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A Vehicle Monitoring System Based on the LoRa Technique

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Abstract**—**Air pollution and climate warming become more and more intensified in many areas, especially in urban areas. Environmental parameters are critical information to air pollution and weather monitoring. Thus, it is necessary to develop a suitable air pollution and weather monitoring system for urban areas. In this study, a vehicle monitoring system (VMS) based on the IoT technique is developed. Cars are selected as the research tool because it can reach a greater number of streets to collect data. The VMS can monitor different environmental parameters, including ambient temperature and humidity, and air quality parameters, including PM2.5, NO_2, CO, and O_3. The VMS can provide other information, including GPS signals and the vibration information through driving a car on the street. Different sensor modules are used to measure the parameters and collect the measured data and transmit them to a cloud server through the LoRa protocol. A user interface is used to show the sensing data storing at the cloud server. To examine the performance of the system, a researcher drove a Nissan x-trail 1998 to the area close to the Da'an District office in Taipei to collect monitoring data. The collected data are instantly shown on the user interface. The four kinds of information are provided by the interface: GPS positions, weather parameters, vehicle information, and air quality information. With the VMS, users can obtain the information regarding air quality and weather conditions when they drive their car to an urban area. Also, government agencies can make decisions on traffic planning based on the information provided by the proposed VMS.

Keywords**—**Vehicle, monitoring system, LoRa, smart city.

I. Introduction

SMART City is an important economic strategic blueprint for a country's economic transformation and upgrade. Many countries have been in the vanguard of the technological advance and initiated smart city development programs, such as the smart grids in the US and the intelligent energy management in Amsterdam [1]. In Taiwan, the Taipei City government has established "Taipei Smart City PMO (the Project Management Office)" to promote projects and be a bridge of the government and the public. These projects promote the development of smart city.

Our environment has become worse because of air pollution. The air pollutants, including PM2.5/10, carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide, are harmful to the public. To deal with serious air pollution problems, the Environmental Protection Administration, Executive Yuan, R.O.C. (Taiwan) [2] has established a system to monitor gas all over Taiwan and shows the results on a map in real time. The map is a graphical user interface which allows people to obtain information regarding gas air pollution conditions and the amount of fouling. The government agency has also established an air quality index (AQI) [2] which determines air quality conditions by using six levels, including good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous. However, the gas observation station is far from each other, which is a problem for air pollution monitoring. In this study, a VMS equipped with several sensors, such as sensors that measure PM2.5, CO, NO2, O3 and GPS, OBD-II, and temperature/humidity is proposed. With the VMS, the air quality parameters could be measured while driving a car on the street, and a wide range of areas would be monitored.

The communication of VMS is based on the LoRa technique, which is a transmission protocol controlled by LoRa Alliance™. LoRaWAN™ is a low power wide area network (LPWAN) specification which could operate things in a regional, national or global network [3]. The advantages of using the LoRa technique are low power consumption and long transmission distance. These advantages are important to the proposed VMS. On the other hand, the LoRaWAN also possesses some key elements of Internet of Things (IoT), such as localization services, mobility networking, and secure communication. The LoRaWAN specification provides an easy operating way between things without the requirement of complicated installations, and it makes users feel free to engage in IoT application. The IoT refers to the connection of devices to the Internet. Cars, house appliances, and even environmental monitors can all be connected via the IoT. When the IoT increases in the future, more devices will have connection with each other [4]. With the LoRa Alliance™, the VMS could connect to other vehicles, devices, and be a part of IoT. Finally, the VMS can also play a significant role of Smart City in the future and the architecture of VMS was introduced in the next section and shown as Fig. 1.

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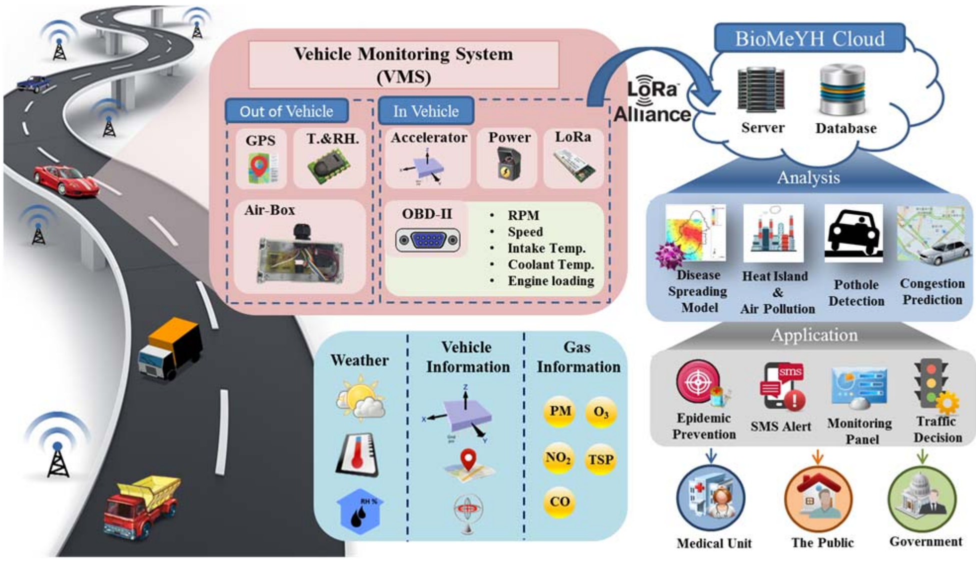


Fig. 1 The architecture of the VMS

II. Vehicle Monitoring System

A. System Architecture

The VMS not only receives traffic information instantly but also monitors air conditions on the road. The system consists of three major parts: a front-end sensor node, a gateway, and a back-end smart platform. A simple graphical user interface is also designed for users to browse the traffic information. With the VMS, users can better understand the real-time vehicle and air quality conditions on the street. And the big data collected the VMS can help government agencies make corresponding strategic decisions.

B. Moving Sensor Nodes

The functions and specifications of main hardware components designed for the proposed system are described as below.

- Vehicle-shield processor (VSP): The VSP is composed of an Arduino mega 2560 and a sensor-shield board (SSB). The Arduino mega 2560 is a microcontroller board based on the ATmega2560 which is a high performance and low power consumption Atmel® AVR® 8-Bit Microcontroller. Because a large number of sensors are employed by the VMS, a microcontroller with enough digital, analog and UART pins is selected. The Arduino mega 2560 has 54 digital input/output pins, 16 analog inputs, 4 UARTs, a 16 MHz clock speed oscillator, a USB port, a power jack, an ICSP header, and a reset button. And it can be easily connected with a computer [5]. The SSB is connected to the Arduino mega 2560. And other sensors, such as an ambient temperature/humidity sensor, a GPS sensor, a vehicle information sensor, and gas sensors can be connected to Arduino mega 2560 through SSB without pins.
- Transmission module: The transmission module in the proposed system is the GIoT Module_GL6509. The transmission module uses the Low Power Wide Area Network (LPWAN) specification. The GIoT Module_GL6509 has two bands of 868 and 915 MHz [6]. It can be adapted to different applications. And it supports AT commands, so users can operate it easily. The interface of the transmission module includes GPIO, UART, and I^{2}C, making it easy to connect with the VSP. With the advantages of low power consumption, user friendly, and wide area networking, the LoRa module is appropriate to achieve the goals of this study. The GIoT Module GL6509 is shown in Fig. 4.

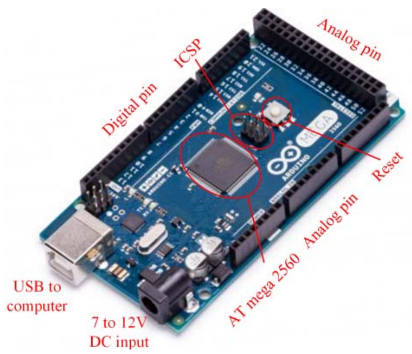


Fig. 2 Arduino mega 2560

Fig. 3 The sensor-shield board

Fig. 4 The transmission module

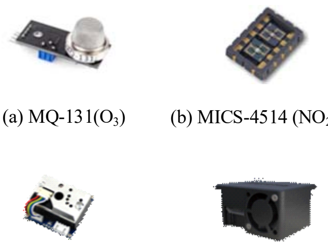
- Weather information module: In this study, ambient temperature and humidity is measured by SHT11. The SHT11 is the temperature/ relative humidity sensor from the Sensirion family. The SHT11 integrates sensor components and signal processing chips on a tiny foot print and provides a fully calibrated digital output. A unique capacitive sensor element is used for measuring relative humidity while temperature is measured by a band-gap sensor. The SHT11 are seamlessly coupled to a 14bit analog to digital converter and a serial interface circuit. This results in superior signal quality, a fast response time and insensitivity to external disturbances. The 2-wire serial interface and internal voltage regulation allows for easy and fast system integration. The tiny size and low power consumption is the reason why we choose it as the temperature and humidity sensor. The sensing ranges of SHT11 in temperature (T) and relative humidity (%RH) are from −40 to 123.8 °C and from 0 to 100 %RH, respectively, and the measurement resolutions in temperature and relative humidity are 0.01 °C and 0.05 %RH @ 25 °C, respectively. The measurement accuracy in temperature and relative humidity of SHT11 is ±0.4 °C and ±3.0 %RH. The appearance of SHT11 is shown in Fig. 5 [7].

Fig. 5 Weather information module

- Vehicle information module: The vehicle information includes information regarding the engine, intake/exhaust, speed/time, driver, and electric systems from the car. With the Freematics OBD-II (On board diagnostics II) I^2C Adapter for Arduino, the vehicle information could be easily obtained by connecting the car with the VSP through the I^2C protocol. The adapter is also equipped with the ELM327 chip which supports AT commands to obtain the corresponding information. Different protocols, such as CAN 500Kbps/29bit, CAN 250Kbps/29bit, KWP 2000 Fast, and KWP 2000 5Kpbs, are integrated with the adapter, so it can be installed on different cars. The appearance of the Freematics OBD-II I^2C adapter for Arduino is shown in Fig. 6 [8].

Fig. 6 Freematics OBD-II I^2C adapter

- Air quality sensors: The Air quality sensors used in the VMS includes MQ-131 (O_3), MICS-4514 (CO/NO_2), GP2Y10 (TSP), and OneAir A4 (PM). The MQ-131 is shown in Fig. 7 (a). It has advantages of fast responses, high sensitivity, stable and long life, simplified drive circuits, and a wide detection range, and is suitable for monitoring O_3. The detection range is 10 ppb-2 ppm [9]. The MICS-4514 is shown in Fig. 7 (b). It is a robust MEMS sensor responsible for the detection of the pollution from automobile exhausts. The detection range for carbon monoxide is from 1 to 1000 ppm and for nitrogen dioxide is from 0.05 to 10 ppm [10]. The GP2Y10 is shown in Fig. 7 (c). This sensor is a dust sensor operated by an optical sensing system. The sensor detects the reflected light of dust in the air. It is effective to detect very fine particles and can be used as an air quality monitor [11]. The OneAir A4 is shown in Fig. 7 (d), which is a PM 0.3/2.5/10 sensor. The sensor operates following the principle of a laser scattering theory. In the air, the suspend particle in the air will be scattered by laser irradiation. The scattered light is collected at a specific angle to obtain the information of the scattering intensity over time. The measuring range is 0−6000 μg/m³ and the operating temperature is −10 to 50 °C. With these sensors, gas which causes air pollution can be monitored in real time [12].



(a) MQ-131(O_3) (b) MICS-4514 (NO_2、CO_2)

(c) GP2Y10 (TSP) (d) OneAir A4(PM2.5/10)

Fig. 7 Gas sensors used in this study

- GPS module: The GPS module is equipped with the Ublox NEO-7M chip. The horizontal localization accuracy is 2.5 m and the sensitivity is −161 dBm when tracking and navigation are performed. It takes 28 seconds for the module to initiate a cold/warm start. The appearance of the GPS module is shown in Fig. 8 [13].

Fig. 8 GPS module

C. LoRa Gateway and Graphical User Interface

The data obtained by the sensors mentioned earlier are transmitted to a LoRa gateway via the LoRa transmission module. LoRa gateways are installed at each district in Taipei City by the Taipei City Government. The LoRa gateway has some limitations. For example, only one packet can be sent per minute, and each packet only contains data up to 11bytes. The data transmission in this study is therefore arranged accordingly. The distribution of the LoRa gateways is shown in Fig. 9.

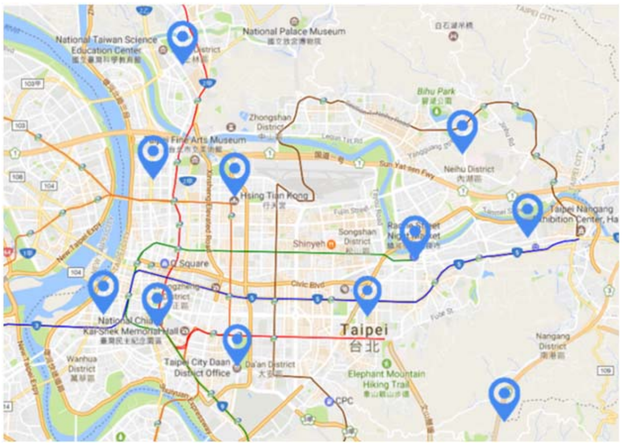


Fig. 9 The distribution of the LoRa gateways

After a packet is sent to the LoRa gateway, the gateway will upload the data to a back-end database. The monitoring information will exhibit on an IBM Bluemix platform through the MQTT protocol. The platform is designed as a graphical user interface, which is shown in Fig. 10. The interface is divided into four major parts: weather information, GPS localization, vehicle information, and air quality. This interface allows users to easily obtain air quality information from the website [14].

D. Operation Scheme of the VMS

The operation procedure of the VMS is presented in Fig. 11. In the beginning, the system waits for a few seconds to start up the GPS module. The GPS module provides the results of localization after warming up. After having the localization information, the system connects to the car, and it takes 3-5 seconds for the connection. Different AT commands will send to the MCU on the car to request the sensors to measure different parameters including car speed, rotational speed, intake temperature, and coolant temperature. And then the gas sensors measure different parameters, such as O_3, CO, NO_2, TSP, and PM. The raw monitoring data are transformed into a bit type to form a data packet. The transmission type of the LoRa module is hex, so it is necessary to transform the data packet from bit to hex. Then, the data packet is sent to the LoRa gateway by the LoRa transmission module. When the data packet is successfully sent to the back-end database, the monitoring information will be displayed on the graphical user interface for users to browse. The location information of the car will update every 70 seconds.

Fig. 10 Graphical user interface

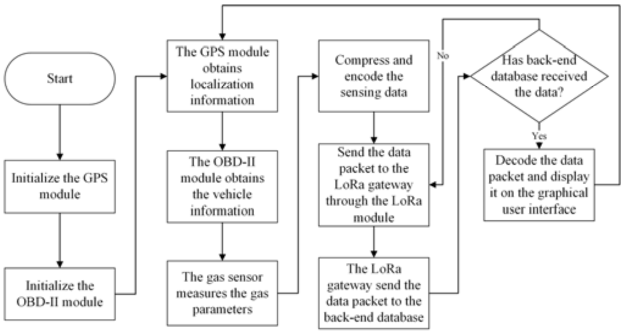


Fig. 11 The flowchart of the proposed monitoring system

III. Experimental Results and Discussion

A. Air Quality Estimation

The air quality is critical to the environment and the public. And the air quality is always influenced by the amount of PM2.5, NO_2, CO, and O_3. As a result, it is necessary to develop a system that could obtain the gas readings from different sensors. In this paper, the process to obtain O3 readings from the O3 sensor serves as an example for performing air quality estimation. In the air quality estimation stage, we take the procedures and methods in [15]-[19] as consideration.

To obtain O_3 readings from the sensor, in the beginning, a sealed bag filled with different concentration levels of the O_3 standard gas. Each gas concentration test lasted for 10 minutes. Between the two tests, the gas filled in the prior test would be extracted out as much as possible. The tested concentration level of O_3 was 0, 100, 200, 300, and 400 ppb. The device using in the experiment is shown in Fig. 12. The flowchart of the O_3 experiment is shown in Fig. 13.

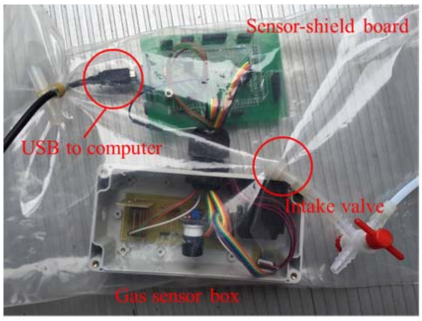


Fig. 12 The device used in the gas experiment

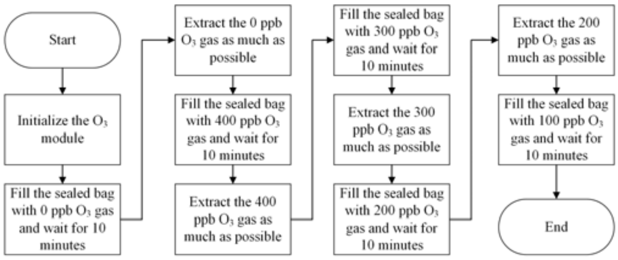


Fig. 13 The flowchart of the O_3 experiment

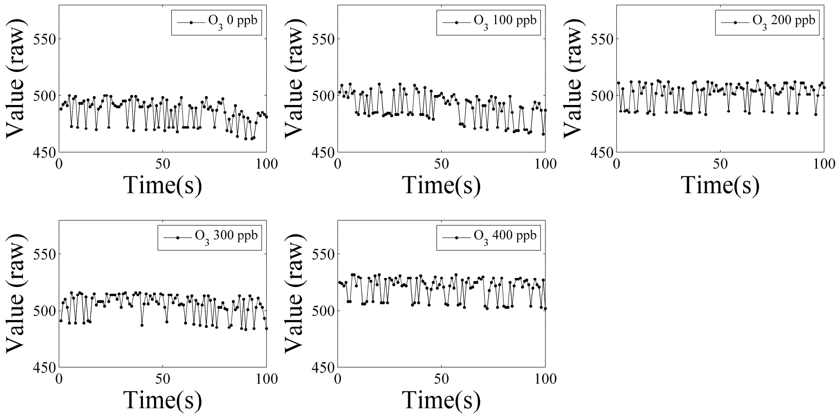


Fig. 14 The results of employing different concentration levels of O_3

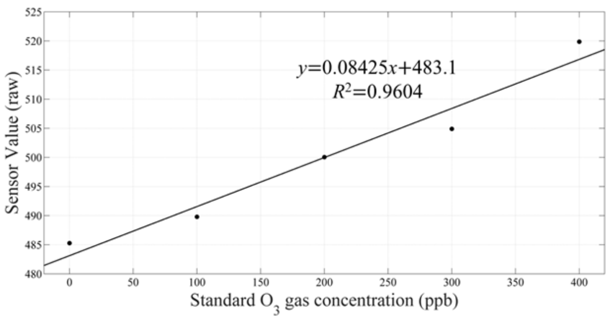


Fig. 15 The scatter of O_3 concentration

As shown in Fig. 14, the raw data obtained from the O_3 sensor often fall into certain areas. As a result, the raw data can be transferred into corresponding readings. The areas of the concentration can be used in the transferring. For example, the average the value of an area can represent the corresponding concentration. Then, the O_3 concentrations can be plotted as shown in Fig. 15. The x-axis is the standard O_3 gas concentration (ppb). The y-axis is the raw data of the sensor readings (raw). An important transfer formula can be established after plotting the concentrations. And the formula is shown as (1):

$$y = p_1 x + p_2 \tag{1}$$

Then, x is denoted as the O_3 reading from the sensor, y is the standard O_3 concentration, and p1 and p2 are the coefficients in the formula. When a new reading is obtained from the sensor, we it will be transferred into a corresponding concentration through the formula.

B. The Testing of the Receiving Rate of the LoRa Transmission Module

To evaluate the performance of the transmission module used by the VMS, a car (Nissan X-trail 1998) was driven around the Da'an District office in Taipei and tested the packet receiving rate. A LoRa gateway was located close to the Da'an District office. The tested distance between the car and the gateway was 0 m (at the Da'an District office), 200 m, 400 m, 600 m, and 800 m. The driving route is shown in Fig. 16. And at each location, the test lasted for 10 minutes. The formula of calculating the packet received rate is shown in (2):

$$R = \frac{P_{received}}{P_{sent}} \times 100\% \tag{2}$$

$P_{recieved}$ is the amount of data packets in the database, the P_{sent} is the amount of data packet sent from the sensor node, and the R is the packet receiving rate (%) of the LoRa module. The test results are shown in Fig. 16.

Fig. 16 The route of the LoRa performance test

As shown in Fig. 17, a 100% packet receiving rate is found when the distance between the gateway and the sensor node is 0 m (at Da'an District office) and 200 m. And the packet receiving rate declines when the sensor node is away from the Da'an District office. It is noted that only a few LoRa Gateways are deployed in Taipei City. The monitoring coverage will greatly increase, if the number of deployed LoRa gateways increases.

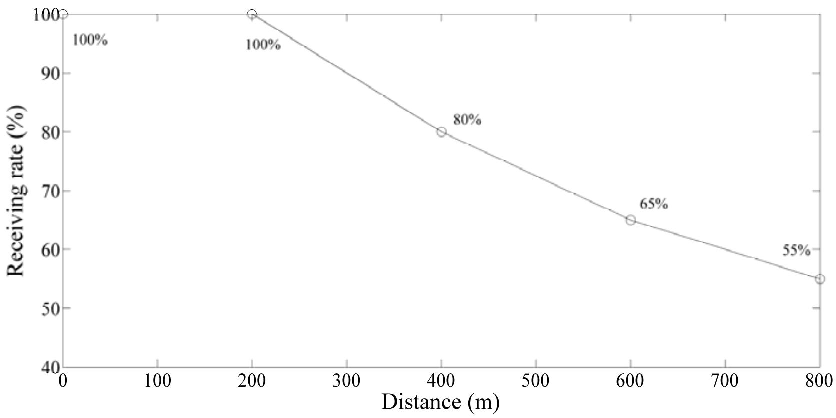


Fig. 17 The packet receiving rate of the LoRa module

IV. Conclusion

The VMS proposed by this paper could not only obtain vehicle information via OBD-II but also collect gas information through different gas sensor modules. Moreover, the GPS module helps drivers locate their car on the street. And all of the data would be gathered and presented in a graphical user interface from users to browse the information. Besides, the data could also be provided to the government to make corresponding decisions.

The idea of Smart City has been widely discussed nowadays. One of important issues for Smart City is the selection of data transmission methods. And the LoRa technique is a good option, because of its advantages of long distance transmission and low power consumption. If more LoRa gateways are widely deployed in the city, the sensed data sent from the sensor module would be transmitted much more stable. Therefore, the proposed VMS will play an important role in the promotion of Smart City.

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