

ASSESSMENT OF DERMAL ETHANOL EMISSION SENSORS: EXPERIMENTAL DESIGN

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ABSTRACT

This paper discusses methods that will be used to experimentally determine the limitations of transdermal ethanol alcohol sensors when used on human subjects. Transdermal ethanol sensors are used to measure the concentration of ethanol emitted by the surface of the skin. The maximum concentration of ethanol in the skin is proportional to the concentration of ethanol in the blood stream but is offset temporally because of the diffusion delay intrinsic to body tissue. Methods to evaluate different model ethanol sensors are discussed as well as the development and function of a portable, transdermal ethanol sensing device suitable for measuring ethanol concentration on the palm of a test subject's hand. In addition, the designs of several experiments are described to test the functional limitations of transdermal ethanol sensors in practical use settings. These experiments include tests to correlate a subject's peak blood and skin ethanol concentrations and experimental determination of different false positive sources.

Keywords: Ethanol, Dermal, Transdermal, Sensor

INTRODUCTION

In the U.S., an estimated 17,000 persons die each year in traffic crashes in which alcohol was a contributing factor (NHTSA, 2006). This continuing problem has motivated a search for new methods to detect intoxicated drivers. Alcohol, once ingested, is absorbed into the blood through the gastrointestinal tract and travels about the body where it is absorbed by the tissues including fat and skin. Alcohol is primarily removed by the liver but approximately 0.7% of the alcohol consumed exits the body through exhaled breath; and a small quantity, 0.1%, is excreted through the skin as sweat (Ramchandani, 2001).

Knowledge of how the body absorbs, digests and excretes alcohol has led to several different methods to assess blood alcohol concentration. The most direct method is to draw blood from the subject and measure the alcohol concentration in a laboratory using gas chromatography. Although highly accurate, this method has the detriment of being both invasive and time consuming which make it impractical for field use. Another method to measure blood alcohol concentration is the use of a device called a breathalyzer. These devices require the subject to exhale into a chamber where an ethanol fuel cell sensor analyzes the concentration of alcohol in the subject's breath. Then using known correlations between the blood and exhaled gas alcohol concentrations the subject's blood alcohol concentration is calculated.

A promising alternative to both these methods is to measure blood alcohol concentration through the use of sensors placed over the skin. Because body tissue also absorbs the alcohol in the blood stream, a subject who has ingested alcohol will have a skin tissue alcohol concentration comparable to their blood alcohol concentration. Giles et al (1987) has shown that non-invasive measurements made on the surface of the skin using low cost semiconductor based ethanol sensors can accurately predict the blood plasma concentration of alcohol in ethanol positive (alcoholic) subjects. Swift et al (1992) showed that dermal alcohol concentration measurements made on the arms of social drinkers over time are proportionally similar to curves generated by breathalyzer measurements made at the same time; but are

offset temporally by the time it takes the alcohol to diffuse through the skin. In Swift's experiments the lag time between the peak breathalyzer and transdermal alcohol measurements was approximately half an hour.

Previous work has shown that sensing alcohol through the skin is an effective non-invasive determinant of blood alcohol concentration; however there are limitations. The diffusion lag of ethanol into tissue can result in under-prediction of a subject's current blood alcohol concentration. In addition, contamination at the sensing site can also affect transdermal measurement. Ethanol and other substances containing volatile liquids, such as aftershave, perfume and hand sanitizers, have been noted to significantly affect the dermal alcohol concentration if present at the site of measurement.

The objective of this paper is to discuss the design of a series of experiments to determine, classify and quantify the limitations inherent to dermal sensing of blood alcohol concentration.

METHODS

Ethanol Sensor Evaluation

There are several low cost, commercially available ethanol sensors on the market which manufacturers suggest are suitable for breathalyzer or ethanol detection applications. The four sensors given in Table 1 will be tested for accuracy, response time and precision.

Table 1. Alcohol Sensors

Manufacturer	Model	Diameter (mm)
HanWei	MR513	12
HanWei	MQ-3	20
Figaro	TGS 822	17
Figaro	TGS 2620	9.2

In all four sensors the active element is SnO₂ which varies in electrical resistance proportional to the concentration of ethanol present in the surrounding gas. The SnO₂ crystals absorb oxygen in a temperature dependent manner, which negatively charges the crystal. This negative charge impedes the flow of current through the crystal. When an atmosphere containing a deoxidizing gas, such as ethanol, is present, there are fewer oxygen molecules available for absorption, reducing the negative charge on the crystal surface; thus reducing the crystal's resistance to electrical current (Figaro, 2004). When properly connected the sensors produce a voltage signal proportional to the concentration of ethanol.

The sensors will be mounted on a single printed circuit board (PCB) designed specifically to accommodate each sensor's footprint. The four sensors will be clustered in close proximity so that when exposed to ethanol vapors all will experience the same level of concentration as shown in Figure 1. Also included on this evaluation board will be a programmable Microchip PIC16F648A microcontroller with a built-in analog to digital converter that will be used to measure the voltage output of the alcohol sensors. After performing the analog to digital conversion the microcontroller will transmit the voltage measurements to a personal computer where the data will be stored for later analysis.

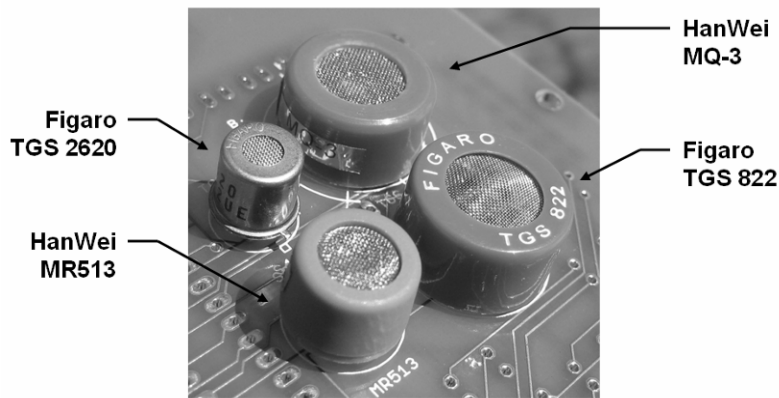


Figure 1. Sensor Cluster on PCB

Test Matrix

Several experiments will be performed using the ethanol sensors to fulfill the research goals of this study. A brief overview of the approach is given in Table 2.

Table 2. Test Matrix

Test Battery	Name	Purpose
1	Bench Calibration/Sensor Evaluation Tests	Validation and calibration of candidate sensors in an ethanol-water vapor bath of known concentrations.
2	Dermal vs. Breathalyzer Measurement Tests	Characterize relationship between breath and skin ethanol concentrations, evaluation of portable transdermal measurement device.
3	Limitation Tests	Examination of methods to trigger false positive readings.

Test Battery 1: Bench Calibration/Sensor Evaluation Tests

In order to evaluate each of the sensors for accuracy, response time and precision, several experiments will be performed using the evaluation PCB. The sensor cluster will be exposed to the headspace of a closed vessel containing a solution of pure ethanol dissolved in distilled water as shown in **Error! Reference source not found.**Figure 2. The theoretical ethanol concentration in the head space will be calculated based on the known masses of solute and solvent and the temperature of the mixture. The actual ethanol vapor concentration will be validated using a gas chromatograph.

The voltage output of each of the sensor's drive circuits and the gas temperature will be measured and recorded once a second by the microcontroller. The voltages will continue to be recorded until all of the values have reached steady state. At this point the sensors will be removed from the headspace. The concentration of the solution will be changed to reflect a different ethanol gas concentration in the head space. This will be done for a total of five different concentrations of ethanol, including a control of 0 mg/dl ethanol concentration.

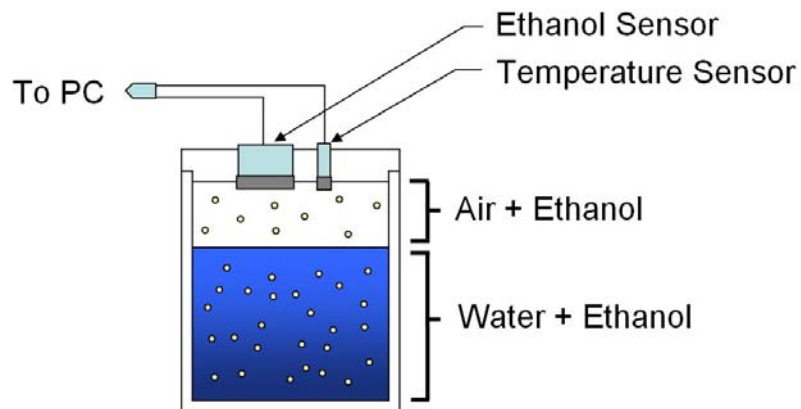


Figure 2. Calibration Setup

Analysis of the data collected from this experiment will allow the performance of each sensor to be compared and contrasted. It will also reveal the response speed of each sensor by calculation of the time required for the signals to reach equilibrium. Additionally, since the concentration of ethanol in the head space is known, a conversion value can be calculated for each of the sensors to translate their voltage output values to ethanol concentration in parts per million (ppm). Following the analysis of the data collected, the sensor best suited for use in a field test unit will be the sensor that is the best compromise between accuracy and reaction time.

Field Test Device

The selected ethanol sensor will be packaged into a portable stand-alone unit. The unit will be used to measure the dermal ethanol alcohol concentration of subjects participating in the experiments that will be described in Test Batteries 2 and 3.

There are several requirements for the field test device: The first is that the device must be rugged and extremely easy to use for both the test subject and the person administering the experiment. The device must be designed to accommodate test subjects who may exhibit deficits in coordination, reaction time and judgment. The device should allow the test subject to easily cover the ethanol sensor with the palm of his or her hand, automatically determine when the signal has equilibrated, measure temperature, display the measurements to the subject, have auditory outputs to indicate when the sample has equilibrated and be able to wirelessly transmit the measured values to a PC or laptop for data collection.

Figure 3 is a block diagram for a portable, embedded system that accomplishes all of the requirements stated previously.

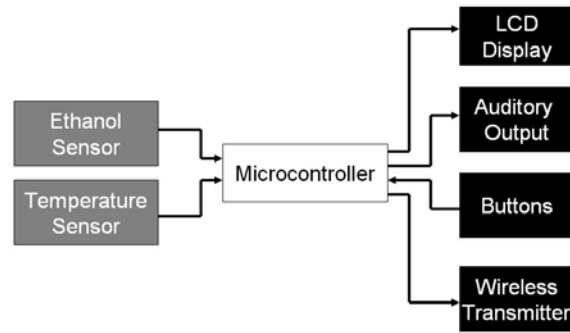


Figure 3. Field System Components

Test Battery 2: Breath and Transdermal Measurement Correlation

This test series will examine the relationship between the breathalyzer ethanol concentration and dermal ethanol concentration as measured by the field test device. In this test series, breathalyzer measurements will be used as a surrogate for blood alcohol concentration.

To develop a correlation between a subjects’ BAC and the measurement made using the field test device, subjects will be asked to drink alcoholic beverages at specific doses and intervals and breathalyzer and transdermal ethanol measurements will record the results. It is known that age, gender, ethnicity and the type of alcoholic beverage as well as other physiological conditions specific to the test subject affect the transport of alcohol through the body. The scope of the following tests is to correlate the maximum BAC recorded with maximum transdermal ethanol concentration recorded in effort to define the value of a ‘positive’ transdermal ethanol measurement.

Two different drink dose patterns are planned. In the first test the subjects will only consume one alcoholic drink over the course of 15 minutes. The second test will require that the subject consume two alcoholic drinks in half an hour. A standard “alcoholic drink” will be any alcoholic beverage containing 0.6 oz of pure alcohol. Breathalyzer and transdermal measurements will be made every 10 minutes after the consumption period until breathalyzer BAC values become negligible. For the initial test series, ten test subjects will be used, five male, five female, of varying age and ethnicity for both tests. Later test series will examine the response of an expanded number of test subjects. The blood and dermal ethanol concentrations are expected to reach a peak and then slowly decline; the magnitude of the peak is of interest in this experiment. The data gathered from this experiment will help to establish the relationship between maximum dermal ethanol concentration and maximum BAC. The time series data recorded for each subject will also allow determination of the time lag between peak BAC and peak transdermal ethanol concentration.

Ultimately, the data from this initial set of experiments and follow-on tests will allow the dermal ethanol concentration to be calculated that correspond to a BAC of 0.08%, a widely used legal intoxication limit. This will set the threshold for transdermal ethanol false positive readings, meaning the dermal ethanol concentration at which a subject’s BAC would have corresponded to a legal intoxicated value.

Test Battery 3: False Positive Evaluation Tests

These tests will address the additional issue of false positive readings caused by contamination at the measurement site. Giles et al (1987) noted that the use of alcohol containing products on the skin can

yield false positive readings of ethanol concentration. If transdermal characterization of blood alcohol concentration using semiconductor based sensors is to be used this will be a major obstacle because many consumers use such products every day. Hand sanitizers, aftershave, perfume, cologne and hand wipes all contain varying amounts of alcohol.

First, the substances that can lead to a false positive will be determined. Next, we will determine how long there is a significant false positive agent presence in the skin after these products are used. The test subjects will use one of the products and dermal measurements will be made every 10 minutes until there is no longer a significant reading. This will be repeated five times for each product for an initial sample of ten test subjects of varying age, gender and ethnicity. This experiment will help to qualitatively characterize how these products can interfere with dermal measurement. The test subjects will be asked to not use any other skin product prior to the experiment.

CONCLUSIONS

This paper outlined a research program to evaluate the utility of four commercially available, inexpensive semiconductor based ethanol sensors for use as instruments to measure dermal ethanol concentration. Following the evaluation a single sensor will be selected for incorporation into a portable, easy to use dermal ethanol sensor for use in experimentation. The experiments that will be performed using this device are designed to explore the limitations of dermal skin measurements when looking for the presence of ethanol. The most significant of these experiments are designed to explore the methods that can cause false positive readings when measuring the ethanol concentration on the palms of test subjects. Of interest are the types of products and/or situations that can lead to false positive readings and the time it takes for these false positive readings to abate. The conclusion and analysis of these experiments will lead to a better of understanding of the obstacles that will be encountered in an automated setting where dermal measurements will be made to determine the sobriety of a subject.

REFERENCES

1. Giles, H. G., S. Maggiorini, G. E. Ranaud, J.J. Thiessen, E.I. Vidins, K.V. Compton, V. Saldivia, H. Orrego, and Y. Israel. "Ethanol Vapor Above Skin: Determination by a Gas Sensor Instrument and Relationship with Plasma Concentration." Alcoholism: Clinical and Experimental Research 11 (1987): 249-253.
2. Guyton & Hall, Textbook of Medical Physiology, 11th Ed. Elsevier, Philadelphia. 2006
3. Swift, Robert M., Christopher S. Martin, Larry Swette, Anthony Laconti, and Nancy Kackley. "Studies on a Wearable, Electronic, Transdermal Alcohol Sensor." Alcoholism: Clinical and Experimental Research 16 (1992): 721-725.
4. Ramchandani, V.A., Bosron, W.F., Li, T.K. "Research advances in ethanol metabolism." Pathol Biol 49 (2001): 676-82
5. NHTSA, Traffic Safety Facts 2005, Early Edition, pp. 54, National Traffic Safety Administration, U.S. Department of Transportation, Washington, DC, Report No. DOT HS 810 631 (November 2006)
6. "General Information for TGS Sensors." 2004. 4 Dec. 2006 <<http://www.figarosensor.com/>>.