Cloud-Based In-Vehicle Air Quality Monitoring System with GSM Module

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***Abstract*—The purpose of this study is to develop a monitoring system that not limited to real-time vehicle tracking, but also with the ability to monitor in-vehicle air quality. In vehicle air quality is referred to indoor air quality (IAQ) inside the vehicle cabin which is lacked of awareness among driver nowadays. Previous research indicates that human spend up to 90% of their daily time inside the closed circulated air environment including, the vehicle. Prolonged use of air recirculation inside the vehicle cabin can lead to a gradual accumulation of carbon dioxide (CO_2) which may occur the symptoms such as fatigue, headaches, and dizziness even deleterious effects on cognitive function towards the occupants. Vehicle cabin is an enclosed environment to prevent the outdoor air directly flow inside the vehicle cabin. However, when the vehicle speed increases the air pressure will be applied onto the joint of the car body and created some leakages then the outdoor air can flow into the cabin then may change the IAQ. A Global System for Mobile (GSM) communications module is utilised as a proxy to push the aggregated information such as real-time vehicle location, IAQ status and timestamps into the cloud database with an iteration of the 30s. The average time delayed for data to reach the cloud database is approximate 3.6s from the time it transmitted. Through the Android mobile application, the user can observe the in-vehicle air quality with the current location in two optional modes: real-time or historical data. The developed device and system were compared with off the shelf device (AeroQual). The Bland-Altman plot method was applied to validate the result of in-vehicle air quality system. The coefficient of determination (R^2) value between these two devices is approximately 0.9. The in-vehicle air quality with vehicle tracking system has been successfully developed and provided a reliable result.**

***Index Terms*—Carbon Dioxide (CO_2); Cloud-Based; GSM module; Real-Time Monitoring**

I. INTRODUCTION

The in-vehicle monitoring system (IVMS) usually combines a series of electronic sensors for the purpose of tracing, evaluating, recording and reporting on vehicle activity as well as monitoring the driver's behaviour [1,2]. GPS application has been widespread commonly attached on IVMS for the modern vehicle tracking system to keep a record of the vehicle travelled location or navigate the user to the final destination. Basically, IVMS could be classified into passive and active system. The passive system uses an internal data logger such as SD card to store all the information. To review back the historical data the user or third party need to download the recorded data manually. On the other hand, the active system using communication modules to update the data in the cloud database automatically. However, the transmission rate between the communication modules and cloud database for the active system depends on the types of the communication protocol being implemented.

Besides that, the IVMS could provide useful data as a feedback to the researchers and allowed them to observe and manipulate the in-vehicle condition. One of the application used IVMS concept, namely, the invention of automatically control Heating, Ventilation and Air Conditioning (HVAC) system inside the vehicles is to provide an adequate comfort level, since, all factors that may affect the thermal environment had been controlled. Packard [3] has introduced the first HVAC service into cars in the late 1930s, and continue to supply the service into every single new-generation vehicle [4]. This ventilation system allows the user to control the temperature inside the vehicle cabin that suits their need by adjusting the fan speed. Nowadays, the HVAC ventilation system has two additional functions which are recirculation (RC) and the outside air (OSA) modes. Switching the HVAC system into OSA mode could draw in the hazardous particulate pollutant from the outdoor environment, for instance, carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NO) and particulate matter ($PM_{2.5}$ & PM_{10}) [5–9]. Generally, drivers may prefer to trigger the RC ventilation mode to prevent the outdoor air pollutant flow into the vehicle cabin and degraded the air quality inside the vehicle cabin.

The technology of HVAC system with RC mode has the ability to reduce the compressor load [10,11] which can fulfill the criteria of car manufacturers in bringing the vehicle's technology into a Green Economy. Nonetheless, metabolic process of the human will produce CO_2 into the environment and the process is known as human bio-effluent [12]. Therefore, the concentration of CO_2 inside the cabin will increase gradually while drivers applied the RC ventilation setting for a prolonged time. This phenomenon happened due to lack of air exchange rate between the air inside the vehicle cabin and outdoor [13].

The American Automobile Association (AAA) Foundation for Traffic Safety estimates that one out of every six deadly traffic accidents, and one out of eight crashes requiring hospitalisation of car drivers or passengers are due to drowsy drivers [14]. By increasing the number of occupants in the vehicle, the concentration level of CO_2 will increase significantly. This hypothesis has been proven by previous research and experiments [15]. The high-level concentration of CO_2 compared to the oxygen (O_2) in the cabin will cause negative impacts on the occupant's health that drives lead to the fatigue, drowsiness and slow in the reaction of action. The Department of Occupational Safety and Health (DOSH) Malaysia has stated that CO_2 is used as an indicator parameter for measuring the ventilation performance, and the CO_2 concentration should be controlled below 1,000 ppm [16].

Prior studies found that the CO_2 concentration below 2% (20,000 ppm) [17,18] is not immediately life-threatening. However, it has some significant effects toward the cognitive performance in the human subject. Generally, the researchers have the similar objective to conduct a series of experiments on cognitive performance on the different level of CO_2 concentration. At this current state, all the assessment on human cognitive performance research was done inside the building. The study level of the concentration is ranging from 500 – 3,000 ppm and the minimum duration of the experiment is 210 minutes. The human subject exposes to the CO_2 concentration greater than 2,500 ppm inside enclosed environment should lead the human to lost in attention [12,19]. The prolonged expose under high concentration of CO_2 (1,400 ppm) would affect the human cognitive performance significantly compared to 100% outdoor air ventilation and the moderate CO_2 (~ 945 ppm) condition [20].

Furthermore, the indoor air quality monitoring device diversification expanded in the market, but most of the devices are not suitable for in-vehicle air quality monitoring. This is due to the communication protocol applied in the commercials product such as WiFi [21], Bluetooth [22] and ZigBee [23], which has limited coverage distance and its dependent on the base device to complete the transmission. There is still a limited cloud-based device that dedicated to measuring the level of air quality inside the vehicle cabin with gathering the GPS and the vehicle speed. System integration between the GPS and air quality monitoring inside the vehicle cabin provided a clear image on the relationships between vehicle speed and in-vehicle air quality. In this project, a high-performance and low-power ATMEGA1280-16AU microcontroller [24] was selected as a brain to this system. The function of this microcontroller is to control the peripherals automatically as well as sampling the sensors data in every 30s. Besides that, the sensors data were aggregated into a string for the prevention of data loss the string would append into local memory card before it pushed to the cloud. A developed Android mobile application has the functionality to allow the user to receive the current parameters or review back the historical data for this system.

II. System Design

IVMS development board will focus on integrating the low costs GPS tracking module (SIM808) with the air quality sensor such as CO_2, $PM_{2.5}$ and PM_{10}. Mainly there are three separate parts to implement in this project: the hardware development (sensor board), the database (cloud-based) and the software development (mobile application). The microcontroller aggregates the data in every 30 seconds as one iteration. Then, by executing the HTTP request function in the Global System for Mobile (GSM) module, the aggregated data will be transmitted to the cloud database. When the cloud database successfully received the aggregated data, next, the PHP script as the server handler will process the incoming data and organised the information into a respective table and columns. Simultaneously, the mobile application has the ability to present the real-time data and recall the historical data. The general flow of interleave scenarios can be explaining from Figure 1.

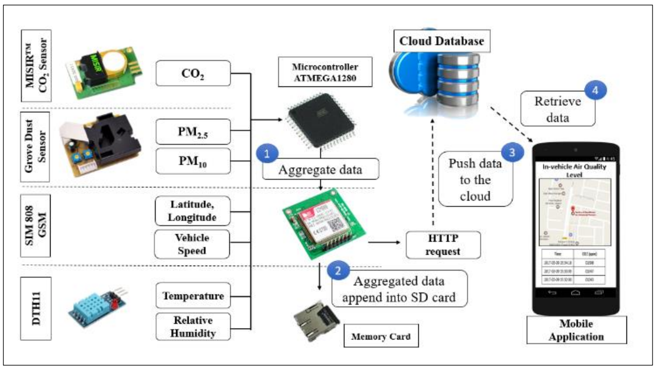


Figure 1: In-vehicle air quality monitoring architecture design.

A. Hardware Development

The developed system is a microcontroller board using the Arduino MEGA bootloader. This designed interface is customised for in-vehicle air quality monitoring as illustrated in Figure 2. It contains SIM808, Grove dust sensor, MISIR CO_2 sensor, DTH11 sensor and micro SD slot that operated in digital form. In order to make this system compatible with all types of vehicle, input voltage designed from 12V up to 36V in range. Then, the developed board can be powered up through car adaptor charger or directly from battery power supply.

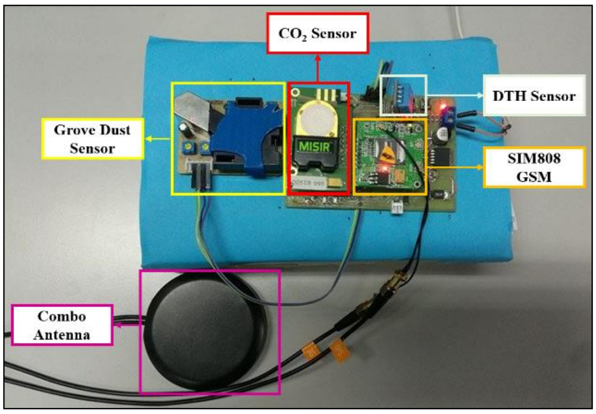


Figure 2: Prototype of the designed interface

The communication modules SIM808 module is allowed to track the current location of the vehicle and push the collected data along the Coordinate Universal Time (UTC) timestamps into the cloud database. For part of air quality sensor modules, namely, the Grove dust sensor was chosen as sampling the $PM_{2.5}$ & PM_{10} because of its low cost and general dependability and durability, followed by the MISIR that has produced a high performance and low power CO_2 sensor as low as 20mW. MIRIS offer 0–5,000 ppm measuring range as well as this sensor has provided the automatic self-calibration feature. The ambient sensor module DHT11 is a low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermostat to measure the surrounding air and output digital values of temperature and humidity to the microcontroller. The developed board presents in full operation mode an average current of 45 mA at 12 V, including an ambient sensor, CO_2 sensor, dust sensor, vehicle tracking system, electronics interface and microcontroller. Furthermore, the microcontroller algorithm presented in the flowchart as illustrated in Figure 3.

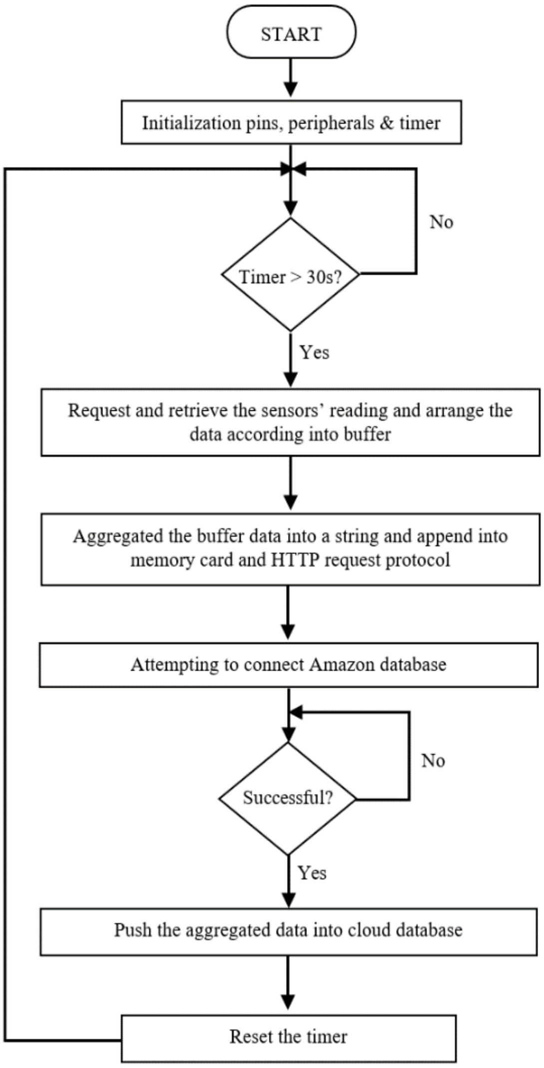


Figure 3: Flowchart of microcontroller algorithm

B. Cloud Database

In every 30 seconds, the device will push the aggregated information to the cloud database. When the database server has detected a new aggregated data entry, a PHP script as server handler will be invoked. The PHP script would retrieve the aggregated data from Uniform Resource Locator (URL) and perform an insert action to certain table and columns inside the database. If the submission is successful, the server should return an 'OK' as acknowledge message. Besides that, the server handler not only has to process the information but also need to convert the time zone. This is due to the GSM communications module is interpreting the timestamp in UTC. Malaysia Time is 8 hours ahead of UTC. The flow to handle the incoming aggregated data from the device is presented in pseudocode as shown in Table 1.

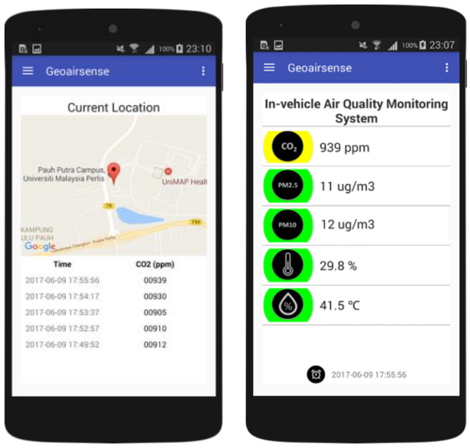
C. Software Development

The level of hazardous gases inside the vehicle cabin should monitor frequently due to the cabin is an enclosed environment. When the hazardous gases concentration accumulated to a certain level, the mild effect on occupants can grow the feeling of fatigue that might disturb driving focus. This situation may danger others road user and occupants themselves. Software development was an important interface that process and present data into a readable form to the user. The data and timestamps from database retrieved and display according to their suitable forms like coordinate to Google map and sensors value to colour code based on their concentration level. There is two type of interfaces have developed: web and mobile application as illustrated in Figure 4.

Table 1
Pseudocode for database handler

Pseudocode to Handle the Aggregated Data from the Device

```
START
    INITIALIZE buffer to empty string
    INITIALIZE RTC variable to 0
    Read input from HTTP GET
    Insert the input into buffer
    IF buffer not equal to empty string variable
        Convert the Coordinated Universal Time (UTC) zone to
         Malaysia time zone (+0800)
        Separate and insert the aggregated data according to
         buffer name
        Insert new row into an existing table and insert the
         separated buffer values based on columns name
        Return TRUE if values successfully insert; else return
         FALSE
            IF the return value equal to TRUE
                Print OK
            ELSE
                Print FAILED TO INSERT VALUES
    ELSE
        Print ERROR OCCURRED
END
```



(a) (b)

Figure 4: The mobile application interface has displayed the real-time data. (a) The real-time data was presented in the form of Google Maps. (b) The latest data was presented with the colour indicator.

The mobile application has been constructed based on Android platform. After user launches the mobile app, top left of the screen displayed an icon which is a sidebar menu. The selection of tab is allowed a mobile app to display the real-time or historical data. As shown in Table 2, the colour indicator feature is to convenience the user when identifying the status of the in-vehicle air quality.

Table 2
Colour indicator to represent the level of air quality in mobile application

Sensors	Colour	Status	Level
CO_2	Green	Good	0-700 ppm
	Yellow	Moderate	701-1200
	Red	Bad	1201 and above
PM_{10}	Green	Good	0-20 µg/m^3
	Yellow	Moderate	21 - 50 µg/m^3
	Red	Bad	51 -150 µg/m^3
$PM_{2.5}$	Green	Good	0 - 10 µg/m^3
	Yellow	Moderate	11 – 25 µg/m^3
	Red	Bad	25 µg/m^3 and above

III. Results and Discussions

The cloud-based in-vehicle air quality monitoring system with GSM module was focused in two aspects, namely, the time taken to push the aggregated data into the cloud database and make an analysis between the developed board and the established portable gas sensor (AeroQual, Series-500) [25] by applying Bland-Altman analysis**.** Noted that, the particulate matter $PM_{2.5}$ and PM_{10} do not have a significant reading in this paper. This is due to the particulate matter sensor act as an indicator to observe and make sure the experiments were conducted inside the vehicle cabin with the cabin ventilation setting triggered on the recirculation mode and all windows were tightly closed. By the time server received data from GSM communication modules, there are have an average of 3.6 seconds difference with the time that the system acquires data from GPS, as illustrated in Table 3. The smallest time difference recorded inside the database means the developed system has the low latency between the communication module and the server will favourably for the user to view the in-vehicle air quality in real-time.

Table 3
Difference time between collected data and server received data

Server Time	RTC GSM	Time Difference (s)
5:55:59 PM	5:55:56 PM	3
5:54:19 PM	5:54:17 PM	2
5:53:40 PM	5:53:37 PM	3
5:53:00 PM	5:52:57 PM	3
5:49:57 PM	5:49:52 PM	5
5:34:42 PM	5:34:39 PM	3
5:33:59 PM	5:33:55 PM	4
5:33:16 PM	5:33:13 PM	3
5:26:32 PM	5:26:27 PM	5
5:25:50 PM	5:25:45 PM	5
	Average	3.6

The graph in Figure 5(a) and 6(a) have illustrated two positive correlation between AeroQual and developed device towards the conducted condition, namely, constant speed (supervised) and real-time traffic condition (unsupervised). The comparison between both tested conditions for the supervised and unsupervised have the coefficient of determination (R^2) value of 0.9758 and 0.9135, respectively. There are strong of the linear relationships between the developed device and off the shelf device.

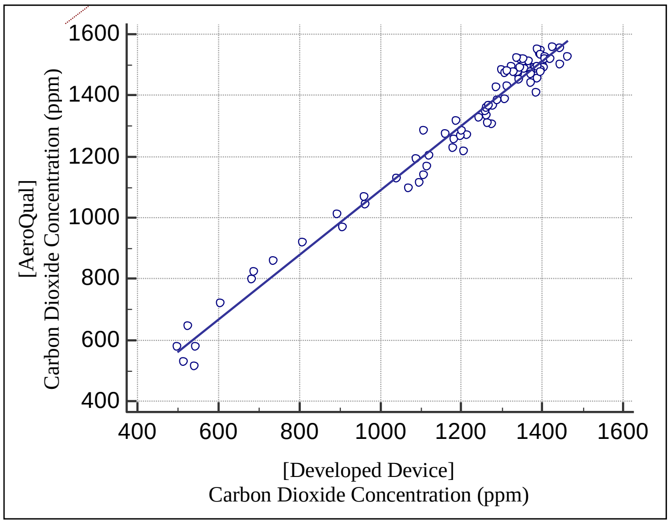


Figure 5(a): The constant speed relation between the established device and the developed device is presented in a scatter diagram.

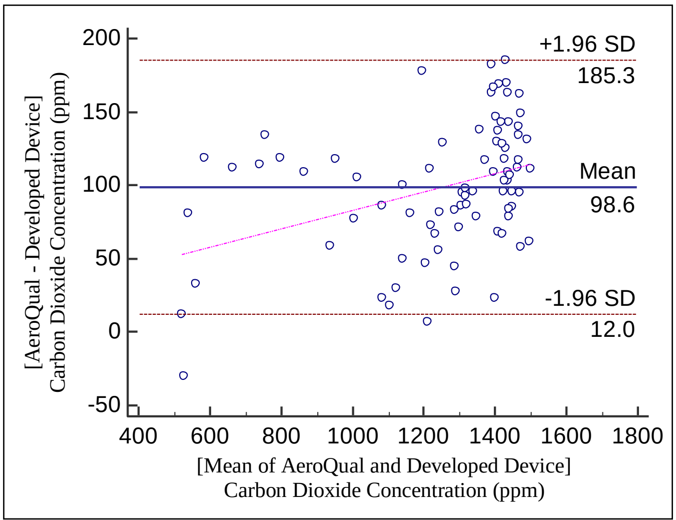


Figure 5(b): The Bland-Altman plots for the constant speed.

Moreover, the Bland-Altman plot as illustrated in Figure 5(b) and 6(b) is one of the effective ways to validate the two measurements techniques by combined graphical and statistical interpretation [26], [27]. The 95% limits of agreement (LOA) reflect all the collected data differences between measurements are projected to plot. The LOA lower and upper limits for supervised speed condition were 185.3 and 12.0, respectively. While the LOA for the unsupervised condition are found as -259.2 and 52.7 for the lower and upper limits, respectively. The significant finding in this research is that the results for the supervised condition have a higher R^2 value compared to the unsupervised result. This can be explained that the vehicle speed is one of the factors will be changed the status of IAQ inside the vehicle cabin. Higher the vehicle speed the larger pressure created against the vehicle's body and so created some leakages between the joint. The outdoor air can flow into the cabin through those leakages. Thus, the fresh air exchange rate for higher vehicle speed will be greater than that of lower vehicle speed [28].

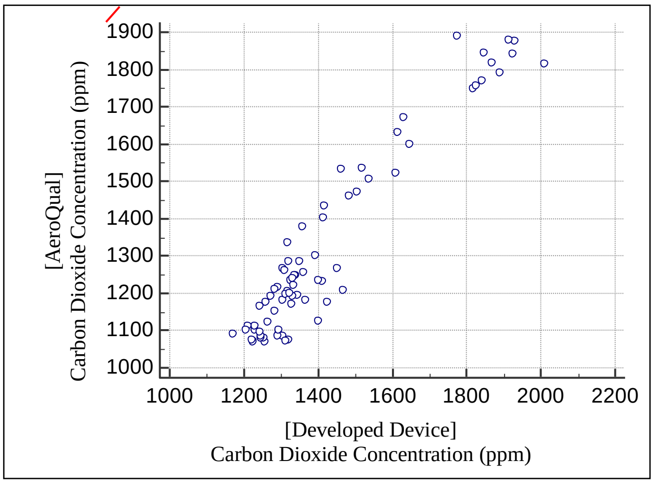


Figure 6(a): The real-time traffic condition relation between the established device and the developed device is presented in a scatter diagram.

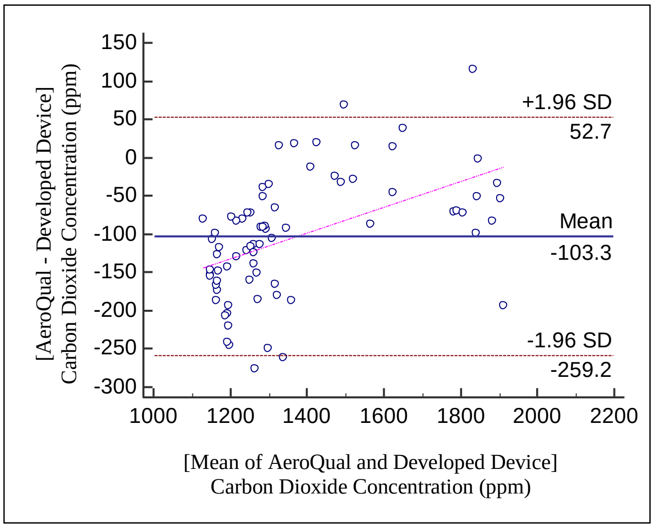


Figure 6(b): The Bland-Altman plots for the real-time traffic condition.

IV. CONCLUSION

The overall system of in-vehicle air quality has been successfully integrated with ambient sensor, CO_2 sensor, dust sensor and vehicle tracking system. The full operation mode in this system has an average current of 45 mA at 12 V. For monitoring purpose, an Android-based mobile application has been developed which allowed users to monitor and review the historical data of air quality inside the vehicle cabin in real-time. The general performance of the system is tested using the Bland-Altman statistical analysis model to validate the current system with AeroQual established commercial data logger. The coefficient of determination (R^2) for the supervised and the unsupervised vehicle speeds tested in recirculation (RC) ventilation condition were 0.9758 and 0.9135, respectively. The closer R^2 value to 1 means that the closer reliability reading from developed device to the established device.

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