DEVELOPMENT OF PORTABLE BREATH-ALCOHOL-DETECTION SYSTEM

Masuyoshi Yamada

Hironori Wakana

Center for Exploratory Research, Research & Development Group, Hitachi, Ltd.
Japan

Paper Number 19-0181

ABSTRACT

A portable alcohol detection system based on exhaled breath analysis has been developed. The system consists of a breath sensor, a smartphone to control the sensor and communicate various data, and a data cloud system. The system can be used to monitor a driver's status from a remote location.

The breath sensor consists of four separate sensors. The first is a water vapor sensor that is used to verify if the applied gas is human breath. The others are semiconductor gas sensors to detect ethanol, acetaldehyde, and hydrogen. The detector is connected to a smartphone, and the driver's alcohol check results are automatically sent to a data cloud system. To prevent abuse of this detector by blowing substitute gas, it can recognize human exhaled breath by detecting small amounts of metabolites as well as saturated water vapor. The ethanol concentration is obtained from the voltages of the three semiconductor gas sensors. Each sensor has a specific sensitivity for ethanol, acetaldehyde, and hydrogen. We apply the differential evolution algorithm to the relationship between each sensor's output voltage and its calibration curve. Then we calculate the ethanol concentration of the human breath. This multi sensor method is more accurate than a single sensor method that only uses one gas sensor to measure ethanol concentration. We also employ an original humidity sensor that was suitably designed to detect highly humid (saturated) water vapor using a comb-shaped electrode pattern.

From our field tests, in which we used more than 30 sets of detectors, we investigated the performance of exhaled breath recognition. When the field test users of our detector did not consume alcohol, their ethanol, acetaldehyde, and hydrogen concentration levels, as a result of natural human metabolism, were 1.8, 1.9, and 0.1 ppm on average, respectively. Based on these data, we set the threshold level on each gas sensor to recognize human breath. As a result, the detector could measure the breath alcohol level within 3 s. It could also successfully distinguish human exhaled breath from ambient air or spray gas.

Since the detector is small (Size: 75 mm(W), 55 mm(D), 20 mm(H), Weight: 20 g, approx.) and connected to a smartphone, it can be used at any time and can contribute to the safety of professional drivers by enabling remote and central management of alcohol test data.

It is possible to connect this detector to a vehicle engine interlock system by wireless communication so that the system can recognize the driver's status, even before they enter a vehicle. This will help prevent drunk driving. We believe that our detector is helpful to decrease alcohol-related accidents and enable remote management of alcohol inspection.

INTRODUCTION

There is a global effort to prevent or stop drunk driving. Therefore, safe driving technology has been extensively researched. In Japan, transportation operators 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 a vehicle's engine [2]. Their systems require drivers to perform the test from the driver's seat once they are already inside the vehicle [3-6]. With our prototype device, drivers can measure their alcohol level from anywhere and, importantly, prior to entering their vehicle. This will reduce the temptation to drive. In addition, our device can confirm if the applied gas is human exhaled breath and simultaneously detect the level of alcohol [7,8]. These advancements will contribute to reducing or eliminating instances of drunk driving.

While our previous prototype allowed the driver to take the test anywhere and prevented tampering by being able to distinguish whether the submitted sample was human breath [7], it had issues such as the possibility of abuse by a substitute taking the test instead of the actual driver, and the need to be able to centrally manage test data from each driver in fleet situations.

To address these issues, we developed a function to prevent the use of substitutes as well as enabling central management of alcohol test data. The developed prototype includes a function to send a facial image to prevent substitution and a data communication system between the smartphone and cloud system.

METHODS

Figure 1 shows an image of the breath-based alcohol detection device and circuit board. The sensor device consists of a water vapor sensor to detect saturated water vapor in human breath and three semiconductor gas sensors to detect ethanol (Nissha FIS, Inc., SB-30), acetaldehyde (SB-33), and hydrogen (SB-19). These sensors are located behind the breath inlet area of a sensor case. The case size is 75 mm (W), 55 mm (D), 20 mm (H), and its weight is approximately 20 g. The device is connected to a smartphone as shown in Fig. 1, and the drivers can measure their alcohol level anywhere including, importantly, prior to entering the vehicle. The alcohol concentration is calculated in the device and then sent to the smartphone. A driver can see his/her alcohol level on the smartphone display, and data is simultaneously sent to a cloud system to be checked by a safety/health officer at a control center. In addition, it is possible to communicate with a vehicle's engine interlock system as developed in a previous prototype [8].

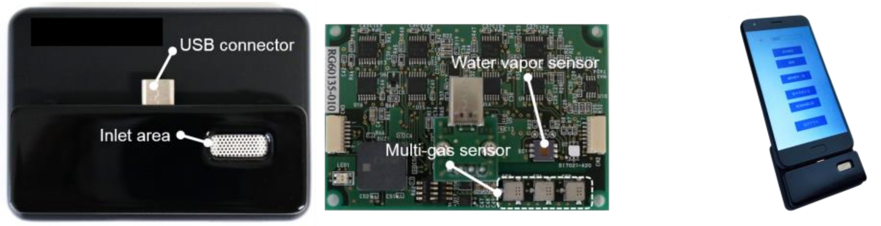

Figure 1. Image of breath alcohol detection device.

Water vapor sensor

Figure 2 shows the schematic of the water vapor sensor, which can detect the saturated water vapor from the exhaled breath with a high degree of sensitivity. When human breath is applied to the sensor, which is an oxide insulator sandwiched between the electrodes, the water vapor from the breath is adsorbed on the insulator, and an electric current flows between the electrodes. When this 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 decreases the distance between them, thus improving the sensitivity of the sensor. This sensor has a heating layer to prevent condensation before it starts measuring. An AC voltage of ±1.5 V at a frequency of 10 Hz was applied to the voltage electrodes to detect water vapor. This device can detect a small amount of saturated water vapor even though the sensor dimensions are only 1.5 mm × 2.1 mm. As a result, the device is highly portable.

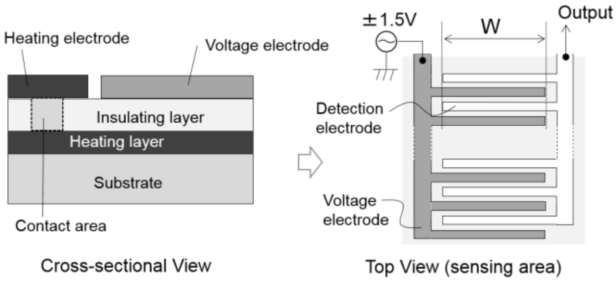

Figure 2. Schematic of water vapor sensor.

Calibration and evaluation

The ethanol concentration in the breath is obtained as follows. After the water vapor sensor acknowledges that a sufficient amount of breath is introduced, maximum voltages of the above-mentioned gas sensors are recorded and sent to a concentration calculation algorithm. This is installed in the circuit board CPU. The algorithm is based on a differential evolutional method [9] and can determine an approximate solution. The relationship between the output sensor voltage and gas concentration are shown as the calibration curve in Fig. 3. The concentrations of ethanol, acetaldehyde, and hydrogen are calculated from the calibration curve and differential evolutional method. The calibration curve was obtained using a thermostatic chamber (100 L) as shown in Fig.4. The temperature and humidity in the chamber were maintained at 34 °C and above 85% for 30 min, respectively.

At each measuring condition, 1 mL of the inside gas was sampled, and each gas concentration was measured by GC-FID.

We also evaluated the effect of the distance of the breath flow path to the gas inlet of the sensor using a breath simulator, as shown in Figure 5. The breath simulator was operated under the following conditions: temperature of 34°C, ethanol concentration of 10 – 150 ppm, breath flow distance of 0 – 40 mm, and gas flow rates of 2.5 – 5.0 L/min. The humidity at the outlet of the simulator was at a saturated water vapor level. We investigated the measurement accuracy of the alcohol concentration, and the dependence of the distance (D) between the outlet pipe and inlet of the sensor.

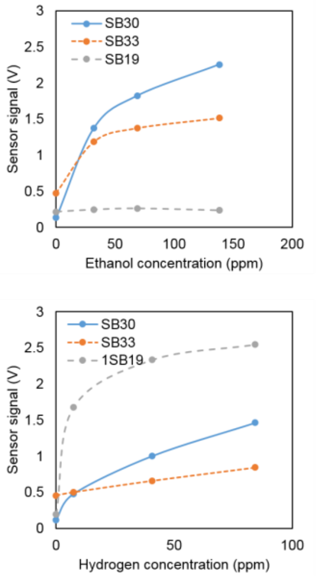

Figure 3. Calibration curves of gas sensors.

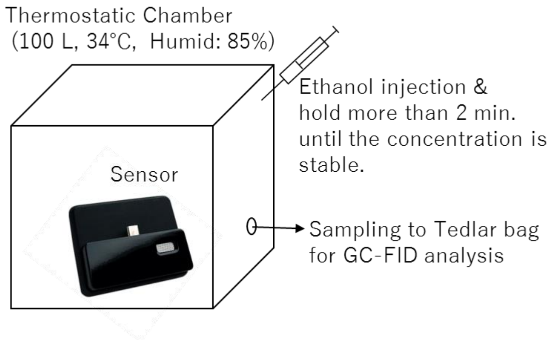

Figure 4. Experimental set up to obtain calibration curve.

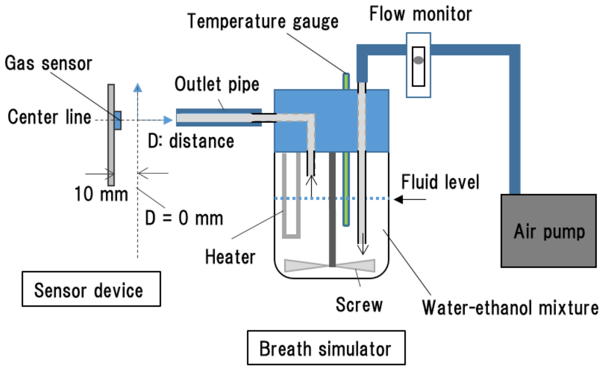

Figure 5. Schematic of a breath simulator system.

RESULTS AND DISCUSSIONS

Breath recognition function

Figure 6 shows an example of the output signal of the water vapor sensor after introducing a human's breath, ambient air, and spray gas. The output signals were obtained at a sampling rate of 1 kHz. The output signal of the water vapor sensor increased with an increase in the amount of exhaled breath and exceeded the level (threshold voltage) for recognizing breath. For ambient air and spray gas, the output signals did not exceed this threshold voltage while introducing gases. The water vapor sensor only reacted to the exhaled breath and not ambient air or spray gas.

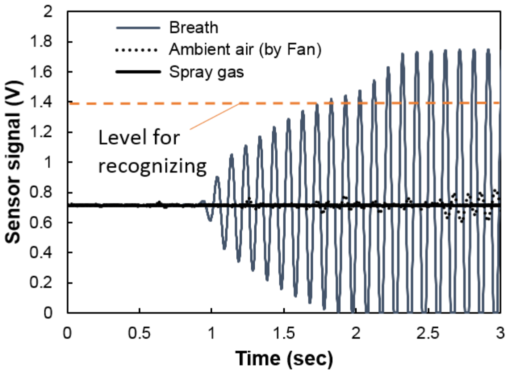

Figure 6. Time dependence of the output signal of water vapor sensor with different sample gases, such as human breath, ambient air, and spray gas.

The gas sensors in our device can also distinguish water vapor from a human breath. Figure 7 shows a comparison of the sensor signals obtained after introducing pure water vapor and human breath. The signals of each gas sensor for the human breath were higher than those obtained for water vapor. This is because the breath includes small amounts of these gases as metabolites. Figure 8 shows the averages and standard variations in ethanol, acetaldehyde and hydrogen concentrations obtained from the breaths of 100 volunteers under non-alcohol conditions. The sensor's threshold levels are determined with these data. Thus, a feature of our sensor device is that it can avoid false detection, which is caused by other gases, such as ambient air and/or water vapor.

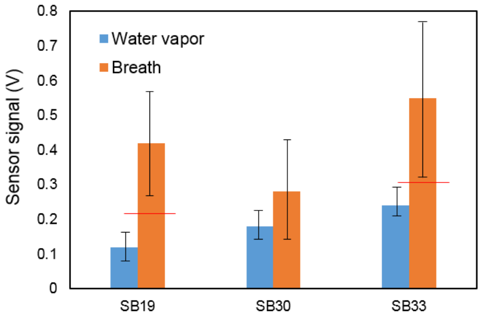

Figure 7. Comparison between water vapor and human breath.

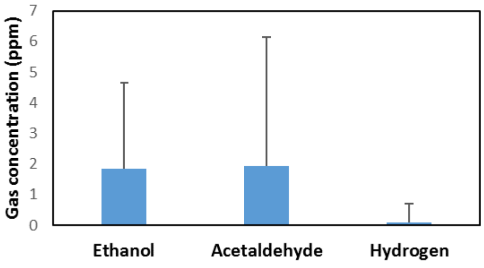

Figure 8. Measured gas concentration in volunteers' breath.

Evaluation of the sensor's applicability

Figure 9 shows the measurement results of an artificial breath, which was introduced using a breath simulator at different distances from 0 to 40 mm. The signal intensity of the ethanol gas sensor (SB30) depends on the distance between the outlet pipe of the breath simulator and the inlet of the sensor device. In the case of distances less than 20 mm, the sensor signals were constant. Therefore, we recommend the sensor to be used at a distance within 20 mm.

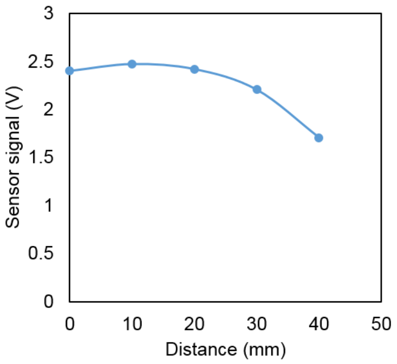

Figure 9. Dependence of ethanol sensor signal on the distance using the breath simulator system.

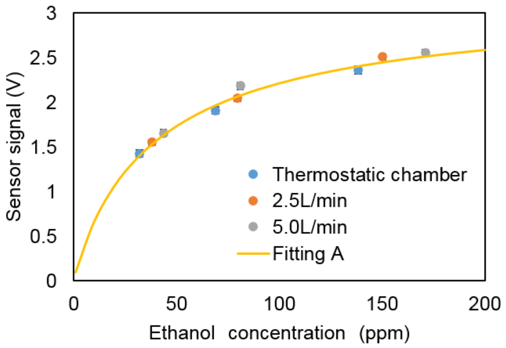

Figure 10. Comparison between the results of the thermostatic chamber and breath simulator.

Figure 10 shows a comparison of the ethanol sensor (SB30) signals measured using a thermostatic chamber and a breath simulator. The distance between the outlet of the breath simulator and the sensor device was 0 mm. "Fitting A" in Figure 10 was obtained using the data from the thermostatic chamber. We investigated the dependence of the sensor signals on the ethanol concentration by applying different gas flow rates at 2.5 L/min and 5.0 L/min using the breath simulator. The experimental results obtained with the breath simulator showed good agreement with the results obtained using the thermostatic chamber (Fitting A). This indicates that the estimated measurement accuracy is less than ±10 ppm.

Breath alcohol detection

Figure 11 shows results of a participant's breath test after they consumed alcohol. The vertical axis represents the output signal of each sensor, while the horizontal axis represents time in seconds. The results were obtained from the participant's exhaled breath after they had 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 (in Japan) immediately. The system exhibited the calculated results of gas concentration within 3 s after the start of breath exhalation.

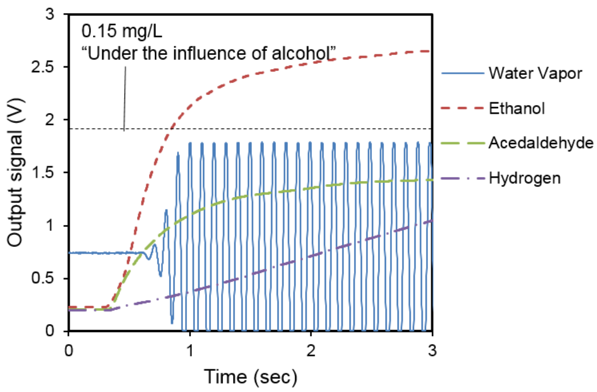

Figure 11. Validation test after consuming alcohol.

CONCLUSION

We have successfully developed a prototype portable alcohol device that is able to distinguish human breath from other gases. This device is capable of distinctively detecting the saturated water vapor and the metabolites from human breath while accurately measuring the alcohol level within 3 s of a driver breathing into the device. We also developed a system that displays the alcohol level measured by the detector on a smartphone and sends the data to a cloud system. A measurement accuracy of ±10 ppm was obtained by introducing an exhaled breath within a distance of 20 mm. We aim to develop our proposed detector to make it more practical for further use.

ACKNOWLEDGEMENT

The authors would like to thank people concerned in Yabu city of Hyogo Pref. for cooperation of our field tests, and Mr. K. Kin of Honda R&D Co., Ltd. for helpful advice.

REFERENCES

[1] http://www.mlit.go.jp/common/000131573.pdf (Japanese edition)

[2] R.P. Compton and J. Hedjund, "Reducing Impaired-driving Recidivism Using Advanced Vehicle-Based Alcohol Detection Systems" in A Report to Congress, National Highway Traffic Safety Administration, Washington, DC, pp. 4-15, 2007.

[3] K. Zaouk, M. Wills, E. Trube and R. Strasssburger, "Driver Alcohol Detection System for Safety (DADSS) – A Status Update," Paper Number 15-0276. Proceedings of the 24nd International Technical Conference on the Enhanced Safety of Vehicles, 2015.

[4] B. Hok, J. Ljungblad, A. K. Andersson, M. Ekstrom and M. Enlund, "Unobtrusive and Highly Accurate Breath Alcohol Analysis Enabled by Improved Mrthodology and Technology," Journal of Forensic Investigation, Vol. 2, Issue 4, 8, 2014.

[5] P. Sanchez, C. R. Zamarreno, M. Hernaez, I. R. Matias and F. J. Arregui, "Exhaled Breath Optical Fiber Sensor based on LMRs for Respiration Monitoring," IEEE SENSORS 2014 Conference, pp. 1142-1145.

[6] L. Cech, M. Nagolu, D. Rumps, B. V. Steeg, D. Treese, B. Laaksonen, S. Tehseldar and T. Ridder, "Introduction of a Solid State, Non-invasive Touch Based Alcohol Sensor," Paper Number 15-0380., Proceedings of the 24tn International Technical Conference on the Enhanced Safety of Vehicles, 2015.

[7] H. Wakana, M. Yamada and M. Sakairi, "Development of Breath-alcohol-detection System," SAE technical paper, 2016-01-1498, 2016.

[8] H. Wakana, M. Yamada and M. Sakairi, "Portable Alcohol Detection System with Breath-Recognition Function," IEEE SENSORS2018 Conference, pp. 939-942.

[9] R. Storn and K. Price, "Minimizing the real functions of the ICEC'96 contest by differential evolution," Proc. Of the International Conference on Evolutionary Computation, pp. 842-844, 1996.