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A mobile air particle system using an optical sensor for haze measurement

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Abstract— This paper presents a development of a mobile haze measurement system which can measure the amount of particulate matter and display in real time. The current haze measurement system called high volume sampler is difficult to move around due to its big size and the reading is not available in real time. Therefore, an alternative for the haze measurement system need to be developed. It uses an optical sensor as a working principle and Arduino board as a microcontroller. The measurement system is able to measure particulate matter from the smoke generated using a mosquito coil. The reading from the developed haze measurement system is verified using a commercial sensor called Dust Mate.

Keywords: optical sensor; haze monitoring; particulate matter sensor

1. Introduction

In Malaysia, haze is caused by open burning either by local or from neighbour country. Lingering smoke from open burning and forest fires from Indonesia especially the land of Sumatra are identified as the primary cause [1]. In the south east Asia region, haze had become a common phenomenon that happened every year. The Air Pollution Index (API) reaching above 300 on many occasions [2]. Haze can be defined as one of the air pollution that will affect living things such as human, animals and also plantations. During haze phenomena, a various substance is present in atmospheric air at specific concentration with higher than their standard ambient level [3].

A small suspended particles or small liquid vapour in the air will causes the atmosphere become partially opaque [4]. It often happens when smoke and dust particles accumulate in relatively dry air. The changes of air may causes a respiratory health problem and weaken the visibility due to the dispersal smoke and other pollutants that become concentrate in surroundings area and forming a low-hanging shroud. There a lot of reasons related to particles that causes a haze phenomenon. Most of the accumulated particles are sourced from human activities which include land clearing, deforestation, open burning, vehicular emissions combustion of fossil fuels in industrial (e.g. CO, NO₂, SO₂) and particulate matter such as organic matter and graphitic carbon [5].

Haze measurement is part of the monitoring of air ambient quality. It is very important because it has a direct impact on living things, and environment especially human health. Air pollution control has become essential need to provide a safer place for today and the next generation. In order to



measure air quality, Indonesia and Singapore use the Pollutants Standards Index (PSI). On the other hand, Malaysia use the Air Pollutants Index (API) which is something similar. On both indices, a reading that is more than 100 is considered as unhealthy and if the reading is above 300, it is classified as hazardous [6]. API for a given time period is determined by measuring the concentration of all five air pollutants which are SO_2 , NO_x , CO , PM_{10} , and O_3 . The maximum of all five pollutants is selected for the API measurement value. The related air pollutants for the API value has to be calculated to show the different of health effect category [7].

Normally PM_{10} is selected as this is the main contributor to the haze in Malaysia due to flying ash of the open burning. Concentration of PM_{10} is normally determined using an instrument called high volume sampler [8-9]. However this instrument is too big and cost too expensive relatively. The reading of PM_{10} concentration using this instrument is also time consuming because it uses filter weighing method. The technology which has been used in haze measurement system is also claimed inaccurate [10]. This is due to measurement time is too long and the real haze concentration has change when reporting. Consequently, the current practice often creates confusion on the true current API measurement value. Therefore, a new method using an optical method is introduced as an alternative for measuring haze index.

The purpose of the project is to develop a portable Air Quality Index (API) with low manufactured cost and can perform a real time measurement. The reading will be displayed on the spot on LCD screen. The measurement system is small in size relatively and handy to carry. It can be used to monitor the air quality for indoor or outdoor measurement.

2. Setup

2.1 Electrical Parts

The main component of the haze measurement system is an optical sensor which is to detect the concentration of dust particle and converts it into a voltage signal. It uses a device called GP2Y1010AU0F manufactured by Sharp. It is an optical sensor which uses an infrared emitting diode as a light source and a phototransistor as the detector. They are diagonally arranged into a small casing as shown in Figure 1. The function is to detect the reflected light of dust in the air. It is effectively detect very fine particles like smoke, and is frequently used in air purifier systems. The sensor has a very low current consumption which is normally 11 mA (maximum 20 mA), and can be powered with up to 7 VDC. The sensor output is in a voltage form. It is proportional to the measured dust density. The sensitivity of the sensor is reported at $0.5 \text{ V}/0.1 \text{ mg}/\text{m}^3$. Basically, the sensor is based on the light beam that emitted into a measurement space. The light will refracted once the particle is present inside the measurement space and the scattered amount of light is measured.



Figure 1: Compact Optical Sensor (GP2Y1010AU0F)

Figure 2 shows a schematic diagram of an internal system consist of Sharp GP2Y1010AU0F optical sensor. On the top of the sensor, there is a hole for dusts or smoke particles to flow through the detection area. The sensor used Infrared Emitting Diode (IRED) as a light source and a photodiode as a detector. Besides that, the sensor has an amplifier circuit to enlarge the signal by the photodiode. Based on Figure 2, the circuit for the optical sensor has 6 terminals and all of them are labeled

accordingly. The second electrical component is Arduino Board as shown in Figure 3. The Arduino Mega is used as a microcontroller and it is known as ATmega1280.

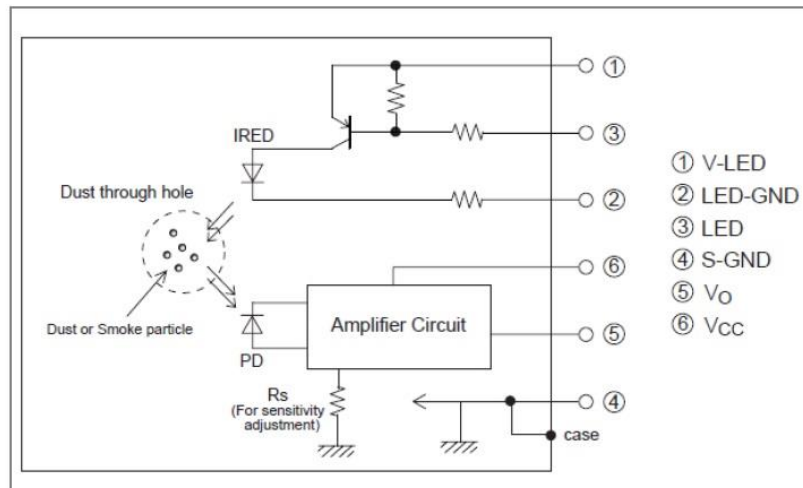


Figure 2: Schematic diagram of the Optical Sensor

It has a total of 54 digital input and output pins. There are 16 analog inputs and 14 can be used as PWM outputs. A power jack, a reset button, 4 UARTs hardware serial port, a 16MHz crystal oscillator and a USB connection with an ICSP header comes together in this sensor. The microcontroller is supported by all the components inside the sensor. It has everything which is needed to support the microcontroller. It can be simply connected to a computer with a USB cable or power it with an AC-to-DC adapter or with an external power supply such as battery. The board needs an external supply of 6 to 20 volts to operate. If supplied with low voltage, the board may be unstable. If high voltage is used, the voltage regulator can damage the board due to overheating. The recommended voltage range is 7 to 12 volts.



Figure 3: Arduino mega board

In order to display the particle concentration, a LCD display is used. A visible image is produced from the LCD by using a crystal liquid. LCD consumes much less power than gas-plasma displays because they work on the principle of blocking light rather than emitting it. An LCD is developed either by an active matrix or passive matrix display grid. The working principle behind the LCD's is based on applying current to the liquid crystal molecule so that the molecule can spin. This causes the angle of light through the molecule change. It also causes a change the top polarizing filter angle. Consequently, only a little light can pass the polarized glass through a particular area of the LCD. Hence that particular area will become dark compared to other. The size of LCD screen used in this haze measurement system is (24 x 69) mm as shown in Figure 4. It can display 16 characters in 2 rows.



Figure 4: LCD (16x2) Display

Interfacing between Arduino IDE with Arduino board is needed in the development of this haze measurement system. Arduino IDE is an open-source system for the user to do the coding and program it to the Arduino board easily. The Arduino IDE software consists of existing developed coding and the core libraries. The IDE is written in Java and based on the processing development environment. The core libraries are written in C and C++.

The battery used in this optical sensor project is a Lithium Polymer (LiPo) battery as shown in Figure 5. It has 2100 mAH capacity and 11.1 V output voltage. It is also capable of discharge maximum continuous current up to 8 C. The main advantage of LiPo battery cell is that it has about four times the energy of density of nickel cadmium or nickel metal hydride battery. LiPo battery is very light and pliable, and can be developed in any size or shape. It can be knocked, hammered, punctured, dropped or hit by a car without any explosion, making it more resistant to damage relative to most batteries.

Nevertheless, there are many disadvantages regarding LiPo batteries such as safety issue. Overcharging and overheating of the LiPo batteries can result in explosion and fire. It is important to follow all the instruction for charging and storage for these kinds of batteries, and to avoid any injury. Improper made of LiPo battery can cause damage to the circuit. It can cause leakage, contamination or internal shorts which lead to major problems. If a LiPo battery is found bulging or out of shape, it should never be charged or used to avoid any safety issue.



Figure 5: Lithium Polymer battery

2.2 Casing

The casing that is used in the measurement system is a rectangular box shape. The shape is simple, stable, and easy to carry to the measurement place. The box is divided into two part as shown in Figure 6. The optical sensor and a blower fan are placed in upper part. The blower will help the dust flow into the chamber and get measured by the optical sensor. The lower part of the box consists of Arduino board and the battery. In order to use the measurement system outdoor, the casing must be water proof. UV resistant grades of acrylic sheet is used for the casing.

The materials weight are far less than a glass and have a good impact resistance than the glass. Acrylic sheet has the benefit of superior light weight. Additionally, thermoformable grades of acrylic sheet generally need less drying before thermoforming compared with other plastics. Acrylic has

superior toughness and it is also durable. Acrylic plastic is highly resistant to various temperature range and humidity, making it is useful for indoor and outdoor applications.

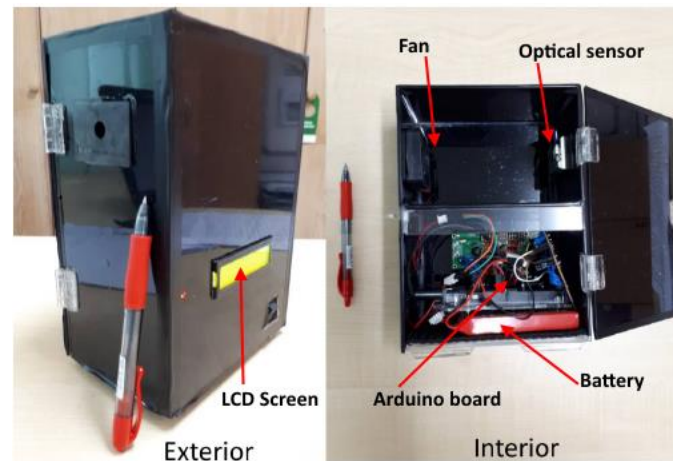


Figure 6: Developed optical sensor measurement system

3. Results and discussion

The flow of the measurement process is arranged as shown in Figure 7. The particulate matter or dust will flow through the sharp optical sensor and detected. In order to do this, a personal computer blower fan is used as shown in Figure 6. The output voltage from the optical sensor will be sent to Arduino board. Then it will be displayed using a LCD screen in term of voltage and particulate matter density in mg/m^3 .

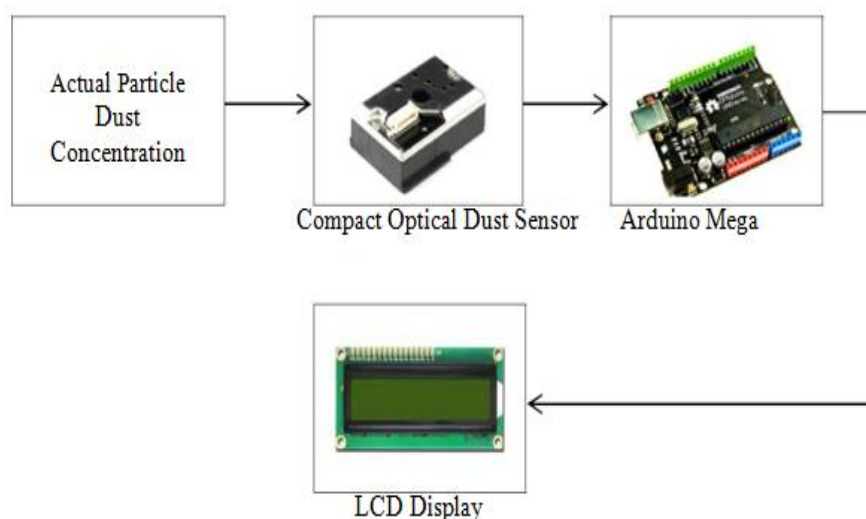


Figure 7: Measurement flow of the optical sensor measurement system

Once the optical measurement system has been constructed, it was tested to do the measurement of smoke. Smoke is used as a simulation for haze because the main contributor for haze is particulate matter or dust in air. There are two experiments were conducted to test the developed measurement system. The first experiment is to measure the smoke concentration or particulate matter in air. The experiments are carried out in a sealed fire chamber room. This is to ensure the smoke or particulate matter is distributed equally in the room. It is also to avoid any interference of wind. The smoke is generated by burning a mosquito repellent coil. The mosquito coil is chosen because it can generate

smoke consistently over time. The reading from the measurement system is taken for every 3 min and the results is shown in Figure 8. Based on the result in Figure 8, the output voltage of the sensor is proportional with the concentration of particulate matter.

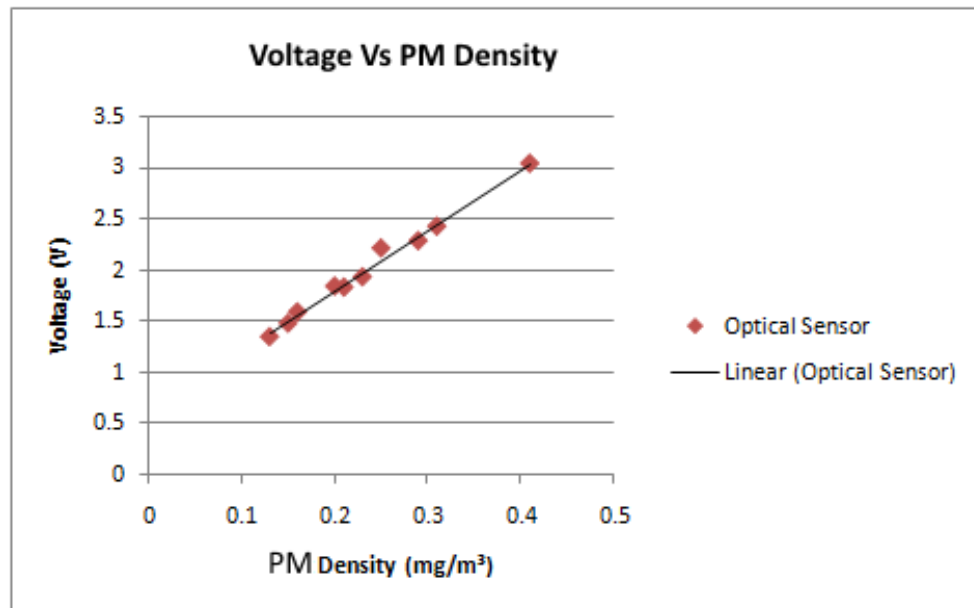


Figure 8: Output Voltage vs PM Density of Optical sensor

In the second experiment, the reading of the developed optical sensor is verified using a commercial sensor called Dust Mate. This is to ensure that the reading from the developed system is correct and aligned the commercial sensor. The reading is taken for every 3 min and the result is shown in Table 1. The concentration for particulate matter from the developed optical sensor is compared with the reading from Dust Mate. The concentration of particulate matter over time for both devices over time is plotted on a graph as shown in Fig. 9.

Table 1: The data of Optical Sensor and Dust Mate

Time, min	Dust Mate (PM2.5), mg/m³	Optical Sensor, mg/m³	Optical Sensor Output Voltage, V
3	0.45919	0.35	1.48
6	0.63618	0.61	3.03
9	0.5963	0.51	2.42
12	0.44598	0.41	1.83
15	0.53841	0.33	1.35
18	0.49339	0.49	2.28
21	0.47876	0.45	2.21
24	0.53342	0.43	1.93
27	0.43995	0.4	1.84
30	0.413497	0.36	1.59

Based on the result in Figure 9, it shows that the particulate matter concentrations measured using the developed optical sensor is aligned with the reading from the commercial sensor, Dust Mate. Though the line for Dust Mate has three peaks and the optical sensor has only two peaks, it has a similar trend. The difference might be due to several reasons such as the amount of particulate matter is distributed unevenly in the sealed chamber room. Thus this make the amount of particulate matter at the sensor tips of both devices are different. However the first 10 min of the reading shows very similar trend for both measurement devices. Based on this observation, the comparison between optical sensor and Dust Mate has been proven that developed optical sensor is functioning properly.

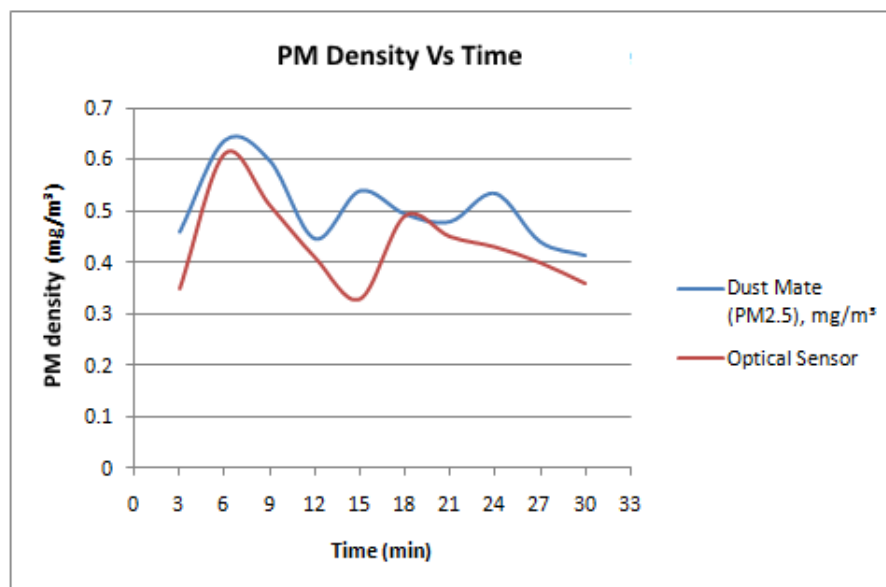


Figure 9: Comparison PM concentration between developed Optical sensor and Dust Mate.

4. Conclusion

In conclusion, the developed optical measurement system was successfully measure the concentration of particulate matter which is the main contributor to haze. The output voltage of the optical sensor is proportional with the concentration of particulate matter. The particulate matter concentration measurement was also verified using a commercial sensor, Dust Mate and it is found that the reading was aligned. The development of this optical particulate matter measurement system can be used as an alternative to monitor haze. Based on this monitoring, it can provide a public precaution to avoid from having any outdoor activities if the level of air is hazardous. The device also give a real time measurement and the cost to develop it is not expensive relatively.

In Future, there are several recommendations for this optical sensor to be improved. For example, a data log memory can be added to save all the reading and transfer to laptop. An alert program can be created so that when the reading of air is unhealthy, the system will trigger a message of current condition to mobile phone via short messaging system (SMS).

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