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# Design and Implementation of a Smart Air Quality Monitoring and Purifying System for the School Environment

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***Abstract*— Students and teachers are exposed to harmful materials in the school where the students generate dusts when playing during the break time. Despite most schools adopting air purifiers in the classroom, the capability of the air purifier is not enough compared to natural ventilation. Therefore, this study proposed a smart air quality monitoring and purifying system for the school environment. The system consists of an outdoor air quality monitoring system, indoor air purifiers, and a server program running on PC. The proposed system allows teachers and students to choose when to use the air purifier or natural ventilation by comparing outdoor air quality and indoor air quality. In addition, the proposed air purifier system includes an intelligent operation that controls the speed of the fan and blower to make sure it does not generate noise that interfere with students in class. This paper also includes the performance evaluation of the air quality monitoring system. As a result, the system has less error than approximately 15% from the reference instrument.**

***Keywords—Air Quality Monitoring, Air Purifier, Natural Ventilation, Fine Dust, Yellow Dust, PM Sensor Calibration***

## I. Introduction

According to WHO, 7 million people die each year from air pollution, of which 4.3 million die from indoor air pollution and 3.7 million die from outdoor air pollution. And 1 million people were affected both indoors and outdoors [1, 2]. Specially, children, compared to adults, have weaker body organs when they are exposed to toxic materials caused by indoor environment [3]. Therefore, most schools adopt the air purifier to maintain the air in the classrooms clean in schools where particulate matter is most critical air pollution. Most of these schools install one air purifier in each classroom without comparing indoor and outdoor air quality during air ventilation through window opening. This could cause pollution that is more dangerous from yellow dusts coming from the atmosphere or toxic materials coming from cars, plants, etc. [4, 5].

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The aim of this study was to develop a smart air quality monitoring and purifying system for the school environment. The proposed system consists of multiple indoor air purifiers, an outdoor air quality-monitoring device, and an administrative server program running on PC. The indoor air purifiers have extra modes based on the class hour and break time to control the noise caused by the fans and blowers. The outdoor air quality-monitoring device mounted on outdoor windows tracks outdoor air pollution and transmits the measured data to the server program. Finally, the server program is installed in a PC managed by the teacher, and it receives the measured data from the outdoor air quality-monitoring device and multiple indoor air purifiers. The server program compares the quality of the indoor and outdoor air, and if the outdoor quality is better than indoor, it notifies the teacher that it is safe to open the windows for natural air ventilation. In addition, the server program can control and turn the air purifiers on or off, and inform the teachers weather to open the window or not. This paper also includes the performance evaluation of the particulate matter sensors we used for the proposed system.

## II. Smart Air Quality Monitoring And Purifying System

Figure 1 illustrates the conceptual overview of the proposed system that consists of a couple of indoor air purifiers, one outdoor air quality monitoring system, and the administrative server program running on PC. The indoor air purifier measures the indoor air quality of the classroom and purifies it based on the measured data while the outdoor air quality monitoring system measures the quality of outdoor air and transmits the data to the server program. The electronic hardware systems of the outdoor air quality monitoring system and the indoor air purifier are the same; however, the indoor air purifier has the interfaces to operate purifying fans and the filter. The outdoor air quality monitoring system and the indoor air purifiers are connected to an administrate PC managed by the teacher through Bluetooth Low Energy (BLE) to communicate together.

## A. Electronic Hardware Design

Figure 2 shows the block diagram and prototype of the outdoor air quality monitoring and indoor air purifier system. The electronic system is powered by 110V~220V household wall outlet, which is converted into 12/24V through the commercial switched mode power supply (SMPS). This high voltage is only used to run the fan of the indoor air purifier to purify indoor air pollution. Then, the power module also converts 12/24V into 3/5V powers to operate other electronic systems i.e., MCU, Bluetooth LE, other sensors, etc. The system operates on a STMicroelectronics STM32F407 [6] (ARM Cortex-M4) chip to manage the outdoor air quality system and the indoor air purifier systems. We used a Plantower PMS7003M sensor [7] to measure the concentration of particulate matters and dusts and a Microchips RN4020 BLE module [8] to communicate with the server program running on the PC.

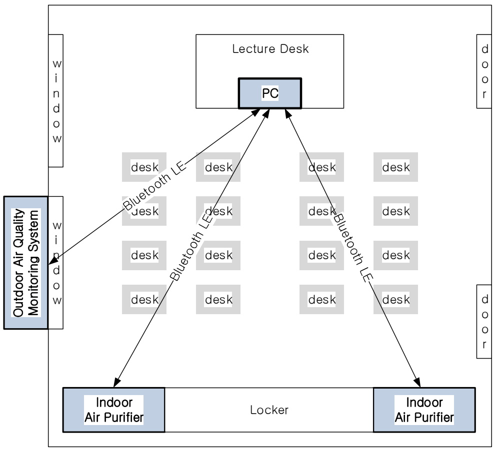



Fig. 1. Conceptual overview of the proposed system.

Unlike the outdoor air quality monitoring system, the indoor air purifier has built-in fans and filters to purify air pollution as shown in Figure 2 (a). The proposed system has a couple of blowers and one brushless direct current motor (BLDC)-based fan that can be controlled through the pulse width modulation (PWM). The fan for air purifiers is Shenzen cooling technology CLS series with a power consumption of 19.8W, fan speed of 2,000 RPM, maximum air flow of 400 cubic feet per minute (CFM), and the noise level is 54.6dBA. It also has a real time clock to keep the time, a humidity/temperature sensor, buzzer, LEDs, LCD display, etc. for convenience purpose.

## B. System Operation

Figure 3 illustrates the operation process of the outdoor air quality monitoring system and indoor air purifier. First, once the system is booted, it initializes hardware used for the system and checks the timer settings. If the timer is not set, the system enters the timer setting mode where the administrator can manually set, or it can set through the network time protocol (NTP) of the server program. Otherwise, the system gets time information including hour and minute from the internal real time clock (RTC). Then the system measures humidity, temperature, and PM 2.5 (less than 2.5 micrometer sized particulate matter). The measured data is filtered by moving average with the window to mitigate measurement noises. Then, the system classifies air pollution into four levels which were motivated by commercial air purifiers. For instance, if PM2.5 is less than 50 $\mu g/m^3$, the air pollution level is ‘normal (2)’ and the fan speed sets as ‘low’. If PM2.5 is higher than 100 $\mu g//m^3$, the air pollution level is ‘bad (4)’ the fan speed sets as ‘max’.

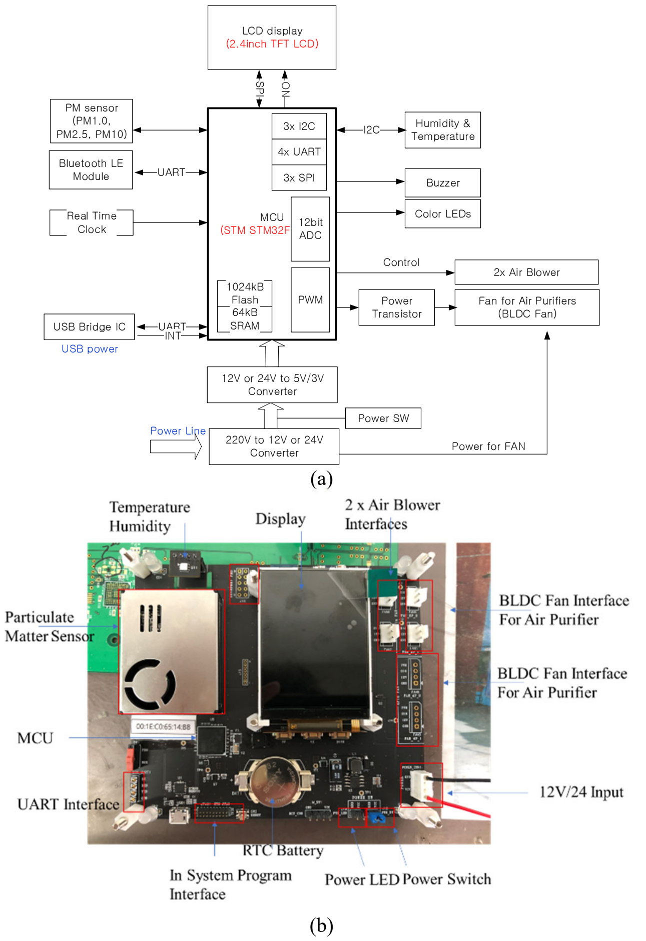



Fig. 2. The electronic hardware system of the outdoor air quality monitoring system and the indoor air purifier: (a) block diagram and (b) prototype. The electronic hardware systems of the two systems are the same; however, the indoor air purifier includes the purifying fans and filters.

Then it checks if the time is within class hour. Even if air pollution level is ‘bad (4)’, the system sets the fan speed as ‘low’ if the time is within class hour. This is because the higher the fan speed the higher the noise level. Therefore, the noise level should be as low as possible during class hours. The system then checks if it is connected with the server computer via Bluetooth LE. If Bluetooth LE is connected, the system generates the formatted data in accordance with the protocol and sends the data to the server computer. Finally, the system investigates whether the server program sent control commands. For example, if it received the ‘turn off’ command from the server program, the air purifier enters the shutdown mode until it receives the ‘wake up’ command again from the server program which is controlled by the teacher or administrator. The air quality monitoring system works in the same manner, except for the fan and blower that are not connected to the electronic system physically.

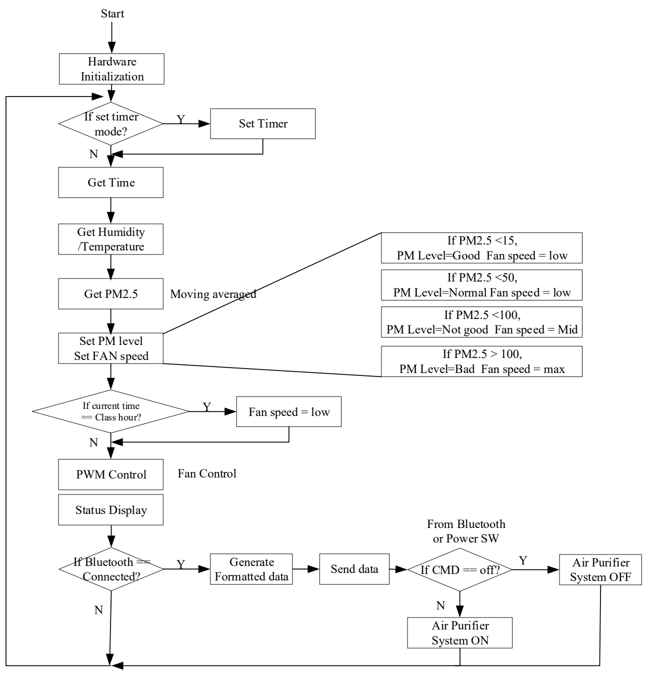



Fig. 3. Flow chart of the outdoor air quality monitoring and indoor air purifier system.

## C. Operation of the Server Program

The server computer connects with multiple indoor air purifiers and the outdoor air quality monitoring system through Bluetooth LE dongle, Silicon Labs BLED112 [9], simultaneously. The server computer can connect to a maximum of 8 peripherals like the outdoor air quality monitoring system or the air purifier system. The server program was implemented in Python, and we used a *bglib* library [10] provided by Silicon Labs to control the Bluetooth LE dongle through serial interface. Figure 4 depicts how the server program works. First, the server program starts a serial initialization process to communicate with the Bluetooth LE dongle. Then, the program builds the window GUI and connects to the outdoor air quality monitoring system and the indoor air purifiers if the serial initialization process is successful. Once connection is successful, the program finds corresponding channels and reads the characteristics of the GATT server of the peripherals to get the data from the connected systems, then it parses the formatted data, insert them into variables, and then update GUI as shown in Figure 5. If the outdoor air quality is better than indoor air quality, it provides more efficient solution by letting teachers open the windows with temperature and humidity for natural ventilation.

If the program receives some commands such as on/off command or filter reset, it sends them to the outdoor air quality monitoring system and the indoor air purifier systems. It repeats the same process after storing the data. The collected data from the server computer in the classroom can be transmitted to the main server in the teacher's or administrate room via TCP/IP.

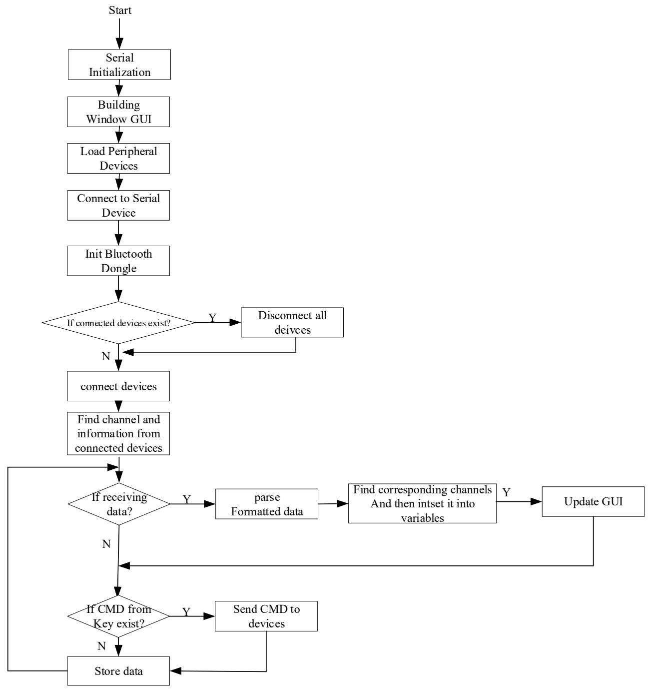



Fig. 4. Flow chart of the server program.

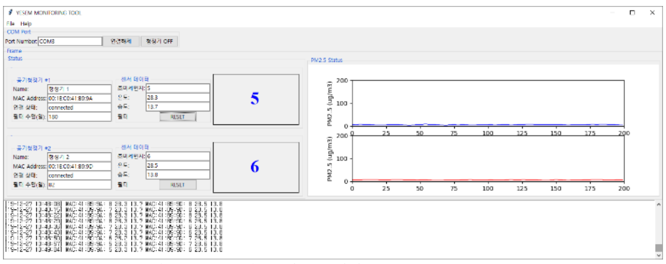


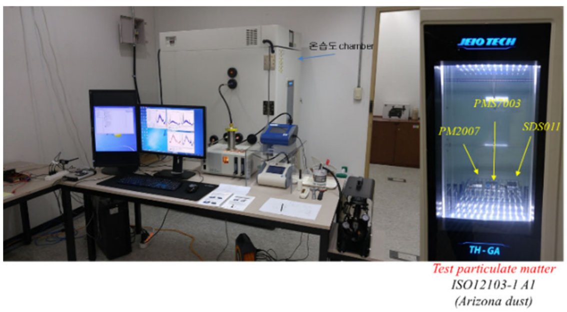

Fig. 5. User interface of the server program.

## III. SYSTEM INTEGRATION AND EVALUATION

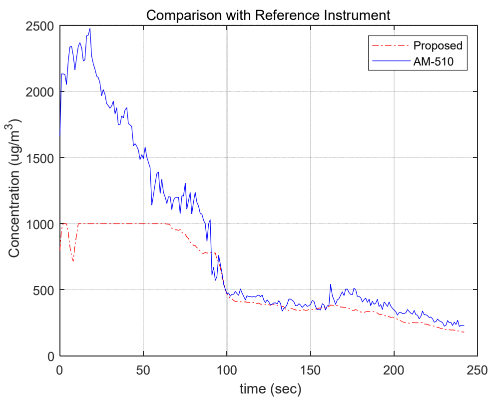
We integrated the air purifier system with the housing as shown in Figure 6. The air blowers and BLDC fan are located on the top of the air purifier and the filter that is compatible with Xaomi's one is installed under the BLDC fan. The main electronic system is mounted in the back of the filter. Since the proposed air purifier is installed in the classrooms, we designed the housing of the air purifier similar with the locker used by students. The housed air purifier is placed next to the conventional lockers and is fixed with the locker not to obstruct the movement of children in the classroom.

The proposed system requires that the concentration of the particulate matters and dusts is accurately measured. We set up an experimental environment to evaluate the performance of the sensing system using PMS7003 as shown in Figure 7 (a). We put the sensing part of the proposed system with the reference instrument, AM 510 [11], which is an aerosol monitor into the chamber. Then, we inserted dust generated by the candle into the chamber while gradually adjusting the concentration from 0 to 2,000 ㎍//m$^3$. Figure 7 (b) shows the result of the evaluation. The error from the reference instrument was approximately 15% under the concentration of 500 ㎍//m$^3$. It also shows that the difference between the reference instrument. The graph also shows that the PM sensor installed on the proposed system measures only under the concentration 1,000 ㎍//m$^3$. In real environment, exceeding 1,000 ㎍//m$^3$ is extremely rare.

Fig. 6. Housed Indoor air purifier system.




(a)




(b)

Fig. 7. Experimental environment and performance: (a) experimental environment and, (b) experimental result.

## IV. Conclusion

Air pollution in schools causes damage to lung tissue and causes lung diseases such as asthma, cancer, etc. This study proposed a smart air quality monitoring and purifying system for the school environment. The proposed system can monitor the outdoor air quality and indoor air quality simultaneously, giving the option of using natural ventilation by opening the windows. In addition, the indoor air purifier operates in consideration with class hours so as not to interfere with students studying. We believe that the proposed system will provide students with a more comfortable learning environment. Finally, the future work includes evaluating purifying capability of the proposed system.

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