EXPERIMENTAL PROOF-OF-PRINCIPLE OF IN-VEHICLE PASSIVE BREATH ALCOHOL ESTIMATION

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Abstract

The reported work is highly related to the DADSS (driver alcohol detection system for safety, [3]) program, and other related initiatives aiming at the prevention of drunk driving. The possibility of breath alcohol estimation in highly diluted breath samples in a vehicle cabin by using carbon dioxide as a tracer gas to compensate for the dilution has been demonstrated and evaluated elsewhere [4-12]. The infrared sensor technology developed by SenseAir AB, Sweden, is enabling unprecedented sensor performance [9]. However, passive breath alcohol detection requiring no cooperation from the driver has remained a major technological challenge. The aim of the present investigation is to obtain experimental proof-of-principle of completely passive, in-vehicle estimation of breath alcohol concentration. A prototype sensor system has been integrated with the casing of the upper steering column within a vehicle. Human subjects, some of them intoxicated by alcohol, are instructed to enter the vehicle and perform a simulated driving task while breathing normally. Sensor signals corresponding to alcohol and CO_2 concentration at the sensor position are recorded and analyzed off-line. The sensor CO_2 signal pattern includes peaks corresponding to increasing CO_2 concentration in expired air reaching the sensor position after leaving the subject's mouth or nose. These peaks will coincide with peaks in the alcohol signal from an intoxicated subject. From the peak magnitudes an algorithm for breath alcohol estimation has been devised. The results indicate that peaks from normal breathing are readily detectable and quantifiable by the sensors, although the dilution factor DF (ratio between expired and actual concentration measured by the sensor) may be as high as several hundred at the steering column sensor position.

Key words. Automotive Safety, Unobtrusive Breath Alcohol Analyzer, Infrared Gas Sensor, Passive Gas Measurement

Introduction

Although a vast majority of vehicle drivers are sober, the number of fatalities and serious injuries related to drunk driving is unproportionately high. The estimated societal costs with drinking driver as the cause corresponds to a total amount of 34 billion USD [1]. According to investigations of the risk to be involved in an accident, there is a sharp increase at high alcohol concentrations [2]. Preventing highly intoxicated people from driving would potentially save many lives.

In this paper results are reported from a study of passive breath alcohol estimation in vehicles. The work is part of the DADSS (driver alcohol detection system for safety, [3]) program, and related to other initiatives aiming at the prevention of drunk driving. The possibility of breath alcohol estimation in diluted breath samples in a vehicle cabin by using carbon dioxide as a tracer gas to compensate for the dilution has been demonstrated and evaluated elsewhere [4-12]. The results are building on the subsequent development of infrared sensing technology led by SenseAir, Sweden.

Completely passive breath alcohol detection requiring no cooperation from the driver has remained a major technological challenge. Important aspects to consider are time to classification and reliability of the measurement.

Methods

Passive measurement of breath alcohol require monitoring of sensor signals in real time. The sensor also needs to respond to biological stimuli related to exhalations, i.e. a reliable tracer gas is needed. In the present sensor design both EtOH and CO_2 was measured utilizing infrared spectroscopy. The CO_2 measurement enables biomarker detection and accounts for the dilution of the breath sample according to

$$DF = \frac{CO_{2\,End\,exp}}{CO_{2\,Meas}} \qquad \text{(eq. 2)}$$

Where DF represents the dilution factor of the breath sample, $CO_{2\,End\,exp}$is the nominal CO_2 concentration of a shallow expiration and $CO_{2\,Meas}$ denotes the measured CO_2 concentration of a locally observed peak.

The sensor was placed inside a purpose built housing and integrated on the upper steering column, figure 1. The sensor system, including the sensor sampling at 5Hz and a fan generating an air flow, was energized from the vehicle battery via a power switch. The setup enabled the following evaluation protocol. A human subject entered the vehicle, sat down in the driver's seat, powered the sensor system by the push of a button, put on the seat belt, acted like driving for approximately 10 minutes, shut the sensor system, removed the seat belt and finally exited the vehicle.

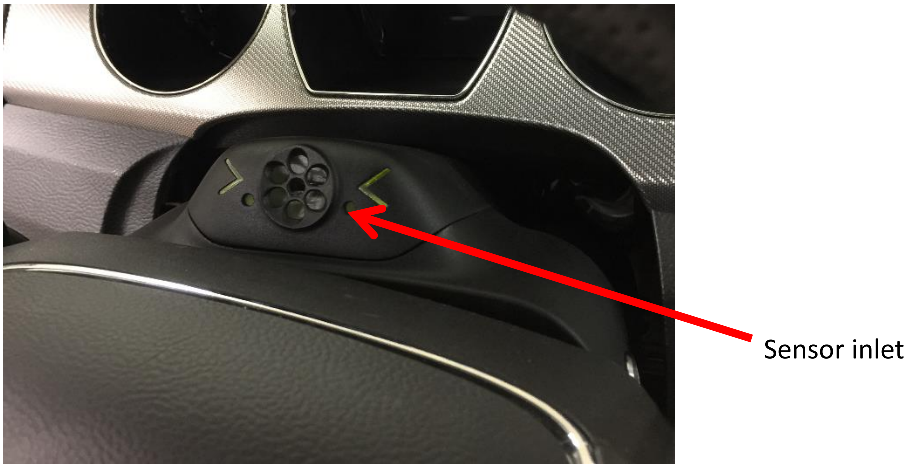

Figure 1: Breath alcohol sensor integrated on the upper steering column.

All together ten subjects took part in the study. Out of these seven subjects were sober and three intoxicated. The sober subjects provided five repetitions each. The intoxicated subjects were given 0.8 g of alcohol per kilogram of body mass. For the intoxicated group the repetitions continued until the breath alcohol concentration was below 0.03 mg/L. Each repetition also included a test in an evidential standard breath alcohol testing instrument (Evidenzer, Nanopuls AB, Sweden).

The data recordings have been evaluated with respect to the measured CO_2 peaks. The occurrence of peaks as well as the magnitude of the measured peaks have been evaluated. From this information an estimated required sensor resolution was estimated. The evaluation also includes correspondence between ethanol and CO_2 in measurements where both gases are present.

Results

Recorded CO_2 and ethanol signals from a sober subject are shown in figure 2. The peaks, marked with black circles, were selected based on an algorithm utilizing strong waveform derivative. The concentration contribution from each peak was determined by calculating the difference between each peak and a baseline value directly before the corresponding peak, marked with green circles. That is:

$$CO_{2\,Meas} = CO_{2\,Peak} - CO_{2\,Base} \qquad \text{(eq. 2)}$$

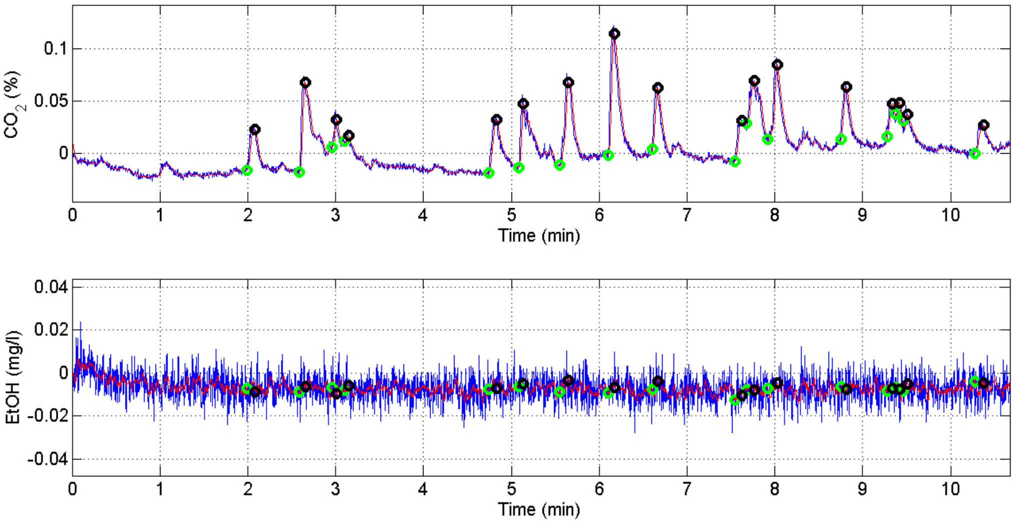

Figure 2: Data recorded from a sober test subject. Upper graph: Measured CO2 concentration increase. Lower graph: Ethanol signal. The baselines of the recordings are quite arbitrary therefore negative number may occur.

Altogether 77 measurements were recorded totaling 631 minutes of measurement time. Throughout the entire duration of that time span 299 CO_2 peaks were detected. Hence, on average, a new peak was detected every other minute. The occurrence of peaks for each subject is given in table 1. The observed variation in peak occurrences between subjects was quite significant. As an example, in the recordings from subject 6 a new peak was found within 30 seconds whereas subject 1 required 10 minutes until a new peak was found.

Table 1: Occurrence of CO2 peaks in relation to measurement time. On average two minutes was required to detect a new peak. However, rather large variation between subjects was observed.

	Subject										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Tot**
Meas. Time (min)	34	46	35	27	23	55	39	130	115	127	**631**
Meas. Peaks	3	9	16	3	14	110	9	88	34	13	**299**
Peak freq. (peaks/min)	0.09	0.2	0.46	0.11	0.61	2	0.23	0.68	0.3	0.1	**0.47**
Time to peak (min)	11	5	2.2	9	1.6	0.5	4.3	1.5	3.3	10	**2.1**

The quality of the peaks is directly related to the magnitude. A measure of the magnitude is the dilution factor, given in eq. 1. The equation gives higher peak magnitude the lower the measured dilution factor. For all 299 peaks the dilution factor was calculated and plotted in a histogram, figure 3. The dilution factor spanned from 25 up to 762. The distribution was clearly skewed towards lower dilutions with a median value at 152.

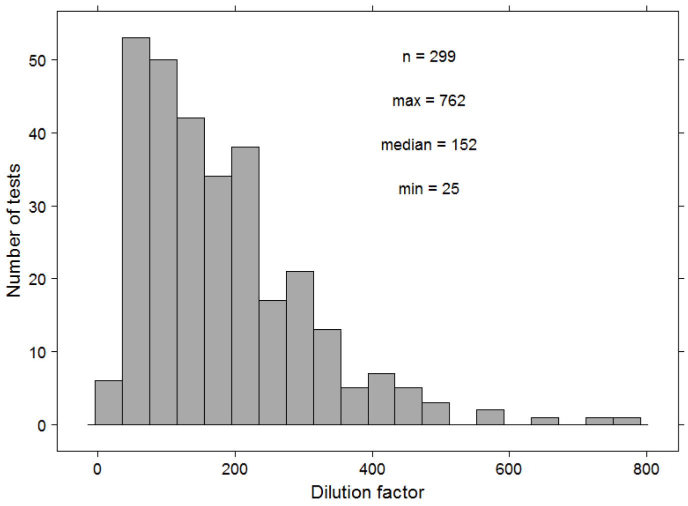

Figure 3: Histogram showing the occurrence of observed peak magnitude.

In figure 4 a measurement with an intoxicated subject is shown. The CO_2 signal, in the upper graph, behavies in a similar fashion as for the sober subjects. However, there are small peaks in the ethanol signal, shown in the lower graph. These movements coincide in time with the CO_2 peaks.

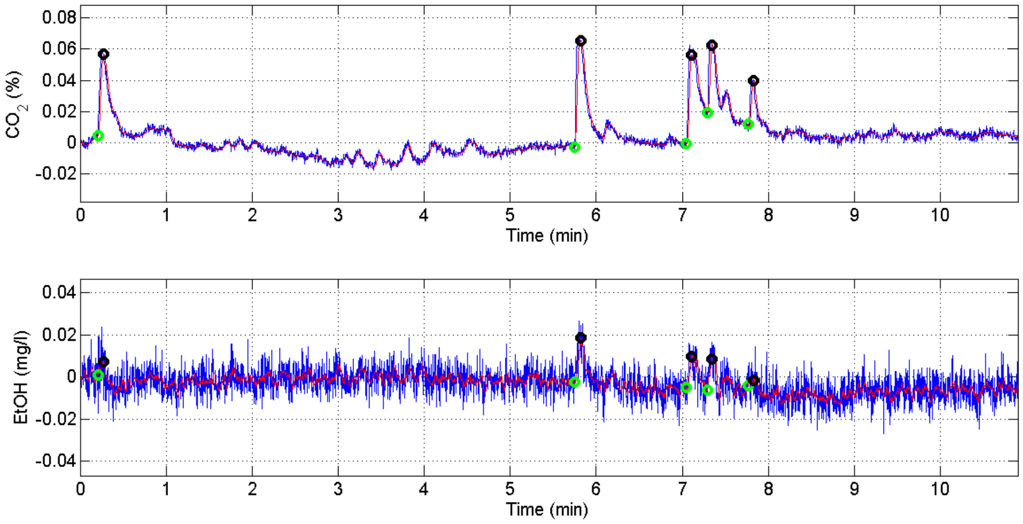

Figure 4: Signals measured from an intoxicated subject. Upper graph: CO2 concentration increase. Lower graph: Ethanol concentration increase.

The two graphs in figure 5 shows measured ethanol in peaks collected from sober subjects, left, and intoxicated subjects, right. The solid line symbolizes the breath alcohol concentration used as the legal limit for drunk driving in the US, i.e. 0.4mg/L, observed at increasing dilution. At lower dilutions, ethanol gas could be resolved from the noise floor. The noise floor is marked in the figure at a 3σ level with dotted lines.

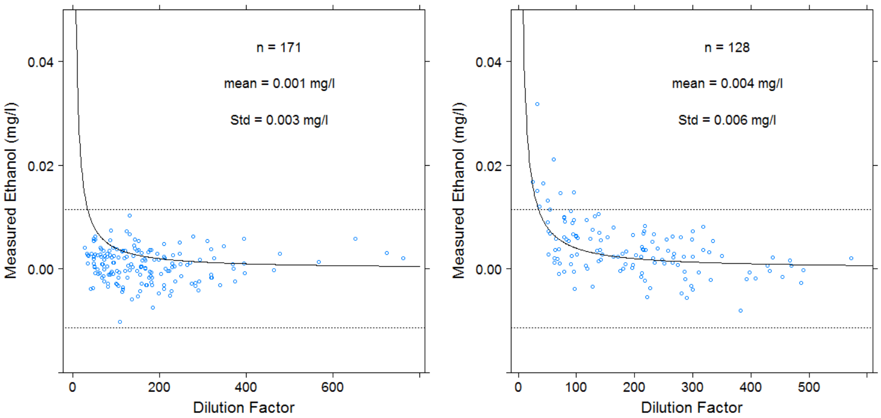

Figure 5: Magnitude of measured ethanol peaks. Left: Sober subjects. Right: intoxicated subjects.

Applying (eq. 1) multiplied with the measured alcohol concentration gives an estimation of the subject's breath alcohol. The practice provides the results shown in figure 6, where the estimated breath alcohol is compared to a reference instrument in scatter plots.

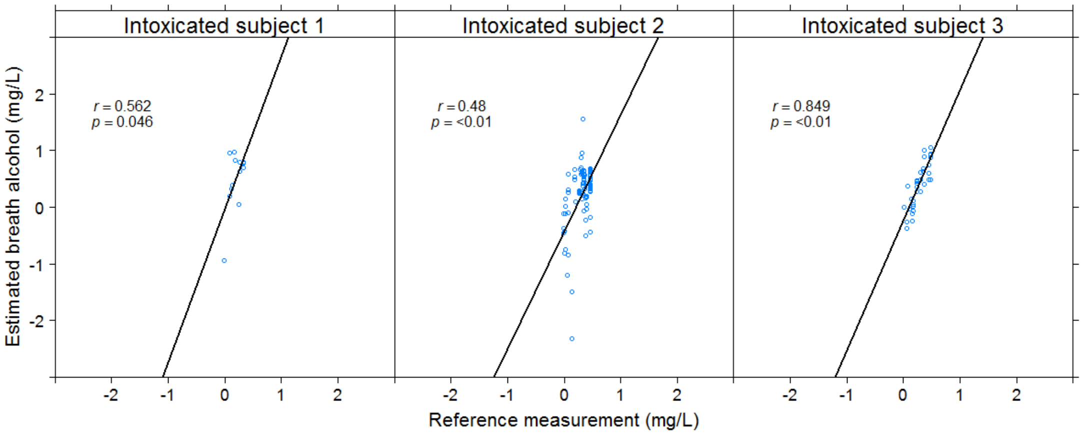

Figure 6: Estimated breath alcohol concentration measured using a completely passive set-up correlated to a reference test.

Discussion

The study setup resulted in 299 detected CO_2 peaks in 631 minutes, which on average corresponds to 0.5 peaks/minute. There was also rather large difference in peak occurrences between subjects. Possibly, there are several factors present that affect the results. Two of these that will have an impact are sensor positioning and the subject's breathing pattern. A sensor positioned closer to the subject will be exposed to less diluted gas samples and the samples will thereby be easier to detect. The sensor will also be less sensitive towards unexpected interference, e.g. side flows or sudden movements. The breathing pattern of the subject will also affect the results. A subject who is breathing through the mouth, initially directs the exhalation in a forward direction. A sensor positioned at the steering column would therefore be positioned in a quite favorable position. However, humans usually breathe through the nose while in a resting position, e.g. while sitting down driving. At normal ambient temperatures the airstream would be directed towards the stomach region of subject and the expired gas would be highly diluted when reaching the sensor.

The study shows that the system setup sets high requirements on sensor resolution. Based on the magnitude of the CO_2 peaks dilutions in the range of 100 to 200 are expected. In relation to the US legal limit, 0.4mg/L breath ethanol, the diluted concentration is 0.004 to 0.002 mg/L. To allow estimation with reasonable accuracy the resolution needs to exceed these concentrations.

The measurements performed using intoxicated human subjects showed alcohol detection coinciding with measured CO_2 peaks. The CO_2 detection ensures biological origin of the detected gas, i.e. the gas does in fact originate from the human subject, and therefore the results shows an example of passive breath alcohol detection in a vehicle compartment. With increasing sensor resolution reliable estimation of breath alcohol will become practical.

There is still a lot of work and effort required in order to provide a reliable solution for a passive system. As stated above, the sensor resolution needs improvement to enable distinguishable measurements between noise, disturbances and actual alcohol peaks. Another important parameter to improve lies in time to detection, which may vary depending on the application.

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