Simultaneous detection of breath and alcohol using breath-alcohol sensor for prevention of drunk driving

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Abstract: Safety measures concerning drunk driving are the major technical challenges in the car industry. We have developed systems to prevent drunk driving by applying our new, non-contact breath-alcohol sensor in which our original breath sensor is coupled with an alcohol sensor. The breath sensor detects breath by measuring electric currents of positively or negatively charged water clusters in breath that are separated by using an electric field. Our breath-alcohol sensor simultaneously detects the electrical signal of breath and alcohol in breath. This insures that the sample is of a person's breath, not an artificial source.

Keywords: breath, alcohol, sensor, drunk driving

Classification: Electronic instrumentation and control

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1 Introduction

Governments have attempted to prevent alcohol-impaired driving primarily through a system of laws, enforcement, and sanctions. Unfortunately, these laws are frequently violated. Vehicle-based alcohol detection systems prevent a person with a positive blood alcohol concentration (BAC) from starting or operating a vehicle. In the United States, current alcohol detection systems are used almost exclusively on vehicles of convicted driving-while-intoxicated (DWI) offenders as a condition of probation or driver license reinstatement. Current breath alcohol ignition interlock devices use either fuel cell or solid-state sensors. Most current interlock devices use the well-established fuel cell technology used in many evidential breath test devices [1]. In addition, the Swedish automobile manufacturer, Volvo, has developed a breath test device intended for use in an ignition interlock system through collaboration with Alcohol Countermeasure Systems Corp. [2].

The main obstacle to using an ignition interlock breath test as optional equipment for general drivers is that it is both invasive and obtrusive. This means that it requires a driver's to actively provide a breath sample through a mouthpiece. An additional issue that must be addressed if alcohol ignition interlocks are to be used more widely is preventing circumvention (providing a sample using an artificial source and drinking while driving after starting a vehicle) [1].

To overcome these difficulties, we have investigated various safety measures against drunk driving. Recently, we have discovered that expired gas includes both positively and negatively charged water clusters and that a person's breath can be easily detected using this information. In addition, we have also shown that this breath sensor is easily coupled with an alcohol sensor. We discuss the first results from our non-contact breath-alcohol sensor, which simultaneously detects the electrical signal of breath and alcohol in breath to prevent circumvention.

2 Breath-alcohol sensor

Figure 1 (a) shows the configuration of our breath-alcohol sensor. This sensor consists of a breath sensor unit and an alcohol sensor unit.

Generally, expired gas contains water clusters that have a saturated vapor pressure of 47 mmHg and a temperature of about 37°C [3]. We have recently discovered that water clusters in expired gas can be easily separated into positively and negatively charged ones by applying an electric field. Therefore, we can easily detect these charged water clusters from a person blowing between parallel plate electrodes comprising a counter electrode, to which

a voltage is applied, and a detection electrode connected to a picoammeter. Small charged water clusters are easily deflected by using an electric field to collide with the detection electrode to generate electric currents. This sensor is much more compact than mass spectrometry to detect electric currents of ions [4].

The alcohol sensor head, which is based on a solid-state sensor in the alcohol sensor, is installed just above the counter and detection electrodes in the breath sensor unit, as shown in Figure 1 (a). As a result of this configuration, breath and alcohol peaks resulting from one blow can be simultaneously detected. In our experiments, solid-state sensors were used as the alcohol sensor because they respond quicker than fuel cell sensors.

Fig. 1. (a) Diagram of breath-alcohol sensor, and (b) serial detection example of breath. (1) Picoammeter, (2) power supply, (3) detection electrode, (4) counter electrode, (5) alcohol sensor head, (6) large charged water cluster, and (7) small charged water cluster.

3 Results and discussion

Figure 1 (b) shows the results of serial measurements of a test subject's breath (male in his 50s) using our breath sensor. The vertical axis represents the signal intensity in the breath peak (the voltage difference between the top and base line in each peak) in volts, while the horizontal axis represents time in seconds. One breath peak corresponds to one breath. These results show that breath measured using our developed breath sensor distinguishes one breath from another. During the test, the distance between the subject and the breath sensor was about 8 cm. The voltage applied to the counter electrode was -750 V with the counter and detection electrodes 10 mm apart. Negatively charged water clusters were detected using the detection electrode in this experiment, although almost the same results were obtained for positively charged water clusters.

To prove that the breath sample is of a person, not an artificial source, we have compared breath peaks obtained by our sensor with artificial peaks. Several types of artificial sources have been investigated, including an air pump coupled with a stainless water-container, which we found to be the most effective artificial source to produce peaks similar to those of our sensor. In this experiment, water was put into a stainless water-container (volume: 500 ml) and was well-temperature controlled to provide saturated vapor by an air pump (pumping speed: 5 L/min). The temperature and degree of vapor humidity were about 20°C and 98%, respectively, at a point 8 cm away from the opening of the stainless water container. The test subject's breath was almost the same as this (the temperature and degree of vapor humidity were about 20°C and 96%, respectively, at a point 8 cm away from his mouth). The expiration time of breath was 3 seconds, and therefore the driving time of the air pump was set to 3 seconds in this experiment.

Figure 2(a) shows the variation in the full width at half maximum (FWHM) values of the breath peaks and the artificial peaks with the voltage applied to the counter electrode. Five measurements were carried out at each voltage (500, 750, 1000 and 1250 V). The vertical axis represents the FWHM values in seconds, while the horizontal axis represents the voltage applied to the counter electrode in volts. The circles and squares indicate the values of breath peaks and artificial peaks, respectively. The FWHM values do not depend on the voltage in breath peak, while the FWHM values become lower as the voltage lowers at artificial peaks. We consider that this is because breath can produce finer and more uniformly sized clusters than an artificial source. As an example, see the breath peak and the artificial peak at the voltage of 500 V in Figure 2(b) and (c), respectively. The breath peak is clearly twice

Fig. 2. Comparison between breath peaks and artificial peaks. (a) FWHM changes as voltage applied to counter electrode (circles: breath, squares: air pump), (b) breath peak at 500 V, and (c) artificial peak at 500 V.

as wide as the artificial peak, and we can easily distinguish between them.

A breath sensor has never been reported that measures the electric currents of charged water clusters in breath, although several methods have been developed for measuring the gas flow rate of breath such as anemometer and detecting chest or abdomen motion such as plethysmography [5, 6, 7, 8]. Compared to these methods, our water-cluster-detecting breath sensor is non-invasive and non-obtrusive and insures that the breath sample is of a person, not an air pump or other artificial sources.

The detection process of charged water clusters can be approximately analyzed by measuring the motion of charged water clusters in the direction of the gravitational force (air resistance, buoyant force, and gravitation) and at right angles to that direction (air resistance and force of electric field). The details of this analysis will be discussed elsewhere.

Figure 3(b) shows the detection results obtained from the expired gas of the subject 30 minutes after drinking 200 ml of whisky and water (alcohol content: 10%) using our breath-alcohol sensor. The sensor was set just behind a steering wheel of a car mock-up, as shown in Figure 3(a). The vertical axis represents the voltage differences observed in the breath and alcohol peaks (the difference between the top and base line in each peak) in volts, while the horizontal axis represents time in seconds. During the test, the subject and the breath-alcohol sensor were about 8 cm apart. To easily distinguish between the breath peak from the breath sensor and the alcohol peak from the alcohol sensor, the output of the alcohol peak is inverted in this figure. The upper curve in the figure corresponds to the breath peak, while the lower peak corresponds to the alcohol peak. The peak tailing of the alcohol peak is larger than that of the breath peak, which is mainly due to the feature of semi-conductor alcohol sensors.

The standup position of the breath peak is almost the same as that of the alcohol peak (20.0 sec). Moreover, the peak-top position difference between the two peaks was much smaller (0.2 sec in this case) than the FWHM value of the alcohol peak (8.4 sec). These results show that breath and alcohol peaks in breath containing alcohol can be simultaneously detected by using

Fig. 3. (a) Photograph of breath-alcohol sensor just behind steering wheel of car mock-up, and (b) simultaneous detection of breath and breath-alcohol.

our breath-alcohol sensor.

These features of our breath-alcohol sensor shown in Figure 3(b) are important for preventing the use of an artificial breath sample and insuring that a breath sample is of a person. Additionally, this breath-alcohol sensor requires no-contact and is easy to use. This means that our breath-alcohol sensor can be used for preventing drinking while driving after starting a vehicle.

We have gathered data for quantitative analysis by conducting experiments on alcohol consumption with subjects from different demographics (male and female, young and old). The details will be described elsewhere.

Experiments involving alcohol being drunk were carried out after approval by the ethical review board of Hitachi, Ltd. I obtained informed consent from all study subjects.

4 Conclusion

We developed a new breath-alcohol sensor and described its operational principle and characteristics. We showed that our breath sensor detects expired gas highly sensitively by using the newly discovered fact that water clusters in breath are easily separated into positively and negatively charged ones by using an electric field. By exploiting this characteristic, our breath-alcohol sensor was shown to detect alcohol in expired gas after confirming the sample was actually of a person's breath. While the sensor is being further optimized, testing of a system for preventing drunk driving will continue.

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