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DEVELOPMENT OF PORTABLE AIR POLLUTION ALARMING DEVICE

Su-Chak Ryu, Keon-Oh Shim, Dong-Hun Lee, * Sung-Kwang Jo

Department of Nanomechatronics Engineering, Pusan National University, 46241, Korea.

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ABSTRACT

This study attempts to develop an air pollution alarming device that can simultaneously detect and warn against harmful substances by replacing oxygen sensors with volatile organic compound (VOC) sensors that can detect pollution in real time. A prototype is designed using a 3D printer and Arduino platform with an applied algorithm that sounds an alarm when dangerous levels are reached. A small closed chamber is manufactured in the laboratory to perform this function, and VOC and oxygen sensors are installed to perform the combustion experiment. The experimental results establish that oxygen is consistently reduced from 21% to 17% whereas the VOCs increase. The eCO2 concentration increases from 400 to 43,069 ppm, and the total VOC (TVOC) increases from 0 to 37,194 ppb. At an O2 level of 17.6%, representing a lack of O2, the points of overlap for the TVOC, eCO2, and O2 curves correspond to eCO2 and TVOC concentrations of 12,289 and 1,542 ppb, respectively. The concentrations of O2 and VOCs are observed to be inversely proportional, and the intersections of the risk level curves for VOCs and O2 are determined.

Keywords: Air quality, Arduino, Alarm system, Drowsy driving Indoor environment.

INTRODUCTION

The interior of an automobile is a closed environment that can cause drowsiness owing to various factors, such as harmful substances, lack of oxygen (O_2), and carbon dioxide (CO_2) poisoning. Data from the Korea Expressway Corporation indicate that approximately 70% of 1035 highway traffic deaths over the past five years (2015–2019) were caused by drowsiness and lack of attention. Drowsy driving manifests in various ways, including individual fatigue, vibration, noise, and decreased attention; however, it is mainly caused when individual mistakes and environmental risk factors overlap [1, 2]. Suppose that a driver continues to breathe for an extended period in a closed-vehicle environment. In this case, the O_2 concentration decreases, and the CO_2 concentration increases, resulting in fatigue of the central nervous system and, ultimately, drowsiness. In the case of long-distance driving, the driver must breathe in a closed space and drive for a long time; therefore, the driver is constantly exposed to the risk of drowsiness caused by the lack of O_2 in automobiles. In addition to the abundance of CO_2 and lack of O_2, the presence of volatile organic compounds (VOCs) in the breath of drives can cause headaches and dizziness, leading to fatal accidents due to periods of drowsiness. Therefore, the continuous monitoring of the atmospheric environment inside automobiles is necessary. Previous studies on the detection and prevention of drowsy driving have included the detection of CO_2 along with drowsy driving through the facial recognition of drivers and biosignals from electromyography and electrocardiogram data [4, 5]. In addition, cognitive distraction of drivers and detection of drowsy driving have been studied using visual information [6]. However, these methods have practical limitations related to cost [7]. These studies also face a cost problem for commercialization, and these technologies are likely to be introduced in recently manufactured vehicles with high precision through repeat learning. They are limited to being utilized in existing commercialized vehicles; hence, this study focuses on cost and efficiency, and applicability to existing commercial or old vehicles.

***Corresponding Author: Sung-Kwang Jo,**
Department of Nanomechatronics Engineering, Pusan National University, 46241, Korea.

Therefore, we fabricated a prototype alarm with lower costs that could detect a risk level that could affect driving before drowsy driving. In addition, MOX sensors suitable for monitoring the interior environments of automobiles were utilized rather than O_2 sensors for exhaust gases mounted outside the car to measure the air quality of the indoor environment of the automobiles. Automobiles are generally equipped with air conditioners such as heating, ventilation, and air conditioning (HVAC), for passengers. This HVAC system has an outdoor-to-internal recirculation system in which outdoor air is introduced and operates at the driver's discretion. In this case, it remains in the outside air or internal circulation unless the driver intentionally manipulates the function. If a driver drives for a long time without opening the window, oxygen is consumed by the passenger's breath, resulting in drowsiness, fatigue, and headaches.

To solve this problem, controlled car interior environment systems (carbon dioxide, oxygen, hazardous substances, etc.) have been considered. In this study, a 3D printer was utilized and an Arduino air pollution detector was fabricated to comprehensively measure and alert against harmful substances and O_2 deficiency to prevent automobile accidents resulting from unsatisfactory indoor conditions.

EXPERIMENT

O_2/VOCs/CO_2 Hazard Levels

The presence of VOCs results in the generation of photochemical smog through the production of photochemical oxidants (e.g., ozone and pan) from liquid or gaseous organic compounds that evaporate easily into the atmosphere owing to their low boiling points. VOCs comprise thousands of substances, including approximately 900 in indoor environments [8]. According to Article 2, Paragraph 10, of the Air Environment Conservation Act, 37 VOCs are subject to management in Korea. Substances corresponding to VOCs have different reference standards, depending on their risk. However, because it is inefficient to measure the concentrations of thousands of compounds individually, combining these substances into total VOC (TVOC) measurements without distinguishing between the different types of VOC is more practical [9]. The TVOC measures the sum of all VOCs and is an important indicator of the overall air quality. It is recommended that TVOCs should be maintained at 500 ppb or lower in indoor environments [10]. Table 1 presents the impact of the TVOC concentration on human health [11].

Table 1. Impact of TVOC concentration on human health

Level	Hygienic Rating	Recommendation	TVOC concentration[ppb]
1	No Objections	Target value	0-60
2	No relevant Objections	Intensified Ventilation/airing Necessary	60-200
3	Some Objections	Search for Sources Intensified	200-600
4	Major Objections	Ventilation and airing Recommended	600-2000
5	Situation not acceptable	Utilize only if unavoidable intense ventilation is necessary	2000-5000

O_2 concentration is another important factor affecting air quality. The O_2 saturation in air is nearly 21%, and O_2 deficiency in confined spaces generally refers to O_2 levels of less than 18%. If the concentration of O_2 decreases to less than 18%, serious effects, such as headaches and nausea, can occur in the human body. CO_2 concentrations above 2000 ppm generally have harmful effects on the human body, such as drowsiness, dizziness, and decreased concentrations. Tables 2 and 3 [12, 13] present the effects on the human body from CO_2 and O_2 concentrations in a closed space.

Table 2. O_2 concentration impact on human on health.

O_2 concentration	Description/Effects
21%	Normal State
18%	Safety State, but Continuous Ventilation is required
16%	Increased Respiratory Pulse, Headache, Nausea, Vomiting
12%	Dizziness, Vomiting, Muscle Weakness, Weight Loss, Falling
10%	Facial pallor, Unconsciousness, Vomiting
8%	Death within 7-8 min of fainting
6%	Confusion, Respiratory Arrest, Convulsions, Death in 6 min

Table 3. CO_2 concentration impact on human health.

CO_2 concentration	Description/Effects
250-350%	Normal outdoor air level
350-1000	Normal air level in a room with good air circulation
1000-5000	Possible headaches, Drowsiness, Loss of Attention, Increased heart rate, Slight Nausea
>5000	Abnormal outdoor air level; possible toxicity and O_2 deficiency; exposure limit allowed for daily workplace exposure

Experiment Design

Various factors can affect drowsy driving, such as VOC, CO_2, and O_2 in car interiors. In the case of factors detected selectively, the device costs more, and the size of the device increases. The device was designed for the prevention of drowsiness rather than the exact point of drowsiness. Therefore, a sensor was considered for the measurement of the integrated organic compounds. Because the device is intended for long-term driving, the sensor must operate at low power, and temperature and humidity can affect the driver and sensor in car interior environments. A measurement system was set up to measure O_2 and TVOC in a confined chamber. The air quality inside the confined chamber was first checked with an OLED, and the data were collected and processed on a PC. In terms of the configuration of the measurement system, an expandable Arduino UNOR3 (Arduino UNO R3) equipped with an ATmega328 microcontroller (MCU) was used for data processing and control. Fig. 1 illustrates the overall experimental configuration. To measure the VOCs and O_2 inside the confined chamber, VOC (Sensirion AG, Stäfa, Switzerland) and O_2 sensors (LOX-02-S, SST Sensing Ltd., Coatbridge, UK) were used, respectively.

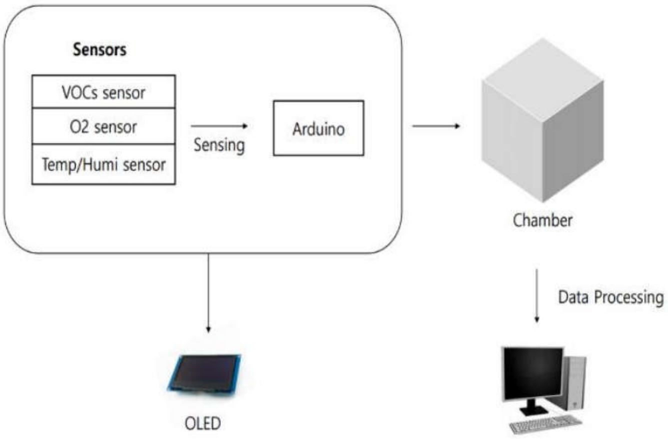

Fig. 1. Experiment configuration

Chamber Experiment Results

The experiments were repeated 60 times in a confined chamber. Because differences can result from the measured values depending on the laboratory's air concentration and atmospheric conditions, outliers were removed, and the collected data were averaged. The initial O_2 concentration in the confined chamber was between 21% and 22%, and the initial concentrations of SGP30 were set to eCO_2 at 400 ppm and 0 ppm. The candles were placed in the confined chamber and extinguished within an average of 4–6 min. The measurement results for the closed chamber shown in Fig 2 and Fig 3.

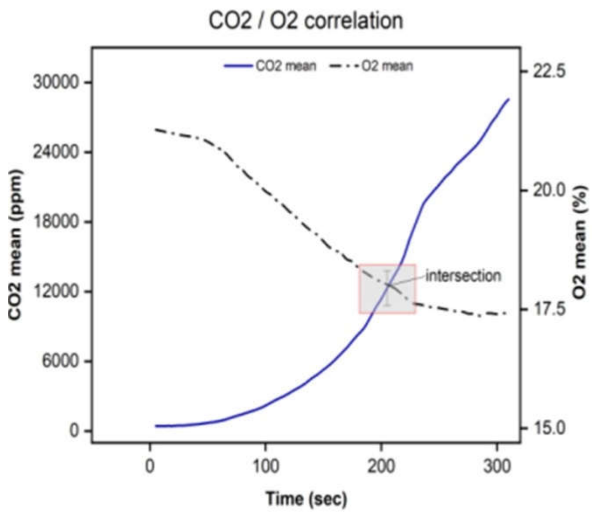

Fig. 2. Correlation between O_2 and CO_2

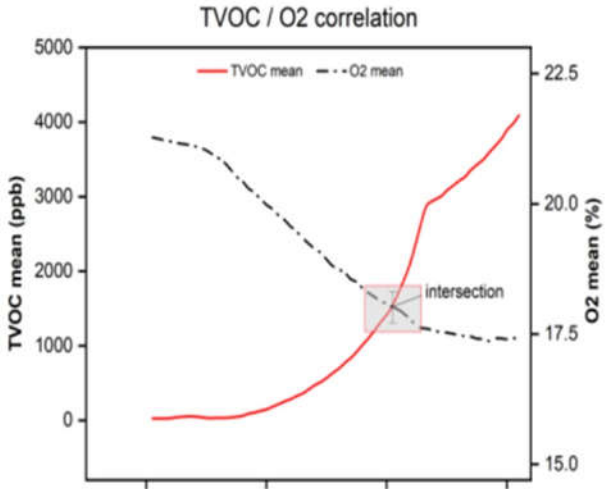

Fig. 3. Correlation between $O_2$and TVOC

The O_2 concentration measured by the O_2 sensor decreased linearly from 21% to 19%, and the average measured values when the candles were extinguished corresponded to the O_2 deficiency, with an O_2 concentration of 17.6% ± 0.5%. For CO_2 and VOCs, the measured values increased linearly as the concentration rapidly increased at the inflection point. When the candle was extinguished, the average measured eCO_2 was 12,899 ± 5 ppm, and the average TVOC was 1540 ± 5 ppb. Consequently, the concentrations of O_2 and eCO_2 were found to be inversely proportional, and the O_2 content obtained through repeated measurements revealed an O_2 concentration that can adversely affect health, inducing drowsiness and headache inside confined spaces. This suggests that alarms should be set on the devices based on the experimental data and confirms that VOC sensors could be used instead of O_2 sensors. The confined small chamber used in the experiments accurately reflected the volume inside confined workplaces and automobiles. However, on average, the combustion time of the candles changed with changes in the volume. As the parameters of the measured sensors were constant per unit volume, the proposed alarm could be generated using a VOC sensor. Table 5 illustrate that the O_2 levels exhibited a linear decline, whereas the eCO_2 and TVOC levels increased linearly, reaching a point of intersection that signified the onset of oxygen deficiency. This point was defined as the alarm threshold in this study and was established by averaging the data that led to this convergence.

Table 4. Alarm Threshold

Parameter (average)	Intersection data
eCO_2	12,289.9ppm
TVOC	1542.3ppb
CO_2	17.6%

PROTOTYPE DESIGN AND FABRICATION

Prototype Structure

Prototypes of the air pollution devices were manufactured using Arduino hardware and 3D printers. The air pollution devices measured as 73.9 mm × 50.9 mm × 28 mm, and each device weighed 80 g. An alarm point was set and a limit threshold was applied based on prior experiments. The primary and secondary alarm ranges were set to < 770 ppb/6144.5 ppm (VOC/ CO_2) and < 1540 ppb/12,289.9 ppm, respectively. The time between reaching the critical value and sending the alert was within one second.

To achieve portability, the prototype measuring devices were manufactured to a small size, and an Arduino Pro Mini was used, which is suitable for low-cost 33 mm × 18 mm small product applications. An on/off switch and light-emitting diodes (LEDs) were added to the device to control and verify the power of the prototype. Lithium polymer batteries (3.7 V) with capacities ranging from 1000 to 4200 mAh were used in several designs and sizes. A charging module TP4056(C-type) was used, and a step-up module was implemented to match the operating voltage of an Arduino Pro Mini 5V and prevent malfunction of the VOC sensor due to the battery voltage.

System Configurations

The prototypes showed the same measurements in the initial 15 s owing to the nature of the sensor. Subsequently, eCO_2 and TVOC were measured in real time using the VOC sensors. The sensor was initially powered for 12 h to establish a baseline each time it began operating. Furthermore, we incorporated an additional humidity sensor and wrote a code for the on-chip humidity compensation.

The manufactured prototype received data in real time and determined the indoor air quality based on the average data mapped to the preset values of the residual O_2, eCO_2 and TVOC. An alarm was set-thrice when the harmful gas or O_2 concentration reached a certain threshold. In addition, a secondary alarm point was established based on the data obtained through repeated measurements to address foreign substances or rapid changes. Abnormal humidity and temperature were reflected in the risk evaluation and warnings were sent continuously when a set value was reached.

Comparison with Existing Sensing Solutions

The metal-oxide gas sensor used in this study is the SGP30, a metal oxide gas sensor. Metal-oxide gas sensors have the advantages of low cost, high sensitivity, and various gas-sensing properties, but are vulnerable to long-term stability and environmental changes. Other methods for detecting VOCs include the proportional-integral-derivative (PID), gas chromatography-mass spectrometry (GC-MS), and organic compound conductor sensors. PID is a method for ionizing and detecting VOCs using light and has the disadvantages of high power consumption, a relatively large size, and a relatively high cost. GC-MS is an advanced analysis technology for quantitative and qualitative analysis of VOCs to achieve accurate results, but it has the disadvantage of being expensive and time-consuming. Organic compound conductor sensors are also unsuitable because the electrical resistance varies with the VOC concentration, which requires correction and is sensitive to environmental conditions. Therefore, they are expensive, power-intensive, and large, which make them unsuitable for use in small devices. Therefore, in this study, we used MOX VOC sensors to detect various volatile organic compounds at a low power and cost. MOX sensors belong to the MQ series, such as MQ-2 and MQ-7, and traditional MOX VOC sensors include BME680, MICS, Figaro TGS, and Winsen. These sensors are environmentally sensitive and measure specific gases rather than TVOC. For the approximate measurement of the overall drowsiness in the vehicle TVOC, the CCS881 sensor is the most similar to the sensor used in this study. SGP30 is the most suitable given its functionality, accuracy, and cost. Comparing the CCS811 and SGP30 sensors, CCS811 requires 48 h of consumption and 20 min of execution, whereas SGP30 is ready to run in only 15 s with smaller and improved long-term stability. This sensor is more affordable than the CCS811.

3D Modeling

3D modeling and design were performed using the Autodesk Inventor software. The inventor is a computer-aided design (CAD) application software developed by Autodesk, a U.S. company that is used to develop three-dimensional digital prototypes for product design, visualization, and simulation. The mark-forged 3D printer is made of carbon fibers. The portable air pollution prototype consisted of three parts: the upper surface, main body, and positioning. The upper surface was designed to serve as a switch for turning the measuring device on and off and providing a ventilation port for air circulation and ventilation. It was designed to facilitate the transmission of the alarm sound. The size of the upper part of the prototype was 73.9 mm × 50.9 mm × 28 mm, and a gap was designed for air circulation as a whole, such that the alarm sound was not blocked; rather, a clear sound was transmitted when the buzzer was triggered. Furthermore, the space and screw-fixing portions of the switch were designed to turn the prototype on or off. For the main body, the positioning part was designed in the form of a crib for portability and can be attached to the driver's seat sun visor in an automobile interior. For a special worker in a sealed space, the device can be fixed to clothes such as a pocket or shirt because the finished product is lightweight and small. The battery size is reflected in the prototype design by setting the typical battery usage time to 12h. In addition, additional prototypes were designed to increase the battery capacity, and various prototypes were fabricated.

CONCLUSION

This study aimed to develop a system to prevent the accumulation of harmful substances by fabricating portable indoor air pollution devices. We deduced that such a prototype could indirectly detect O_2 and VOC levels simultaneously using VOC sensors, which have numerous applications, such as the prevention of automobile accidents, because polluted air in such a confined space can cause drowsiness and impaired driving. The system was designed to provide alerts when the concentration of toxic air in a vehicle exceeds a certain threshold. A small chamber was manufactured to perform this function, and a closed-environment candle combustion experiment was conducted. From the results of this experiment, eCO_2 and TVOC increased linearly, O_2 decreased linearly, and the intersection and inflection points of the O_2, TVOC, and eCO_2 curves were determined. In addition, when the candle was digested, the O_2 concentration was 17.6% ± 0.5%, and TVOC and eCO_2 were measured to be 12,289.9 ± 5 ppm and 1542 ± 5 ppb, respectively. An air pollution detection prototype that could indirectly detect O_2 levels was manufactured using Arduino hardware and 3D printers and was designed to be portable and cost-effective.

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