressure value of the environment.

C. *Testing and Performance Examination*

Testing and performance examination was carried on the developed atmospheric dust particle sizes, density and some atmospheric parameter instrument. All the sensors are standard sensors for dust, temperature and relative humidity were SEN0177, BMP108 and HIH4041 respectively. It was found that the dust sensor in the instrument measured particle sizes PM1.0 ($\mu g/m^3$), PM2.5 ($\mu g/m^3$), PM10 ($\mu g/m^3$) and density range from $0.0\ \mu g/m^3$ to $512\ \mu g/m^3$ with the resolution of $1 \mu g/m^3$ each. It has correlation of 0.9998 which was close to unity when compared with available atmospheric dust size and density instrument as shown in Table 1, the error is about $\pm 0.0015\ \mu g/m^3$. The response time was ≤ 1 s which shows that the developed instrument has a quick logging system. The temperature sensing device measures temperature between – 40ºC to 85ºC with a resolution of $0.25/^oC$ and humidity maximum range is about 99% respectively. Table 4 and Figure 3 2 indicated the result obtained from the Meteorological garden at The Federal University of Technology Akure between 28/03/2019 for two hours at every 4 minutes. The atmospheric dust particle sizes and density was plotted against time. The dust density spatial variation of the garden at that time is between $0\ \mu g/m^3$ and $94.1\ \mu g/m^3$.

III. CONCLUSION

The atmospheric dust particle sizes and density instrument developed shows good response and the performance was excellent when compared with available atmospheric dust particle sizes and density instrument. The range of dust particle sizes measurement ranges from PM1.0 ($\mu g/m^3$), PM2.5 ($\mu g/m^3$), PM10 ($\mu g/m^3$) with resolution of $1\mu g/m^3$ and the density measurement ranges from $0.0\ \mu g/m^3$ to $512\ \mu g/m^3$ with error of $\pm 0.0015\ \mu g/m^3$. The temperature and relative humidity measure good accuracy when compared with standard weather station. The developed atmospheric dust particle sizes and density instrument is inexpensive easy to maintain, service and repair if malfunctioning. The performance evaluation shows that its continuous measurement can be used for dust and particle monitoring to study the effect of particulate matter on human health, the effect of dust on communication signal, the effect of particulate matter to the environment and its effect on the energy distribution (solar panel) with respect to time.

Time (min)	PM1.0 ($\mu g/m^3$)		PM2.5 ($\mu g/m^3$)		PM10 ($\mu g/m^3$)	
	Developed	Compared	Developed	Compared	Developed	Compared
10	42	43	66	68	66	67
20	42	41	66	66	66	66
30	29	31	43	43	48	47
40	29	30	44	45	51	52
50	29	30	44	44	51	51
60	30	30	44	43	56	57
70	30	30	46	45	55	54
80	30	29	46	46	55	55
90	30	30	46	47	53	53
100	30	30	45	44	50	50
110	30	31	45	46	50	50
120	32	32	47	46	55	55
130	32	33	49	51	56	56

Table 3: Testing and Examination

Time Interval(min)	temp (°C)	STDI temp (°C)	RH (%)	STDI RH (%)
0	25.3	25.3	84.2	84.5
30	25.3	25.3	84.2	84.2
60	25.4	25.4	83.7	83.8
90	25.4	25.4	87.2	87.2
120	25.5	25.5	83.6	83.5
150	25.5	25.6	83.9	83.9
180	25.5	25.5	83.9	84.0

210	25.5	25.5	82.9	82.9
240	25.5	25.5	82.9	82.9
270	25.5	25.5	82.6	82.6
300	25.5	25.4	83.3	83.3
330	25.5	25.5	82.5	82.5
360	25.5	25.6	82.9	82.9
390	25.5	25.5	82.6	82.6
420	25.5	25.5	82.8	82.8
450	25.5	25.5	82.8	82.7
480	25.5	25.5	82.5	82.5
510	25.4	25.4	82.5	82.5
540	25.5	25.5	82.8	82.8
570	25.5	25.6	82.2	82.2
600	25.5	25.5	82.3	82.3
Standard Instrument from Campbell (STDI)				

Table 4: Examination of Temperature and Relative Humidity

Time (hr)	PM1.0 (µg/m³)	PM2.5 (µg/m³)	PM10 (µg/m³)	temp (°C)	RH (%)
14:00	20	46	46	25.3	83.42
14:04	20	46	46	25.3	84.22
14:08	26	48	49	25.3	84.22
14:12	29	50	58	25.4	83.74
14:16	29	50	58	25.4	87.24
14:20	29	50	58	25.5	83.58
14:24	27	47	48	25.5	83.9
14:28	27	47	48	25.5	83.9
14:32	27	47	48	25.5	82.94
14:36	25	44	46	25.5	82.94
14:40	25	44	46	25.5	82.63
14:46	25	44	46	25.5	83.26
14:52	26	45	51	25.5	82.47
14:56	26	45	51	25.5	82.94
15:00	26	45	51	25.5	82.63
15:04	30	47	48	25.5	82.79
15:08	30	47	48	25.5	82.79
15:12	30	47	48	25.5	82.47
15:16	24	43	49	25.4	82.47
15:20	24	43	49	25.5	82.79
15:24	24	43	49	25.5	82.15
15:28	28	45	48	25.5	82.31
15:32	28	45	48	25.4	77.05
15:36	28	45	48	25.4	81.03
15:40	28	46	48	25.5	82.31
15:44	28	46	48	25.5	82.47
15:48	28	46	48	25.5	83.1
15:52	28	43	45	25.5	82.15
15:56	28	43	45	25.5	83.26
16:00	28	43	45	25.5	82.63
16:04	25	42	43	25.5	82.94
16:08	25	42	43	25.5	82.15
16:12	25	42	43	25.5	82.47
16:16	24	43	44	25.5	82.31
16:20	24	43	44	25.5	82.47
16:24	24	43	44	25.5	81.83

Table 5: Measured Dust Particle Sizes and Density from Arduino Microcontroller Analog Output

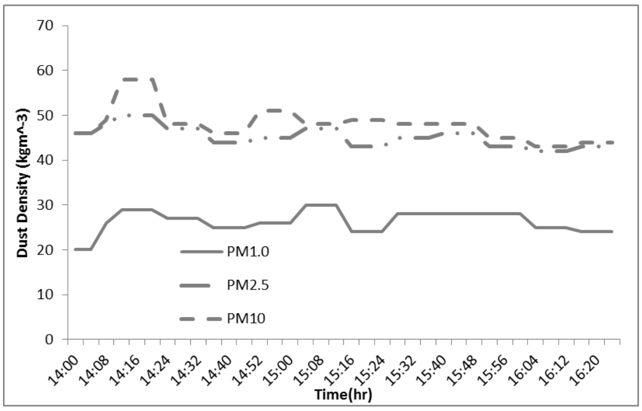

Fig. 2: Dust Density Measurement at Meteorological garden at The Federal University of Technology Akure on 28/03/2019

References

[1] Aaron J. Cohen, H. Ross Anderson, Bart Ostro; Ross Anderson, H; Ostro, B; Pandey, K. D.; Krzyzanowski, M; Künzli, N; Gutschmidt, K; Pope, A; Romieu, I; Samet, J. M.; Smith, K (2005). "The Global Burden of Disease Due to Outdoor Air Pollution". Journal of Toxicology and Environmental Health, Part A. 68 (13–14): 1301–7. PMID 16024504. doi:10.1080/15287390590936166

[2] Brown J. S, Gordon T, Price O, Asgharian B, (2013). "Thoracic and respirable particle definitions for human health risk assessment". Part Fibre Toxicol. 10: 12. PMC 3640939 . PMID 23575443. doi:10.1186/1743-8977-10-12.

[3] Dermator J. (2011). An overview analysis of the time people spending outdoors.

[4] Hogan, C. Michael (2010). Emily Monosson and C. Cleveland, ed. "Abiotic factor". Encyclopedia of Earth. National Council for Science and the Environment, 10 (80–87).

[5] Hongli Liu, Xiong Zhou and Lei Xiao, (2012), “Detection of the Concentration and Size Distribution of Indoor Inhalable Particle Based on Mathematical Morphology”. IJCSI International Journal of Computer Science Issues, 9 (6); 3

[6] Li Tianhua and Wu Ying, (2014), “Design of indoor dust concentration monitor based on light scattering detection method”, Academic Jornals 9(9); 321-324, Doi: 10.5897/SRE2014.5910

[7] Mohammad Reza Maghami, Hashim Hizam, Chandima Gomes, Mohd Amran Radzi, Mohammad Ismael Rezadad, Shahrooz Hajighorbani, (2016). “Power loss due to soiling on solar panel” Renewable and Sustainable Energy Reviews 59: 1307–1316. http://dx.doi.org/10.1016/j.rser.2016.01.044

[8] Oke A.O. (2018). “Development of a dust measurement system”. Federal University of Technology Akure, Unpublished Thesis. 1(5).

[9] Particulate Matter | Air & Radiation | US EPA Retrieved on July-08-2017

[10] Shaharin Anwar Sulaiman, Atul Kumar Singh, Mior Maarof Mior Mokhtar, Mohammed A. Bou-Rabee (2014). “Influence of Dirt Accumulation on Performance

of PV Panels". The International Conference on Technologies and Materials for Renewable Energy. Environment and Sustainability, TMREES14, Energy Procedia 50: 50 – 56. doi: 10.1016/j.egypro.2014.06.006

[11] Simone Simões Amaral, João Andrade de Carvalho Jr., Maria Angélica Martins Costa and Cleverson Pinheiro (2015). "An Overview of Particulate Matter Measurement Instruments". Atmosphere 6: 1327-1345; doi:10.3390/atmos6091327

[12] U.S. Environmental Protection Agency, National Ambient Air Quality Standards (NAAQS), http://epa.gov/air/criteria.html