Research Report

Development of a New Breath Alcohol Detector without Mouthpiece to Prevent Drunk Driving

Toshiyuki Taguchi, Kiyomi Sakakibara, Atsushi Nakashima, Toshihiro Wakita, Shohei Yabu and Bunji Atsumi

Report received on June 16, 2011

ABSTRACT Breath alcohol interlock systems are used in Europe and the U.S. for drunk driving offenders. Although a certain effect has been revealed in the prevention of drunk driving, problems to be solved remain with commercialized detectors, i.e., a person taking the breath alcohol test must strongly expire to the alcohol detector through a mouthpiece for every test, more over the determination of the breath alcohol concentration requires more than 5 seconds. The goal of this research is to develop a device that functions suitable and unobtrusive enough as the interlock system. For this purpose, a contact free alcohol detector, which doesn't require a long and hard blowing to the detector through a mouthpiece, has been developed as a tool available on board for the prevention of drunk driving. The detector consists of an electric suction fan, an alcohol sensor, and an oxygen sensor mounted in a gas flow passage. It doesn't require a mouthpiece for the detection because driver's expired breath is captured by the suction fan. The influence of fluctuations of the alcohol sensor signals caused by air mixing is extremely reduced by the calibration of alcohol concentration using an oxygen level of driver's expired breath that is measured simultaneously with the alcohol content. The detector is able to measure breath alcohol concentration rapidly and easily, compared with the current breath alcohol detectors which require a blowing through a mouthpiece. Good accuracy has been demonstrated in an experiment with the drunk subjects.

KEYWORDS Alcohol, Sensor, Drunk Driving, Breath, Oxygen, Preventive Safety

1. Introduction

In Japan, a number of fatal accidents caused by alcohol-impaired driving started to decrease since the revision of the Road Traffic Law in 2002. Furthermore, the fatal accident caused by alcohol-impaired driving decreased greatly in 2007, because of the increment of safety awareness and the severe penalties to a conviction for driving under the influence of alcohol (DUI), which was started after the tragic accident resulting in the death of three infants in Fukuoka, Japan in 2006. However, in 2007, the fatal accident caused by alcohol-impaired driving still occupies more than 8% of the whole fatal accidents, and the fatality rate of the accident caused by DUI is still 9.4 times higher than that of other traffic accidents.[1-2] Therefore, a wider approach is required to prevent alcohol-impaired driving.

Also, in the U.S., 1 million people were arrested for DUI in 2004. In addition, there were 16,694 deaths as the results of alcohol-related motor vehicle crashes, and alcohol-related motor vehicle fatalities account for 39 percent of all motor-vehicle-related deaths.[3] In most US states, breath alcohol ignition interlock devices (BAIIDs) have been used for DUI offenders for more than ten years, and a certain effect has been revealed in reducing DUI-recidivism. A BAIID is a technology of breath alcohol test as a means of estimating blood alcohol concentration (BAC). A BAIID is a device hardwired into the ignition circuit of a vehicle that prevents the vehicle from starting until a breath sample has been given, and the analyzed result of ethanol content is found to be below the programmed limit. Every time a driver attempts to start a vehicle, the driver must take a deep breath and blow a long and hard breath sample into the alcohol detector through a mouthpiece. The current interlocks are secondary interlocks, which is enforced for a DUI offence. On the other hand, a primary interlock is designed for all users regardless of prior driving history. Therefore, as a primary interlock device, not only accuracy but also convenience is required—ability to perform alcohol estimation with very little effort, or wasted time.

The goal of this research is to develop a device that functions suitable and unobtrusive enough as a primary interlock. For this purpose, a contact free alcohol detector, which does not require a long and hard blowing to the detector through a mouthpiece, has been investigated. The accuracy of the measurement was verified by an experiment with the drunk subjects.

2. Methods

2. 1 Construction and Issues of a Contact Free Alcohol Detector

The interlocks in current use, which require a blowing through a mouthpiece, have the limitation in the point of convenience because of two restrictions:

1) Requirement of a mouthpiece.
2) Requirement of a long and hard blowing for more than 5 seconds.

Requirement 1) is necessary to prevent the expiration being diluted by ambient air and to make the expiration certainly reach the detector. Requirement 2) is necessary to get an exhaled air sample deep from the lungs, alveolar air, which is needed for the accurate estimation of BAC. Breath alcohol concentration (BrAC) is correlated with BAC in pulmonary alveolus because of the gas exchange with the blood. Since exhaled air is a mixture of alveolar air and tracheal air that remains in the airways, the accurate estimation of BAC requires the air sample deep from the lungs, so the driver must take a deep breath and blow a long and hard exhaled air.

Figure 1 shows the schematic representation of a new breath alcohol sensing unit provided with a contact free alcohol detector without a mouthpiece. It consists of an electric suction fan, an alcohol sensor and an oxygen sensor mounted in a cubical metal case that has a gas flow passage. To measure the breath alcohol concentration, a driver exhales to the detector for 1-2 seconds. Driver's breath sample is captured and directed to reach the sensors through the gas flow passage by an electric suction fan. A tin oxide semiconductor alcohol sensor and a limiting current type zirconium solid electrolyte oxygen sensor are used in the sensing unit. These sensors are connected to a personal computer through the A/D converters, as shown in **Fig. 2**.

The most important issue on the contact free method is that the alcohol sensor output fluctuates even if the alcohol concentration in breath is constant, because two restrictions mentioned above are not satisfied. As a breath sample (alveolar air) is diluted by ambient air, it is necessary that the measured alcohol sensor level is calibrated so that the estimated breath alcohol concentration is not affected by the dilution ratio.

2. 2 Calibration Method

In the contact free alcohol detector, for the purpose of correcting the alcohol (ethanol) level which is measured with alcohol sensor after diluted by ambient air, the oxygen level of driver's breath is measured simultaneously with the alcohol content. The concentration of oxygen is almost constant in pulmonary alveolus because of the gas exchange, and the oxygen level of human expiration is known to be approximately 15% at 760 mmHg—partial pressure of oxygen (P_{O_2}) is 115 mmHg in an expiration, approximately 70% is from alveolar air (P_{O_2} = 100 mmHg) and 30% is from tracheal air (P_{O_2} = 150 mmHg), [4] while the ambient air oxygen level is about 20%.

The dilution ratio of the oxygen in breath ($[O_2]_{dil}$) is described as below.

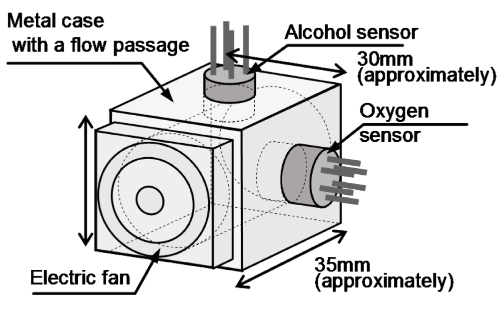


Fig. 1 Alcohol sensing unit.

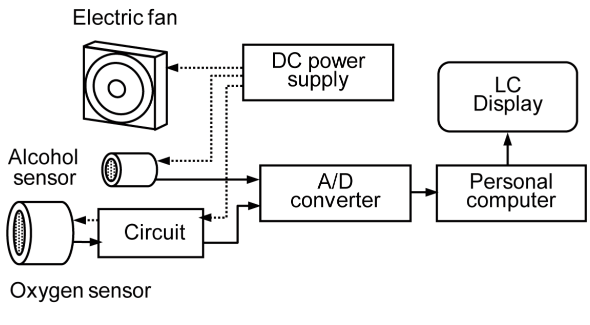


Fig. 2 Block diagram of measurement system.

$$[O_2]_{dil} = ([O_2]_{breath} - [O_2]_{base}) / ([O_2]_{peak} - [O_2]_{base}) \quad \cdots\cdots (1)$$

$[O_2]_{breath}$: Oxygen concentration in breath
$[O_2]_{base}$: Oxygen concentration in ambient air
$[O_2]_{peak}$: Peak value of the decrease of oxygen concentration which is measured with the oxygen sensor after diluted by ambient air

The dilution ratio of the breath alcohol ($[EtOH]_{dil}$) is described as below.

$$[EtOH]_{dil} = ([EtOH]_{breath} - [EtOH]_{base}) / ([EtOH]_{peak} - [EtOH]_{base}) \quad \cdots\cdots (2)$$

$[EtOH]_{breath}$: Ethanol concentration in breath
$[EtOH]_{base}$: Ethanol concentration in ambient air
$[EtOH]_{peak}$: Peak value of ethanol concentration which is measured with the alcohol sensor after diluted by ambient air

On the supposition that the dilution ratio of the oxygen in breath is equal to that of the ethanol in breath, $[O_2]_{dil} = [EtOH]_{dil}$, the ethanol concentration in breath ($[EtOH]_{breath}$) is calibrated by Eq. 3.

$$[EtOH]_{breath} = ([EtOH]_{peak} - [EtOH]_{base}) * ([O_2]_{breath} - [O_2]_{base}) / ([O_2]_{peak} - [O_2]_{base}) + [EtOH]_{base} \quad \cdots\cdots (3)$$

As mentioned above, the oxygen concentration in breath ($[O_2]_{breath}$) is known to be approximately 15% at 760 mmHg, so that the ethanol concentration in breath($[EtOH]_{breath}$) can be calculated by : 1) the ethanol sensor measurement which consists of the ambient air level ($[EtOH]_{base}$) and the peak level ($[EtOH]_{peak}$); and 2) the oxygen sensor measurement which consists of the ambient air level ($[O_2]_{base}$) and the peak level ($[O_2]_{peak}$). With the proposed system shown in Fig. 2, the calculation of breath ethanol concentration is completed within 3 seconds after the exhalation to the detector.

Also, Eq. 3 is applicable even if the breath is not diluted by ambient air—in the case of the current breath alcohol detector which requires a blowing through a mouthpiece. In such a case, Eq. 3 becomes Eq. 4 because ($[O_2]_{breath} - [O_2]_{base}$) is equal to ($[O_2]_{peak} - [O_2]_{base}$) in Eq. 3.

$$[EtOH]_{breath} = [EtOH]_{peak} \quad \cdots\cdots (4)$$

It indicates that Eq. 3 is applicable for any dilution ratio, including the case that the breath is not diluted by ambient air. Taguchi et al. (1994) reported a similar calibration method using a water vapor level in the breath that is measured by a humidity sensor instead of an oxygen sensor.[5] There are some advantages in using the oxygen level instead of the water vapor level. First, oxygen in breath can reach the detector even if at very low temperature. Second, the ambient oxygen level in a vehicle has better stability than the ambient humidity level. Therefore the oxygen calibration method is expected to yield better accuracy than the water vapor calibration method.

2. 3 Experimental Validation

Experimental validation of the contact free alcohol detector was conducted with the breath of the drunk subjects. Thirty–six healthy males and fourteen healthy females, ages 23–61 (50 subjects, mean age 39.3) participated in the experiment; all subjects had taken an alcoholic patch test on the skin (ASK Non-profit Corporation) beforehand to check the safety of drinking alcohol. They were informed about the purpose of the study and gave their consent to participate.

The procedure of the experiment was as follows. The subjects drank alcohol beverages for about two hours while eating snack. They exhaled to the alcohol detector at a distance of approximately 15 cm for 2-3 seconds before drinking and every 30 minutes while drinking; five measurements were carried out for each subject. They were informed to stop drinking and wait for 10 minutes before exhaling to ensure that mouth alcohol has dissipated. They also exhaled into the gas sampling bag (Tedlar Bag, manufactured from polyvinyl fluoride, GL Sciences Inc.), and the ethanol concentration of the expiration in the sampling bag was determined by means of gas chromatography, using Agilent Technologies 6890GC, as the accurate ethanol concentrations of the expiration. In addition, to compare the detection performance with the current breath alcohol detector, the breath alcohol concentration was also measured with an electro chemical (fuel-cell) type detector with a mouthpiece (ACS ALERT J4X.ec). The accuracy of the measurement of the proposed contact free alcohol detector was estimated by a statistical method using SPSS 13.0 package.

3. Results

An example of the response curves of alcohol sensor and oxygen sensor is shown in **Fig. 3**. As the result of the expiration of 2-3 seconds, the alcohol sensor output was increased, and the oxygen sensor output was decreased temporarily.

Figure 4 illustrates the correlation between the gas chromatography analysis and the alcohol sensor output for 250 measurements from 50 subjects, and **Fig. 5** shows the correlation between the gas chromatography analysis and the alcohol sensor output calibrated by oxygen in a breath sample for the corresponding 250 measurements. As shown in Fig. 4, the alcohol concentration calculated from the alcohol sensor output does not indicate a sufficient correlation with the ethanol concentrations measured by the gas chromatography, correlation coefficient r = 0.672, because the expiration is diluted by ambient air arbitrarily. In contrast, Fig. 5 reveals that the alcohol concentration calibrated by breath oxygen is significantly correlated with the ethanol concentrations measured by the gas chromatography, r = 0.929. The root mean square error of prediction (*RMSEP*) in the alcohol concentration calibrated by breath oxygen was 0.047 mg/L. In comparison, current fuel-cell type breath alcohol detector results in the correlation of r = 0.992 and *RMSEP* of 0.017 mg/L.

These results show that the calibration method for alcohol concentration using the oxygen level of driver's expired breath is effective for reducing the influence of fluctuations of alcohol sensor output caused by arbitrary dilution of the driver's expiration. Although the accuracy of the proposed detector is lower than that of the current fuel-cell type detector, this new detector has the potential to be used for a convenient breath alcohol detection device on board. It is known that the metal oxide semiconductor type alcohol sensors (solid-state sensors) respond to several volatile organic compounds other than ethanol.(3) It will be possible to improve the accuracy of the proposed alcohol detector by improving the selectivity of the alcohol sensor.

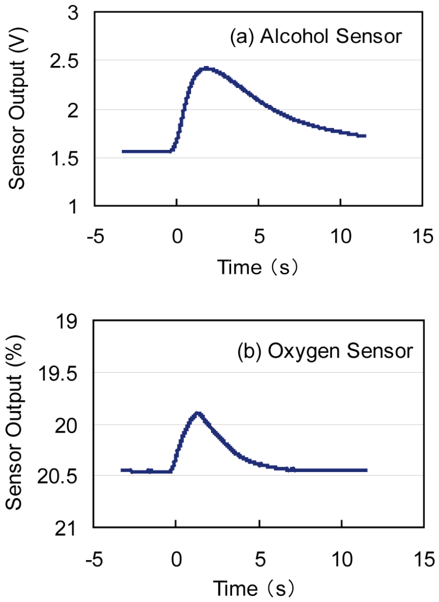


Fig. 3 Response curves of alcohol sensor (a) and oxygen sensor (b).

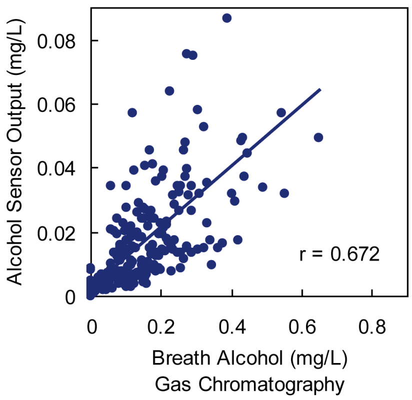


Fig. 4 Correlation between the gas chromatography analysis and the alcohol sensor output for 250 measurements from 50 subjects.

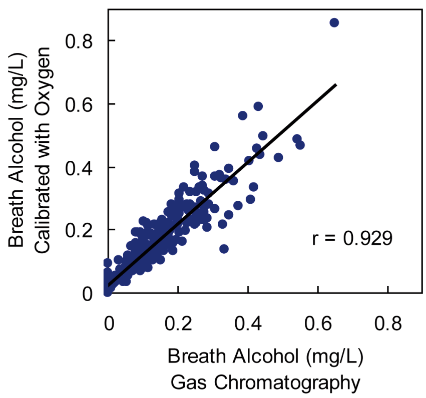


Fig. 5 Correlation between the gas chromatography analysis and the alcohol sensor output calibrated with oxygen in a breath sample for 250 measurements from 50 subjects.

4. Conclusion

A novel detector of breath alcohol, a contact free alcohol detector, has been proposed. It consists of an electric suction fan, an alcohol sensor and an oxygen sensor mounted in a gas flow passage. A mouthpiece is not required for the detection because driver's breath sample is captured and directed to reach the sensors through the gas flow passage by the electric suction fan. The influence of fluctuations of alcohol sensor output caused by arbitrary dilution of the driver's expiration is extremely reduced by the calibration of alcohol concentration using the oxygen level of driver's expired breath that is measured simultaneously with the alcohol content. The detector is able to measure breath alcohol concentration rapidly and easily, compared with the current breath alcohol detectors which require a blowing through a mouthpiece. Good accuracy has been demonstrated in an experiment with the drunk subjects. Although further investigations are necessary for implementation of such a device on board, the proposed breath alcohol detector will contribute to the prevention of alcohol-impaired driving in the near future.

References

(1) National Police Agency (Japan), Fatal Traffic Accidents in 2007 (in Japanese), (2008), p.30, National Police Agency.

(2) National Police Agency (Japan), Traffic Accidents Situation in 2007 (in Japanese), (2008), p.34, National Police Agency.

(3) Pollard, J. K., Nadler, E. D. and Stearns, M. D., "Review of Technology to Prevent Alcohol-Impaired Crashes (TOPIC)", DOT HS 810 833 (2007), NHTSA.

(4) Furukawa, T. and Honda, Y., *Modern Textbook of Physiology 3rd edition* (in Japanese), (1994), pp.673-681, Kaneharashuppan.

(5) Taguchi, T., Inagaki, H., Atsumi, B. and Kimura, K., "Study of Breath Alcohol Detector", *JSAE Review*, Vol.15 (1994), pp.229-233.

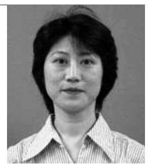
Toshiyuki Taguchi

Research Fields:
- Human Factors
- Biological Engineering

Academic Societies:
- Society of Automotive Engineers of Japan
- Japanese Society for Medical and Biological Engineering

Award:
- JSAE Outstanding Technical Paper Award (2000)

Kiyomi Sakakibara



Research Fields:
- Human Factors
- Environmental Biotechnology

Academic Societies:
- The Society of Instrument and Control Engineers
- The Japanese Association for the Study of Taste and Smell
- Human Interface Society
- Japan Ergonomics Society
- Society of Automotive Engineers of Japan

Atsushi Nakashima

Research Field:
- Human Factors

Academic Society:
- Human Interface Society

Toshihiro Wakita

Research Field:
- Human Factors

Academic degree: Dr. of Information and Computer Science

Academic Societies:
- IEICE
- Society of Automotive Engineers of Japan

Shohei Yabu*

Research Field:
- Vehicle interior design

Bunji Atsumi*

Research Fields:
- Research and Development of Anti-drunk Driving System
- Advanced Development in Vehicle Human Factors Area
- Development of the New Items for Reduce the Driving Fatigue or Stress
- Chairman of JAMA Anti-drunk Driving Technology Working Group

Academic societies:
- Japan Ergonomic Society
- Society of Automotive Engineers of Japan

Awards:
- JSAE Fellow Grade (2010)
- JSAE Award of Merit in JSAE activity (2007)
- JSAE Outstanding Technical Paper Award (2005)

*Toyota Motor Corporation