Sensors Based on the Internet of Things for Semi-Outdoor Air Cleaners: An Alternative Method for Controlling Haze and COVID-19

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Abstract:

Background: Particulate matter has been connected to COVID-19 occurrences, whereas Internet of Things (IoT) technology can be utilized to address the demand for ambient air quality monitoring.

Objective: The purpose of this research is to create a low-cost IoT platform that can be integrated with multi-air sensors and a ventilating fan controller for public semi-outdoor air conditions, and to protect us from the haze and the COVID-19 crisis.

Materials and Method: The IoT platform was designed and built, with two-way data communication, between a dual ventilating fan, air quality sensors, and a chatbot platform.

Results: The results of a preliminary test were collected and interpreted, including the operation of the ventilation system, aerosol reports, and IoT interfacing. When PM2.5 levels reached 50 $\mu g/m^3$, a set of ventilating fans was activated and ran indefinitely until the aerosol level dropped below 50 $\mu g/m^3$. The chatbot system was divided into two LINE groups, the first of which was used to send a machine code. This chatbot could respond within 1-5 seconds, depending on Wi-Fi stability, to monitor the status of the ventilation system as well as any types of aerosol levels (CO_2, formaldehyde, TVOC, PM2.5, PM10, temperature, and humidity). Another report system was used to only report machine status and aerosol levels every 1 hour or as users desired, which was designed for people who want to know the air quality levels in their location.

Conclusion: Multi-sensors and the LINE chatbot can both detect aerosols as well as control ventilation fans. With the exception of a SIM card included with the Wi-Fi 3G system, which is suitable for developing countries during the haze and COVID-19 crisis, all platforms are free for potential users.

Keywords: COVID-19, Internet of things, Particulate matter, Haze, Semi-outdoor air quality

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Introduction

Since the end of 2019, the COVID-19 pandemic has had an impact on many global sectors, particularly following declarations of lockdown policies in many countries. Haze pollution levels in some countries have changed as a result of the COVID-19 situation. A machine learning approach was used in Malta to predict the effect of COVID-19 on NO_2 and O_3 concentrations. The results revealed statistically significant reductions in NO_2 concentrations related to traffic, while O_3 levels increased.[1] Similarly in Mexico City, air quality improved during the lockdown due to lower NO_2 and PM2.5 levels, caused by lower motor vehicle emissions, despite higher O_3 levels.[2] Reduced activity in France as a result of lockdown policies resulted in lower NO_2, PM10, and PM2.5 concentration levels.[3] In China, 10 Chinese mega cities, indicators of traffic pollution, NO_2 which is one of the primary traffic pollution indicators, were significantly lower during the pandemic, whereas particulate matter pollution varied.[4] On a global scale, data from 34 countries and five continents revealed a 34.0 percent reduction in NO_2 concentration and a 15.0 percent reduction in PM2.5 concentration during strict lockdown periods, while O_3 concentration increased by 86.0 percent.[5]

Several studies have found that certain air contaminants, such as PM2.5, PM10, CO, NO_2, SO_2, and O_3, increase COVID-19 mortality rates. However, some research indicates that COVID-19's indirect effect may aid in the reduction of air pollution. The presence of particulate matter has been linked to an increase in COVID-19 incidents.[6] After controlling for many area-level confounders, a study in the United States found that higher historical PM2.5 exposures are associated with higher county-level COVID-19 mortality rates.[7] A rapid systematic review conducted between December 2019 and September 2020 discovered that pollutants independently associated with COVID-19 incidence and mortality were firstly PM2.5, followed by PM10, NO_2, and O_3 in the acute phase, while PM2.5 and NO_2 had similar relationships in the chronic phase. As a result, both acute and chronic air pollution exposure can have an impact on COVID-19 epidemiology.[8] Population density is strongly correlated with COVID-19 infection and mortality, as well as with PM2.5 concentration, this according to a global exploratory study of the relationship between population density, PM2.5 concentration, and confirmed COVID-19 ases.[9] Furthermore, according to satellite data, global air pollution is an important cofactor increasing the risk of COVID-19 mortality.[10]

To evaluate and monitor various parameters of air quality, Internet of Things (IoT) technologies and sensor networks such as comprehensive network communication, information tracking, Cloud-based decision making, and online management, have been developed in response to the need for ambient air quality monitoring.[11] For indoor air measurement, one of the existing infrastructures that can be developed into a model for marketing purposes is sensor-based home IoT, on the theme of air quality improvement.[12] Indoor aerosol concentrations, such as volatile organic compounds (VOC), CO, CO_2, and temperature-humidity, are typically reported and further analyzed using Cloud computing and a web server or application.[13] During the COVID-19 pandemic, a solution for indoor air quality monitoring and prediction, based on IoT and machine learning, was developed. GSM/Wi-Fi technology is used to transmit real-time air conditions to a web portal and a mobile application. The Long and Short Term Memory (LSTM) model is used to forecast aerosol concentrations.[14] For outdoor air quality monitoring, an air quality measurement device called "Smart-Air" was created that can detect

PM10 in South Korean subway tunnels and present it to an IoT gateway.[15]

A previous study found that a low-cost prototype of a water-based air purifier that can be used in semi-outdoor conditions could also be operated manually. It has out-of-the-box IoT connectivity.[16] Some details of ventilating fans combined with IoT systems are required to develop this machine. To realize an IoT-type electric fan, a Pulse Width Modulation (PWM) signal generation module was integrated with an embedded system with a Field-Programmable Gate Array (FPGA). The use of Wi-Fi and Long Term Evolution (LTE) technology is now a promising technology.[17] Another paper described an IoT system that was linked to the Cloud and a building control unit. The proposed system can balance Indoor Air Quality (IAQ) and outdoor air pollution before adjusting the proper airflow rate of the indoor ventilating fan.[18]

As previously stated, the goal of this study is to design and fabricate a low-cost IoT platform that can be integrated with multi-air parameter sensors and a ventilating fan controller for public semi-outdoor air conditions, as well as to provide protection from haze and the ongoing COVID-19 crisis.

Materials and Method

The method for using aerosol sensors and a ventilating system with an IoT platform is shown below;

Design Architecture

Figure 1 depicts two-way data communication between a ventilating fan and air quality sensors and a chatbot platform. According to the Air Quality Index (AQI), which was developed by the United States Environmental Protection Agency (EPA), an AQI of 0 to 50 is good and presents little or no threat to health.[19] Therefore, when the PM2.5 levels in the semi-outdoor area reached 50 µg/m^3, an air quality module reported the data to a microcontroller unit (MCU), using Transistor–Transistor Logic (TTL), and a dual ventilating fan was activated. After PM2.5 levels fell below 50 µg/m^3, the dual ventilating fan was turned off. The data was transmitted via a Local Area Network (LAN) that was linked to a 3G Wi-Fi module. The Cloud storage and IoT system then sent an air quality report to a chatbot every 1 hour or whenever the user specified. In this study, a twin duct ventilation fan was employed to evacuate air at a total rate of 1800 m^3/h.[20]

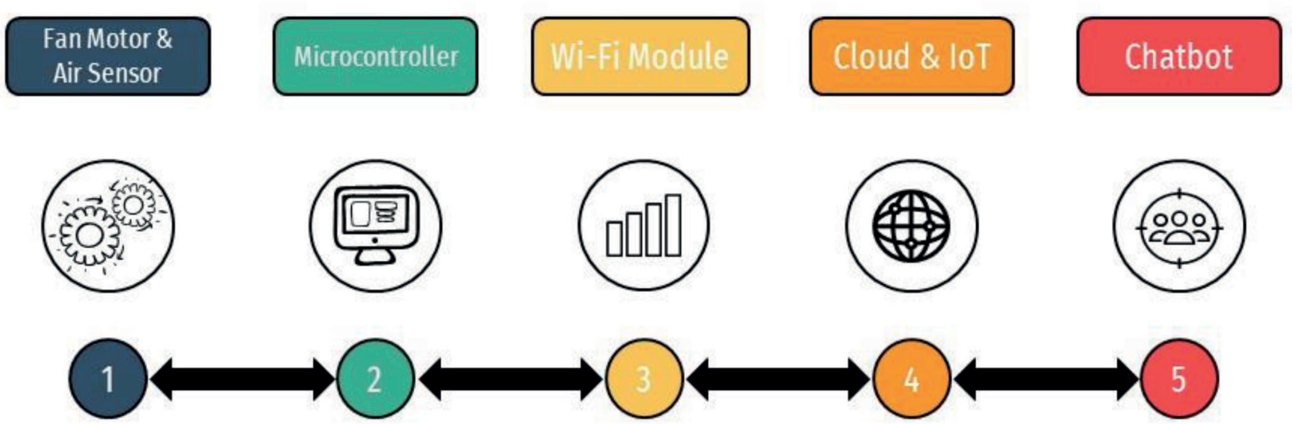

Figure 1 IoT system planning for semi-outdoor air cleaner.

Air Quality Module and Microcontroller

For environmental air quality monitoring, a seven-in-one air quality module (Model: AQM-RK14V), operating temperature 0-50°C, working humidity ≤ 95%RH, dimensions 61*48*13 mm (L×W×H) was used. CO_2 (400-5,000 ppm, resolution 1 ppm ± 25%), formaldehyde (HCHO 0-2,000 μg/m^3, resolution 1 μg/m^3 ± 25%), TVOC (0-50,000 μg/m^3, resolution 1 μg/m^3 ± 25%), PM2.5 (0-999 μg/m^3, resolution 1 μg/m^3 ± 10%), PM10 (0-1,000 μg/m^3, resolution 1 μg/m^3 ± 10%), temperature (-40-125°C, resolution 0.01°C ± 0.03°C), and also humidity (0-100%, resolution 0.04% ± 3%RH) were all measured and interpreted. The device was calibrated during its manufacture. After installation, the sensor calibration procedure comprises a quarterly comparison with reference-grade air monitors, taking into account ambient variables. This information would confirm the sensors' accuracy and data reliability. Every second, all seven groups of monitoring data were automatically sent to the MCU via a UART TTL interface. The sensor is positioned at the top of the air purifier to avoid interference and misinterpretation from the air inlet and outlets.

The MCU also included the Arduino Mega 2560 Rev3 board, the I-Autoc KSIM series single phase AC output solid state relay, and the XH-M609 12-36V battery low voltage disconnect protection module. A microcontroller was connected to a dual ventilation exhaust fan model HF-200, 130W, 220V, air flow rate 900 m^3/h. An electrical signal was delivered between the MCU and the ventilation system using the PWM signal. After receiving data from an air quality module, a feedback loop between MCU, air sensors, and a ventilating fan was introduced.

Wi-Fi Module and IoT Platform Development

A Wi-Fi 3G module also included an Ethernet shield (Model: W5500), and a D-LINK (DWR-920) Wireless N300 4G Router, allowing an Arduino board to connect to the internet via LAN cables. Using the Serial Peripheral Interface (SPI), the MCU could connect to an Ethernet shield.

The data was then sent to the NETPIE 2020 IoT platform via Message Queuing Telemetry Transport (MQTT), which can report real-time sensor monitoring as well as Cloud platform control. An Application Programming Interface (API) code was written in PHP language for chatbot development. This code was saved on the internet hosting service "GitHub", and the URL was then sent to a Cloud platform called "Heroku". Using the Heroku platform, all data was then transferred between the MCU and the LINE chatbot. Finally, the MCU transmitted PM2.5 levels to an outdoor P5 SMD LED screen module, 64 x 32 dot, 320 x 160 mm installed on top of an air purifier unit.

To test the system, the air purifier and accessories were used constantly for one month. The early tests of overall systems, which comprised the operation of the ven tilation system, aerosol reports, and IoT interfacing, were gathered and analyzed.

Results

Response of Ventilation System

When PM2.5 levels reached 50 μg/m^3, a set of ventilating fans was activated and worked continuously until the aerosol level dropped below 50 μg/m^3. Figure 2 depicts the operation of a real-time LED screen module seen at the air purifying station.

Figure 2 A semi-outdoor air cleaner with an onsite LED screening. PM2.5 levels were displayed on screen.

Ordering via LINE Application

The chatbot system was divided into two LINE groups, the first being the operation system, also known as the "BoonG" group. This LINE chatbot was used to send a machine code that included the words "on", "off", and "report" in both Thai and English. Within 1-5 seconds, depending on Wi-Fi stability, the chatbot was able to respond with the status of the ventilation system as well as any types of aerosol levels (CO_2, formaldehyde (HCHO), TVOC, PM2.5, PM10, temperature (0C), and percent humidity), as shown in Figure 3.

Figure 3 LINE messenger was used to send direct messages for air cleaner control.

Secondly, the reporting system, also known as the "BOONG 2021_Notify" group, was used to only report machine status and aerosol levels every 1 hour or as desired by users in the "BoonG" group. This chatbot was created for people who want to know the air quality levels in specific locations, as shown in Figure 4.

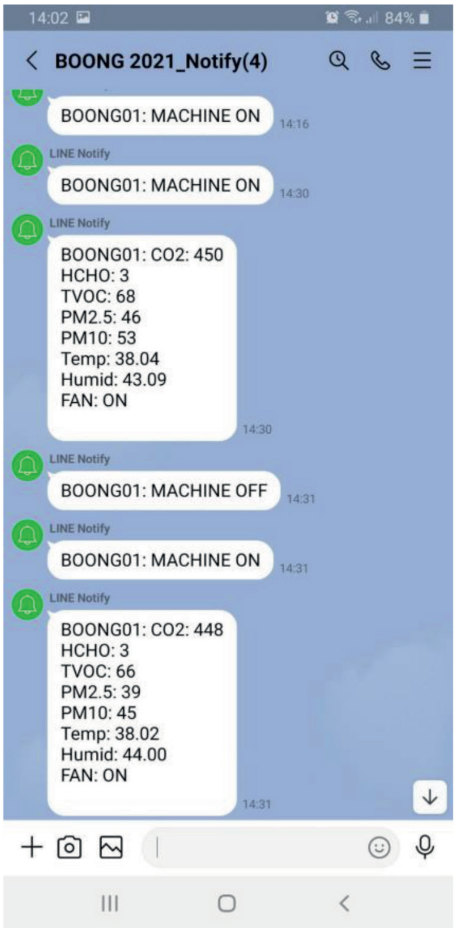

Figure 4 For multi-users, air pollution reports and machine status were available.

Discussion

This air quality IoT platform can be used to demonstrate a low-cost semi-outdoor air purifying control model. The advantages of this apparatus also include real-time air monitoring and hourly reporting via LINE chatbots. All platforms are free and suitable for many developing countries. In addition, an LED screen module is available for sharing real-time PM2.5 levels at the air ventilation site. Using a feedback loop between a microcontroller, PM2.5 levels, and a ventilation exhaust fan, the machine can limit the workload of a dual fan motor to extend its useful life. However, some issues that should be investigated further include, first and foremost, maintenance costs for a SIM card that was included with the Wi-Fi 3G system remain. Before implementing this instrument in those areas, infrastructures such as electricity and telecommunications networks must be completed. This machine should ideally be used for multi-air purifying nodes, using a grid system to collect air quality in each area in the future. Second, the IoT system should be capable of detecting or forecasting certain air conditions, such as conflagration, storm, rain, and earthquake. Third, the clear analysis of error margins, measurement accuracy, and probable causes of error in PM2.5 measurements should be done. Typical error analysis would include comparing the sensors' results to those from a reference-grade monitor under various environmental conditions. Fourth, dependability parameters such as reading consistency over time, sensor drift, and performance under various temperature and humidity conditions should be evaluated. Fifth, comparing error and reliability statistics to data from similar air quality monitoring systems is currently challenging. Finally, any information should be collected and analyzed as part of big data.

Conclusion

The semi-outdoor air cleaner integrates IoT-based air quality monitoring and fan control to manage PM2.5 and other pollutants in public spaces. The system uses an air quality sensor module (AQM-RK14V) connected to an Arduino Mega 2560 microcontroller (MCU) to measure pollutants, including CO_2, formaldehyde, TVOCs, and particulate matter (PM2.5 and PM10). Positioned at the top of the air cleaner to avoid airflow interference, the sensor continuously sends data to the MCU, which activates dual ventilating fans via a relay if PM2.5 levels exceed 50 $\mu g/m^3$. The fans automatically turn off once the air quality improves, with their speed controlled by the MCU using PWM signals. Data transmission occurs via a D-LINK 4G router and Ethernet shield, which connects the MCU to the NETPIE 2020 IoT platform through the MQTT protocol for real-time data reporting. An LED display provides PM2.5 readings onsite, while users receive updates and control options through a LINE chatbot. This chatbot, divided into two groups, allows users to control the cleaner or receive periodic air quality reports. After sensor calibration and system testing, the device is deployed in a semi-outdoor area, offering a low-cost air quality management solution. The system's automation and ease of use make it ideal for public areas affected by haze and air pollution, providing accessible real-time air quality data and automatic pollutant management to enhance public health during events like the COVID-19 pandemic. This low-cost IoT platform was created to enable prediction and protection from haze and the COVID-19 crisis. Aerosol detection and ventilation fan control are made available via multi-sensors and the LINE chatbot. All platforms are free, with the exception of a SIM card included with the Wi-Fi 3G system, which is suitable for developing countries during the haze and COVID-19 crisis.

Conflict of Interest

The author has no conflict of interest to declare.

Author Contributions

Arnon Jumlongkul created, evaluated, and drafted the text; Watchara Jamnuch designed and tested the machinery system; while Pitchayapa Jumlongkul reviewed and proofread the article.

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