

PM 2.5 MONITORING SYSTEM USING WIRELESS SENSOR NETWORKS FOR SMART CITY

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Abstract

Air pollution caused by fine particulate matter 2.5 (PM 2.5) is a leading health crisis for people around the world including Thailand. This paper proposes a low-cost and real-time PM 2.5 monitoring system using wireless sensor network and the Internet of Things (IoT). The system is designed to monitor PM 2.5 via Blynk application on smart phone and via LCD monitor by showing the detection results in the Air Quality Index (AQI) which is easy to understand. Furthermore, our system is calibrated with the standard instrument to ensure accuracy and reliability. The results show that our low-cost system is able to provide a reliable real-time monitoring of the PM 2.5 condition.

Keywords: Air quality index, Particulate matter 2.5, Wireless sensor network, smart city

Introduction

PM 2.5 (particulate matter less than 2.5 micrometers in diameter) is a harmful air pollutant which is one of the major environmental risk to health. The sources of PM 2.5 are from, for example, engine combustion of vehicles, open burning, industry and power plants. It can be related to the cause of lung cancer, ischemic heart disease, stroke, asthma and other problems in respiratory system. Therefore, it is urgent to look for ways to monitor the PM 2.5 pollution in order to protect oneself by wearing specific mask or avoiding the area where PM 2.5 concentration exceeds the guideline.

In this paper, a real-time PM 2.5 monitoring system is developed using particulate matter sensor or SPS 30 sensor (Livio, 2019) which is a high

quality sensor. It uses laser scattering technique to radiate suspending particle in the air and uses Sensirion's innovative anti-contamination technology. Thus, a sensor service life can last over eight years. This technology enables accurate measurements from the device's first use, which comes with miniature and ultra-slim. Moreover, the SPS30 sensor provides users with the estimated mass concentration and the number of particles of PM 1.0, PM 2.5, PM 4.0, and PM 10.0 which the mass concentration range of the sensor is between 1 to 1000 $\mu\text{g}/\text{m}^3$. Since there have been many studies on the Internet of Things (IoT) and the wireless sensor network (WSN) for smart cities (Mary *et al.*, 2018; Sikder *et al.*, 2018; García *et al.*, 2018; Qin

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et al., 2019), we have applied both of them to our system for monitoring and recording the PM 2.5 information and also for creating a medium to share it. We use a powerful microcontroller ESP32 with built-in Wi-fi and Bluetooth to implement the IoT. It will share the information received from the WSN by using air card to the LCD display and the Blynk application on smart phone. The result of PM 2.5 concentration will be shown in the Air Quality Index (AQI) and color code which is easy to interpret. Our system can run on solar power and batteries which can operate 24 h a day. The accurate results of the PM 2.5 monitoring system are referred to and compared with the Air Visual application.

The paper is structured as follows. In section 2, we describe the methodology of the design of our PM 2.5 monitoring system. The experimental results of the system from testing and actual recording are given and explained in section 3. Finally, the conclusion will be discussed in section 4.

The Proposed Methods

In this section, we explain the module of our proposed PM 2.5 monitoring system. Our system is equipped with a 40 watt solar panel as a power source and a 12 volt battery as a power storage. There is also a component called solar charger which is connected between solar panel and battery in order to avoid overcharging which can cause permanent battery damage and loss of functionality over time. Then, there is a 5 volt 3 amp voltage regulator board which will supply constant 5 volt to all other devices including air card and microcontroller ESP32. Air card is a wireless adapter for transmitting and receiving data in a cellular network to microcontroller ESP32. The microcontroller ESP32 was applied to control the operation of SPS30 sensor and control the wireless data transmission. SPS30 sensor is the main sensor which is used to measure the concentration of PM 2.5. It is a compact, high quality, optical particle sensor. The detection result will also be shown on the LCD display. The hardware connection of the proposed system is given in Figure 1 and Figure 2(a). PM 2.5 concentration result from the monitor system is used to compare with two standard PM 2.5 detection monitors. Firstly, the comparison is made with the Xiaomi PM 2.5 Air Quality Monitor, the standard equipment for PM 2.5 detection in real-time. It uses light scattering techniques to detect particles in the air and can offer accurate information. Secondly, the Air Visual application is also used for comparison. This application is widely used to detect PM 2.5, AQI, temperature, weather and also direction and speed of wind in real-time. It supports both iOS and

Android. Moreover, the application will show the color levels of air quality in the measured area and provides a graph of air pollution trends for 24 h retrospective free of charge. One of the Air Visual detection system station is located in Nakhon Ratchasima. This application is able to check the backward data and forecast the air quality in a specific area of globalization.

In Figure 2(b) shows our PM 2.5 monitoring setup at the station 1. In our experiment, there will be total of 3 stations. The system can transmit PM 2.5 information to the ThingSpeak cloud computing. By using the smart phone and Blynk application, anyone can see the PM 2.5 monitoring results of all 3 stations.

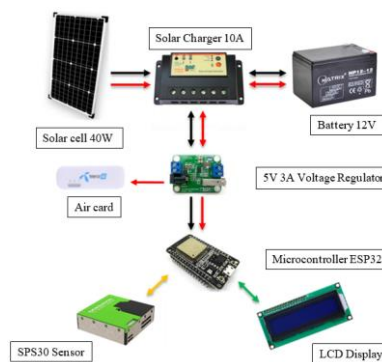
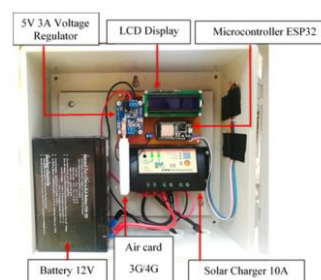


Figure 1. Diagram for hardware connection of PM 2.5 Monitoring System.



(a)



(b)

Figure 2. (a) Hardware Connection and (b) System setup of Station 1.

Experimental Setup

In this section, we show the results of PM 2.5 monitoring system and compare them with the ones using Xiaomi PM 2.5 Air Quality Monitor and Air Visual application. Figure 3 and Figure 4 give the results of PM 2.5 concentration from SPS30 sensor in $\mu\text{g}/\text{m}^3$. The results from our system with SPS30 sensor are also compared with the ones from Xiaomi PM 2.5 Air Quality Monitor. The solid and the dashed lines represent the PM 2.5 dust concentration by the SPS30 sensor of PM 2.5 monitoring system and Xiaomi PM 2.5 Air Quality Monitor, respectively. From the result, we found that the data obtained by the SPS30 sensor and Xiaomi PM 2.5 Air Quality Monitor is related. The relationship can be written by

$$y=1.85x \quad (1)$$

$$R^2=0.99 \quad (2)$$

where y is the PM 2.5 dust concentration by Air Visual application and x is the PM 2.5 dust concentration by SPS30 sensor of PM 2.5 monitoring system. The R^2 (R-square) is 0.99 or 99%. The values of x can be calibrated by using Equation (1). Figure 5 and Figure 6 show the comparison between both data after calibration.

The results from our system with SPS30 sensor are also compared with the ones from Air Visual application (Airvisual, 2019) which has become one of the most reliable sources of air quality data show

in Figure 7. The solid and the dashed lines represent the PM 2.5 dust concentration by the SPS30 sensor of PM 2.5 monitoring system and Air Visual application, respectively. From the result, we found that the data obtained by the SPS30 sensor and Air Visual application is related. The relationship can be written by

$$y=1.52x \quad (3)$$

$$R^2=0.84 \quad (4)$$

where y is the PM 2.5 dust concentration by Air Visual application and x is the PM 2.5 dust concentration by SPS30 sensor of PM 2.5 monitoring system. The R^2 (R-square) is 0.84 or 84%. The values of x can be calibrated by using Equation (3). Figure 8 shows the comparison between both data after calibration.

In Figure 9, the comparison is made in Air Quality Index (AQI). The concentration of PM 2.5

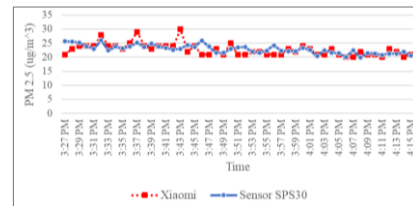


Figure 5. Comparison of PM 2.5 dust concentration from Xiaomi PM 2.5 Air Quality Monitor after calibration.

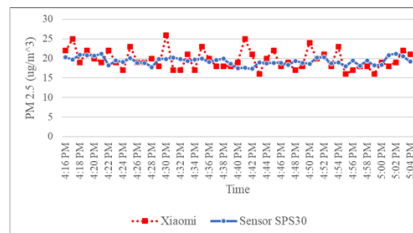


Figure 6. Comparison of PM 2.5 dust concentration from Xiaomi PM 2.5 Air Quality Monitor after calibration.

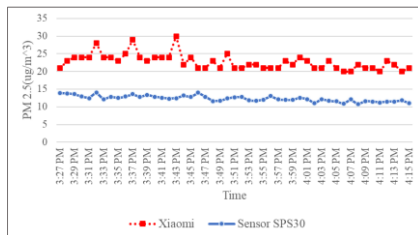


Figure 3. Comparison of PM 2.5 dust concentration from Xiaomi PM 2.5 Air Quality Monitor.

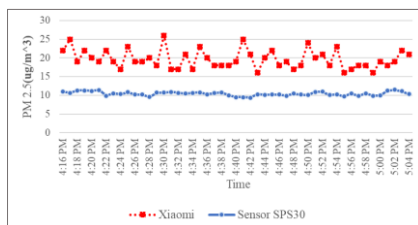


Figure 4. Comparison of PM 2.5 dust concentration from Xiaomi PM 2.5 Air Quality Monitor.

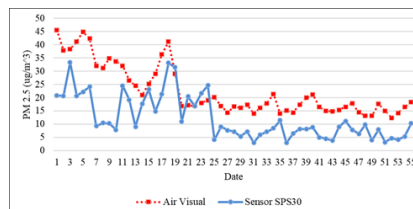


Figure 7. Comparison of PM 2.5 dust concentration from Air Visual and SPS30 sensor.

in Figure 1 can be converted to the Air Quality Index by using the following equation (Air Quality Index, 2019)

$$[AQI] = \left\{ \left(\frac{I_{\max} - I_{\min}}{C_{\max} - C_{\min}} \right) \times (C_i - C_{\min}) + I_{\min} \right\} \quad (5)$$

where AQI_i is the Air Quality Index. C_i is the PM 2.5 concentration from the sensor. $C_{\max}$ and $C_{\min}$ are the maximum and minimum of PM 2.5 dust concentration range in the Table 1. $I_{\max}$ and $I_{\min}$ are the maximum and minimum values of Air Quality Index corresponding to $C_{\max}$ and $C_{\min}$, respectively. The PM 2.5 concentration in Air Quality Index from both sources are also found to be related. The relationship can be described by

$$y = 1.44x$$

$$R^2 = 0.88$$

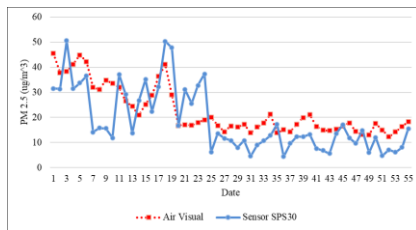


Figure 8. Comparison of PM 2.5 dust concentration from Air Visual and SPS30 sensor after calibration.

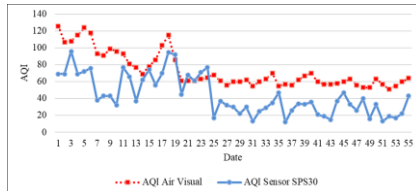


Figure 9. Comparison of Air Quality Index from Air Visual and SPS30 sensor.

where y is the PM 2.5 dust concentration by Air Visual application and x is the PM 2.5 dust concentration by SPS30 sensor in Air Quality Index. The R^2 (R-square) is 0.88 or 88%. Figure 10 shows the comparison between both data after the value of x is calibrated

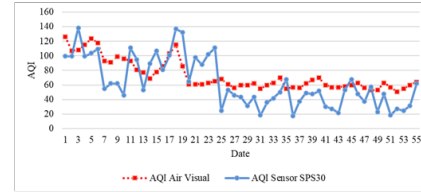


Figure 10. Comparison of Air Quality Index from Air Visual and SPS30 sensor after calibration.



Figure 11. (a) PM 2.5 of station 1, station 2 and station 3 and (b) PM 2.5 and AQI of station 1, station 2 and station 3 on Blynk application.

Table 1. Air Quality Index PM 2.5 (PM 2.5 AQI).

AQI values	PM 2.5 (ug/m ³)	Air Pollution Level	Healthy Implication
0-50	0-12	Good	Air quality is considered satisfactory, and air pollution poses little or no risk.
51-100	12.1-35.4	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
101-150	35.5-55.5	Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
151-200	55.6-150.4	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
201-300	150.5-250.4	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.
300-500	250.5-500	Hazardous	Health alert; everyone may experience more serious health effects.

In Figure 11, it can be seen that the Air Quality Index from the Air Visual is slightly higher than the one from the SPS30 sensor. This might be because the two sensors are not exactly installed at the same place. The location of the Air Visual sensor is closer to the center of the city where there is more traffic than the one of the SPS30 sensor.

Conclusions

We propose a method for PM 2.5 monitoring system by using wireless sensor networks and the SPS30 sensor which can detect small particles using laser scattering technique. The microcontroller ESP32 was applied to control the operation of SPS30 sensor and control the wireless data communication. It also shares the information received from the WSN to the LCD display and the Blynk application on smart phone shown in Figure 11. The system can operate 24 h by using electrical power from solar cells and battery. Our results have been compared and calibrated with the ones from Air Visual application to ensure reliability. The results show that our proposed low- cost system is able to provide a reliable real-time monitoring of the PM 2.5 condition. Thus, it can be used as a prototype of PM 2.5 monitoring product for smart cities. For suggestion, in order to reduce the error of AQI between Air visual application and our PM 2.5 monitoring system, one might try to move the SPS30 sensor closer to the position where the sensor of Air visual is installed.

Acknowledgement

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