Portable Alcohol Detection Device with Breath Recognition for Smart Keys
- Evaluation of Sensor Unit for Portable Device -

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ABSTRACT: We have developed a portable breath-based alcohol detection device that can easily determine whether a person has consumed alcohol. The device consists of a sensor to detect saturated water vapor in human breath and three semiconductor gas sensors to detect ethanol, acetaldehyde, and hydrogen. The device can determine whether the gas introduced into it is human exhaled breath and can detect the alcohol level at the same time. This ensures that the sample is of a person’s breath, not an artificial source. The selected gas sensors exhibited low relative standard deviation (RSD) for the repeated measurements. Each gas concentration is calculated using an algorithm based on a differential evolution method with a measurement accuracy of approximately ±5 ppm. These functions can be integrated into a smart key.

KEY WORDS: safety, alcohol drinking, driver condition monitoring / alcohol detection system, smart key function [C1]

1. Introduction

The problem of high fatal accident rates due to drunk driving persists, and it must be solved. Preventing drunk driving is an ongoing focus of progress in safe driving technology. In Japan, transportation companies are required to use an alcohol detector to test whether professional drivers are under the influence of alcohol before they begin their shifts (1). Meanwhile, in the U.S., the National Highway Traffic Safety Administration (NHTSA) has launched and directed the development of ignition interlock technology that connects alcohol detectors to the ignition of a vehicle’s engine. Conventional breath alcohol ignition interlock devices use either fuel cells or solid-state sensors. Systems using fuel cells are used more widely for evidential breath testing (2).

These systems have been used in various places, such as public transport offices and trucks, but are rarely used by general drivers because they require a mouthpiece for introducing breath and it takes more than 1 minute to output the measurement results; therefore, they are not suitable for frequent use. To expand the use of alcohol detection systems to general drivers, improvement of their usability is necessary.

Several methods have been developed to easily measure the gases in exhaled breath and non-invasively detect alcohol in the blood (3-6). To prevent errors when using an alcohol interlock, it is necessary to avoid false detection due to other gases, such as ambient air, and develop a water vapor sensor to detect the saturated water vapor in the person’s breath. In a previous paper, we reported on a water vapor sensor to detect water vapor in a person’s breath and showed that the sensor could be easily coupled with an alcohol sensor (7-9).

This paper reports on a prototype portable breath-based alcohol detection system and evaluates the performance of our sensor unit. Our system does not require a mouthpiece for sampling the breath and includes an automatic interlock algorithm depending on the alcohol detection results.

2. Breath alcohol detection system

Figure 1 shows a photograph of our breath-based alcohol detection device and the sensor unit. The developed portable device has advantages over the other ignition interlocks. Other systems may require drivers to perform the test from the driver’s seat once they are already inside the vehicle. With our device, drivers can measure their alcohol level anywhere including, importantly, prior to entering their vehicle, thus reducing the temptation to drive. In addition, the device can confirm that the applied gas is human exhaled breath at the same time as detecting the level of alcohol, which is an enhancement over currently available devices. And, our system can exhibit faster detection than that of a conventional alcohol detection system with fuel cell technology by superior responsiveness of the gas sensors.

![Figure 1 Photograph of breath alcohol detection device.](image_url)

The water vapor sensor in the sensor unit can detect the saturated water vapor from human breath with a high degree of sensitivity. When human breath is exhaled onto the sensor, which is an oxide insulator sandwiched between the electrodes, the water...
vapor from the breath is adsorbed on the insulator, and then an electric current flows between the electrodes. When this phenomenon occurs, the sensor can recognize if the applied gas is human breath. Furthermore, micro comb-shaped electrodes are used to extend the length of the electrodes and narrow the distance between them, improving the sensitivity of the sensor, as shown in Fig. 2. This enables the device to detect a tiny amount of saturated water vapor even though the sensor area is only a 3 mm square. As a result, the device is highly portable and can be used prior to the driver entering his vehicle. The device is also battery powered; this is possible due to using low power consumption technology.

![Schematic illustration of detection part of water vapor sensor.](image)

**Fig. 2** Schematic illustration of detection part of water vapor sensor.

![Results of participant’s breath test with or without consuming alcohol.](image)

**Fig. 3** Results of participant’s breath test with or without consuming alcohol.

We chose semiconductor gas sensors to detect alcohol. However, these sensors tend to respond to various gases. Therefore, to accurately calculate alcohol levels, it is necessary to determine other gases’ effect on the sensors. Figure 3 shows the results of the participant’s breath test with or without consuming alcohol measured by gas chromatography. In typical exhaled breath, the hydrogen gas concentration is approximately 10 ppm (10) and is independent of the amount of alcohol consumed. Additionally, acetaldehyde, which is a metabolite of ethanol, exists in exhaled breath after alcohol is consumed. All the remaining gases in exhaled breath are in sub-ppm concentration or are not detected by the sensors. Therefore, to calculate the alcohol concentration, we attempted to detect ethanol, acetaldehyde, and hydrogen for the accuracy improvement.

To calculate the gas concentration, we selected three types of semiconductor gas sensors (FIS Corporation): hydrogen-specific (SB19), ethanol-specific (SB30), and acetaldehyde-specific (SB33). These sensors were evaluated in a temperature- and humidity-controlled chamber (100 L) by using various gas concentrations of ethanol, acetaldehyde, and hydrogen. The temperature and humidity in the chamber were kept at 35°C and above 85%. We also investigated the measurement accuracy of the alcohol concentration and the gases that affect measurement in the ambient air. The device shall not detect these gases when they are over their threshold values based on EN50043-2, as shown in Table 1. Each gas concentration is calculated by applying an algorithm based on a differential evolution method (11).

| Type                  | mg/L |
|-----------------------|------|
| Acetaldehyde          | 0.08 |
| Acetone               | 0.25 |
| Carbon monoxide       | 0.10 |
| Diethyl ether         | 0.15 |
| Ethyl acetate         | 0.08 |
| N-Heptane             | 0.10 |
| N-Hexane              | 0.10 |
| Methane               | 0.15 |
| Methanol              | 0.05 |
| N-octane              | 0.10 |
| N-pentane             | 0.10 |
| 2-propanol            | 0.05 |
| Toluene               | 0.10 |

### 3. Evaluation of sensor unit

#### 3.1. Water vapor sensor

In our prototype device, an AC voltage of ±1.5 V with an offset voltage of 0.75 V was applied to the voltage electrode of the water vapor sensor at a frequency of 10 Hz. The output signals were obtained at a sampling rate of 1 kHz. Figure 4 shows the time dependence of the output signal of the water vapor sensor after introducing a person’s breath, ambient air, and spray gas. The output signal of the water vapor sensor increased with increasing amount of exhaled breath and exceeded the level (threshold voltage) for recognizing breath. In the case of ambient air and spray gas, these output signals did not exceed this threshold voltage while introducing gases. Our water vapor sensor only reacted to exhaled breath, not to ambient air or spray gas. Thus, a feature of our water vapor sensor is it can avoid false detection caused by other gases such as ambient air or spray gas.
3.2. Multi-gas sensors

The 40 sensor-units were evaluated in this study. Figure 5 shows the experimental process of measurements that are performed three times as a schematic view. The injected gas (100 ppm) in the chamber was held for a length of 2 minutes. Next, the chamber was vacuumed for 5 minutes to release the air. The typical results are summarized in Table 2. The measurement data of SB30 at an ethanol gas concentration of 100 ppm exhibited a low relative standard deviation (RSD) of 0.27%, which corresponds approximately to an ethanol concentration of 1.4 ppm. The RSDs of SB33 and SB19 were 0.92% and 1.09%, which correspond approximately to 5.0 ppm and 5.6 ppm, respectively. These results indicate that good reproducibility was obtained for our selected gas sensors.

To estimate alcohol concentration, calibration curves were obtained by fitting the experimental data in a temperature- and humidity-controlled chamber (100 L). Figure 6 shows the calibration curves of the three gas sensors (SB30, SB33, SB19) for stardered gases of ethanol, acetaldehyde, and hydrogen. The method for estimating each gas concentration is as follows. The signal intensities ($I$) of the three gas sensors are given as

$$I_{SB30} = base_{E30} + \frac{(max_{E30} - base_{E30})}{1 + (A_{E30}/(X_{E} + X_{H}))^{2}} + A_{E30}X_{H} \quad (1)$$

$$I_{SB33} = base_{A33} + \frac{(max_{A33} - base_{A33})}{1 + (A_{A33}/(X_{A} + X_{H}))^{2}} + A_{A33}X_{H} \quad (2)$$

$$I_{SB19} = base_{H19} + \frac{(max_{H19} - base_{H19})}{1 + (A_{H19}/(X_{H} + X_{A}))^{2}} + A_{E19}X_{E} + A_{A19}X_{A} \quad (3)$$

where $X_{E}$, $X_{A}$, and $X_{H}$ stand for the gas concentrations of each gas, and base, max, A, and B stand for their coefficient constants. $X_{E}$ stands for the ethanol gas concentration converted from the output voltage of SB33. $X_{A}$ stands for the acetaldehyde gas concentration converted from the output voltage of SB30. From the above expressions, each gas concentration is calculated by applying an algorithm based on a differential evolution method \(^{(1)}\). The equation of error is given as

$$F(X_{E}, X_{A}, X_{H}) = (I_{SB30} - V_{SB30})^2 - (I_{SB33} - V_{SB33})^2 - (I_{SB19} - V_{SB19})^2 \quad (4)$$

where $V_{SB30}$, $V_{SB33}$, and $V_{SB19}$ stand for the output voltage of each gas sensor. Each gas concentration is calculated from the optimal solution by which the error $F(X_{E}, X_{A}, X_{H})$ in Eq. (4) is minimized.

### Table 2  
Each gas sensor’s output value for each 100 ppm gas on experimental process.

| Gas Type | SB30 | SB33 | SB19 |
|----------|------|------|------|
| Ethanol  |      |      |      |
| 1st (V)  | 1.145| 0.688| 0.391|
| 2nd (V)  | 1.140| 0.687| 0.402|
| 3rd (V)  | 1.139| 0.682| 0.397|
| Av. (V)  | 1.141| 0.686| 0.397|
| Standard deviation | 0.003 | 0.003 | 0.006 |
| RSD (%)  | 0.27 | 0.48 | 0.39 |
| Acetaldehyde |      |      |      |
| 1st (V)  | 1.500| 1.770| 0.730|
| 2nd (V)  | 1.504| 1.790| 0.237|
| 3rd (V)  | 1.532| 1.802| 0.234|
| Av. (V)  | 1.512| 1.787| 0.233|
| Standard deviation | 0.018 | 0.016 | 0.004 |
| RSD (%)  | 1.18 | 0.92 | 0.23 |
| Hydrogen |      |      |      |
| 1st (V)  | 0.054| 0.032| 1.211|
| 2nd (V)  | 0.055| 0.030| 1.237|
| 3rd (V)  | 0.051| 0.028| 1.230|
| Av. (V)  | 0.053| 0.030| 1.226|
| Standard deviation | 0.002 | 0.002 | 0.013 |
| RSD (%)  | 3.65 | 7.15 | 1.09 |
A feasibility study of our device has been completed, and the technology has been enhanced throughout the validation tests. We investigated the effect of several gases in the ambient air, and the device shall not detect these gases over their threshold values based on EN50436-2. The results were positive and show that the calculated gas concentrations were less than the limit of 0.10 mg/L (52 ppm) in Japan, as shown in Table 3.

Table 3 Evaluation results of various gases for alcohol-interlock system

| Type        | mg/L | Ethanol (ppm) | Acetaldehyde (ppm) | Hydrogen (ppm) |
|-------------|------|---------------|--------------------|----------------|
| Acetaldehyde| 0.08 | 0.0           | 61.2               | 0.8            |
| Acetone     | 0.25 | 0.0           | 377.9              | 0.0            |
| Carbon monoxide| 0.10 | 0.0         | 0.3                | 1.4            |
| Diethyl ether| 0.15 | 0.0          | 45.6               | 0.5            |
| Ethyl acetate| 0.08 | 22.1         | 0.0                | 0.1            |
| N-Heptane   | 0.10 | 0.0           | 28.9               | 0.0            |
| N-Hexane    | 0.10 | 0.0           | 36.1               | 0.0            |
| Methane     | 0.15 | 0.0           | 0.3                | 0.6            |
| Methanol    | 0.05 | 15.7          | 0.0                | 0.5            |
| N-octane    | 0.10 | 0.0           | 19.0               | 0.0            |
| N-pentane   | 0.10 | 0.0           | 39.2               | 0.0            |
| 2-propanol  | 0.05 | 24.1          | 5.7                | 0.0            |
| Toluene     | 0.10 | 4.1           | 0.0                | 0.0            |

In accordance with Japan’s regulations on drunk driving, the device has an improved ability to accurately measure the ethanol concentration in exhaled breath. The ethanol concentration is measured by three types of semiconductor gas sensors to detect ethanol in breath after drinking, metabolized acetaldehyde in breath after drinking, and hydrogen. This method has an improved accuracy compared with devices that only use an ethanol sensor, as shown in Fig. 7. Each gas concentration is calculated using an algorithm based on a differential evolution method and obtained with a measuring precision of approximately 5 ppm. Also, the device is capable of measuring as little as 0.01 mg/L (ethanol concentration) compared to 0.15 mg/L of alcohol, which is the legal limit for “driving under the influence of alcohol” and the charge of drunk driving in Japan.

Figure 8 schematically shows a flow chart of our prototype system for an alcohol interlock. The system measured the output signals of each gas sensor at the level for recognizing breath of the water vapor sensor. The system then immediately estimated each gas concentration by numerical analysis, and the gas concentration results and a message are displayed on a screen in the vehicle. If the ethanol concentration is below limit L₀, the “Safe to drive” message is displayed on the screen. If the ethanol concentration is above limit L₁, the “You cannot drive” message is displayed. If the ethanol concentration is above L₂ and below L₃, the “Need to re-evaluate” message is displayed. Limits L₁ and L₂ can be adjusted in accordance with each country’s regulations. In this experiment, the limit of L₁ and L₂ were set to 40 ppm and 78 ppm, respectively, in accordance with the Japanese legal limit of 0.15 mg/L (78 ppm).
In our alcohol detection system, the algorithm to detect ethanol in a person’s breath uses a combination of the water vapor sensor’s signal and the calculated ethanol concentration. Our system has the measurement time of 3 seconds to reduce the influence of output level by the individually exhaled breath. Figure 9 shows the results of a participant’s breath test with or without consuming alcohol. The vertical axis represents the output signal of each sensor, while the horizontal axis represents time in seconds. Figure 9(a) shows the results where the participant had not consumed alcohol. The output signal of each gas sensor were under the legal limit level of 0.15 mg/L (in Japan). In the case of breath where the participant had consumed alcohol, the detection results were obtained from the participant’s exhaled breath 60 minutes after he consumed 200 ml of wine (alcohol content: 13%). The signal intensity of each gas sensor increased until the end of the exhaled breath and exceeded the legal limit level of 0.15 mg/L immediately. Our system exhibited the calculated results of gas concentration within 3 seconds after the start of breath exhalation and had faster detection than that of a conventional alcohol detection system with fuel cell technology.

![Output of sensor](image)

**Fig. 9** Validation test with or without consuming alcohol, (a) had not consumed alcohol and (b) consumed alcohol.

4. Alcohol-interlock system

We fabricated a car mockup with an alcohol-interlock system, as shown in Fig. 10. This system enables the sending of measurement results to a vehicle and/or smartphone through a wireless unit and functions as a smart key of the vehicle. In our system, the portable breath alcohol detection device was operated by wireless communication with an excitation coil of 125 kHz from the receiver inside the console after setting up the console. The measurement results of the alcohol level were sent by a radio frequency signal of 314.55 MHz with a bandwidth of approximately 60 kHz from a portable device that acts as a smart key.

By giving the recorded measurement result of the alcohol detector to the engine ignition mechanism, the system can prevent the vehicle’s engine from starting if it detects that the driver’s breath is over the preset limit. Also, an alert indicator shows the measurement result on the vehicle’s display panel if the detector equipped smart key is close to the driver’s seat.

Furthermore, our device can be connected to a smartphone and face recognition will be incorporated to confirm that the person behind the wheel is the same person that has been checked by the breath sensor device. We have been executing a field test for the robustness improvement of our system.

![Demonstration result of system integrated smart key](image)

**Fig. 10** Demonstration result of system integrated smart key function.

5. Conclusion

We have successfully developed a prototype portable alcohol device that is tamper-resistant as it can distinguish human breath from other gases and can be integrated into a smart key. This device is capable of distinctively detecting the saturated water vapor from human breath and accurately measuring the alcohol level within 3 seconds once a driver breathes into the device. We also developed a system that can show the alcohol level measured by the detector on the vehicle’s display panel. It can become an ignition interlock to stop the driver starting the engine when it detects that the driver is under the influence of alcohol.

To develop a more practical breath alcohol detection system, we plan to further develop our portable prototype breath alcohol detection system.

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