Unobtrusive Breath Testing

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Abstract

Background
Breath testing today requires cooperation, significant physical effort, and is time-consuming. In order to reach an increased acceptance for general breath testing among drivers and professionals whose sobriety is of importance for a safe work environment, a less obtrusive breath testing procedure is desirable.

Aim
The aim has been to develop a breath alcohol analyser enabling fast, simple contact free breath testing with less physical effort. The sensor should meet the automotive industry's requirements of long-time stability, and short start-up and response time, regardless of the ambient temperature. The long term goal is extensive implementation of an in-vehicle integrated unobtrusive alcohol detection system.

Results
The physiological rationale of the use of CO_2 as a tracer gas has been investigated, and a new non-dispersive infrared gas senor enabling measurements of both breath alcohol and expired CO_2 have been developed. The gas sensor has been evaluated with excellent results in sensitivity, cross-sensitivity. In a controlled drinking study a strong correlation (r=0.95) was found between reference tests and tests performed from a distance of a few centimetres with the new sensor. As proof-of-principle of unobtrusive breath testing we have now shown detection of normal human mouth and nose breathing, and artificial gas pulses containing alcohol from a distance over 60 cm in a vehicle compartment.

Future
To improve sampling of the driver's breath, future work focuses on optimised signal acquisition and selection of positions within the vehicle compartment. Present challenges and important input to this work will be the influence from external air flows (ventilation), difference in breathing pattern (mouth/nose), passengers, and e.g. wind shield fluid. The sensor also provides possibilities to other applications, e.g. for access and passage control.

Introduction

To prevent drunk driving the police in many countries perform sobriety screening tests with use of breath analysers. In some countries the police are also entitled to perform evidential breath testing at the police station or even by the roadside. In addition to screening, installation of alcohol ignition interlocks, so called alcolocks, is a preventive measure. The first alcolocks were introduced in the late 20th century for conditional withdrawal of driver's license for people sentenced for drunk driving. The preventive effects of alcolocks increase with their increased use as quality assurance of commercial transport services. Pioneering work was performed in Sweden, and according to the Swedish Public Transport Association, and the Swedish Transport Administration alcolocks are installed in approximately 60% of all taxis, 85% of public buses (The Swedish Public Transportation Association, 2013), in all cars used in driving schools, and in connection to key cabinets and passage systems at work places. Today an increased international activity is seen, e.g. Finland and France have taken significant actions towards mandatory alcolock implementation in commercial transport services. A breath testing procedure less obtrusive than today's is desirable to reach increased acceptance for general breath testing among drivers and professionals whose sobriety is of importance for a safe work environment. State-of-the-art alcolocks require a significant volume, often in the order of 0.7-1.2 l (CENELEC, 2007), forcibly expired in a mouthpiece. This requirement is related to the fact that the breath alcohol concentration (BrAC) increases with expired volume, Fig 1. The increase over time is the result of continuous interaction between the breath and the mucous membrane of the airways (Wright et al., 1975, p. 208, George et al., 1993, p. 2444).

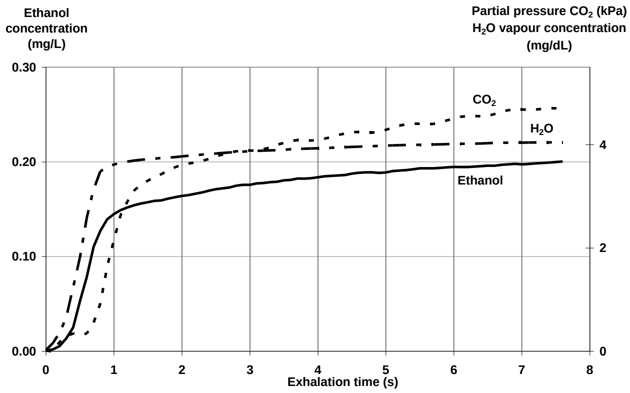

Figure 1. Expirogram illustrating the order of appearance and increase of water (H_20), ethanol, and carbon dioxide (CO_2) concentrations over time. Recorded with a modified Evidenzer instrument (Nanopuls AB, Sweden) (Kaisdotter Andersson et al., 2009, p.5-6).

Aim

The aim was to develop a breath alcohol analyser enabling fast, simple contact free breath testing with less physical effort. The sensor should meet the automotive industry's requirements of long-time stability, and short start-up and response time, regardless of the ambient temperature. The long term goal is extensive implementation of an in-vehicle integrated unobtrusive alcohol detection system.

Method

For achievement of proof-of-concept, extensive interdisciplinary verification tests are being undertaken. Under the leadership of Autoliv, SenseAir is responsible for design and verification of the gas sensor. Hök Instruments is responsible for the clinical human studies related to respiratory physiology, and the human-machine interface. Hök Instrument also performs verification tests of the sensor performance through experimental bench test set-ups, and in-vehicle tests.

Results

The validity of using carbon dioxide as a tracer gas

The method of using CO_2 as a tracer gas relies on two assumptions, which have been investigated and verified. The first is that similarities exist in the expirograms for ethanol and CO_2, during normal and provocative breathing pattern (Kaisdotter Andersson et al. 2009, p. 4; Kaisdotter Andersson et al, 2011, p. 54). The second assumption, that the end-expiratory

pCO_2 can be considered to be a constant, has been found valid after verification of small intra and inter individual variations in end-expiratory pCO_2 in healthy subjects (n=21, pCO_2 4.4±0.5 kPa), and subjects with respiratory impairment (n=9, pCO_2 3.9±0.7 kPa) (Kaisdotter Andersson et al., 2009, p. 4). The later appearance and the slower relative increase in concentration of CO_2, as compared to the ethanol (Fig. 1), make CO_2 a suitable quality indicator of the breath sample. Besides enabling reliable breath testing in smaller exhaled volumes simultaneous real-time measurement of CO_2 can be used to determine the fraction of breath in a diluted air sample.

From a diluted breath sample the BrAC valid for an undiluted breath sample can be estimated with equation (1):

$$BrAC = AC_{measured} * ((CO2_{end\text{-}expiratory} - CO2_{background})/(CO2_{measured} - CO2_{background})) \quad (1)$$

BrAC= BrAC in undiluted sample; $AC_{measured}$ = alcohol concentration measured in diluted sample; $CO2_{end\text{-}expiratory}$ = constant assumed for CO_2 in end-expiratory (undiluted) sample (4.8 kPa (4.8 vol%); $CO2_{background}$= background level of CO2 measured before test; $CO2_{measured}$ = CO_2 measured in diluted sample.

Although the effect of elevated background level of CO_2 is not extensive in normal ambient air (CO_2 ~0.04 vol%, 0.8% of the end-expiratory CO_2), nor in closed compartments with good in-door air quality (~0.1 vol%, 2% of the end-expiratory CO_2) the factor of dilution is calculated with respect to the measured background level of CO_2.

The non-dispersive infrared gas sensor

The new gas sensor based on non-dispersive infra-red (NDIR) technology enables measurement of both expired alcohol and CO_2. Based on the principles established by White [White, 1942] SenseAir has developed a highly sensitive alcohol sensor, with a long optical path length within small physical dimensions. The small dimensions are advantageous for integration, and the small volume of the cavity does not add unnecessary dead volume to the breath sensor. With detectors designed for measurement of breath alcohol and CO_2 at approximately 9.5 µm and 4.26 µm, respectively, the sensor has shown high specificity and sensitivity, and fulfils the alcolock standard requirements of cross sensitivity in the (CENELEC, 2007). A housing for handheld use has been designed, Fig 2.

Figure 2. A prototype of the handheld breath alcohol analyser designed for directed breath.

The performance of the new sensor has been evaluated through controlled drinking studies. Fig 3 illustrates the relationship between the BrAC measured in undiluted breath with a reference instrument and the BrAC estimated from the measured concentration of ethanol and

CO_2 in a diluted breath. The breath tests were performed a few centimetres from the inlet of the hand held prototype, see Fig 2, resulting in a dilution factor of less than 2.5.

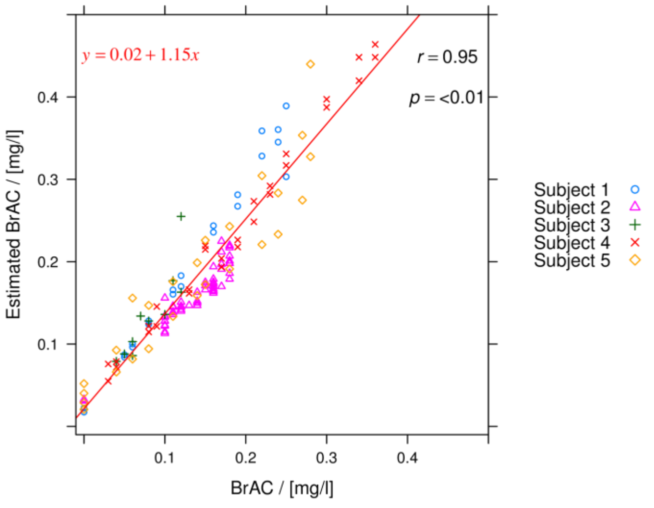

Figure 3. A strong correlation (r=0.95) has been found between the breath alcohol concentration (BrAC) measured with a reference instrument (FST, Intoximeters Inc.,US) and the BrAC estimated from diluted breath samples (subjects: n=5, breath tests n=143).

Unobtrusive breath testing/In-vehicle integration and testing

The dilution affects the BrAC measurement accuracy and for unobtrusive testing in the vehicle compartment the distance between driver and sensor will be critical. The relationship between the dilution of ethanol and CO_2 and how it depends on the distance can be seen in Fig 4. Dilution factors between 3 and 20 are attained for the distances 10, 20 and 30 cm. At 40 cm the dilution factor increases, and exhibiting large variations.

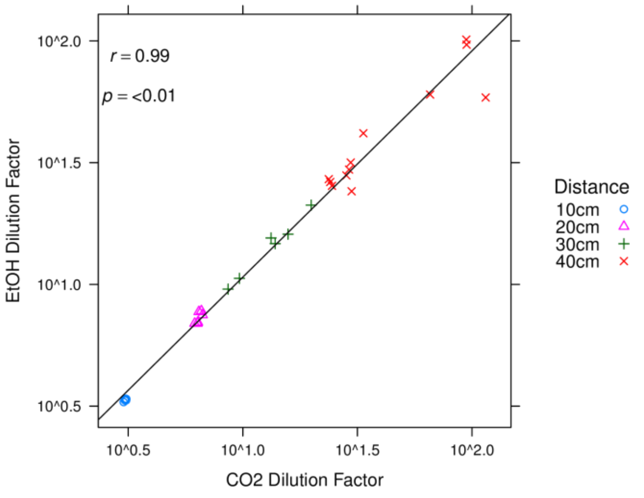

Figure 4. Log-log correlation of ethanol and CO_2 dilution, measured at a distance of 10-40 cm (n=30). The correlation can be seen over the distances but also in the random variation within the larger distances. The gas pulses had an ethanol concentration of 0.4 mg/l and 5 vol% CO_2 and were delivered with a total volume of 0.6 l during 2 sec.

After establishing with bench-tests that breath detection is feasible over longer distances in-vehicle test were performed, Fig 5(a). Fig 5(b) present how the ethanol and CO_2 signals correlate, during ten consecutive gas pulses delivered from a distance of 65 cm.

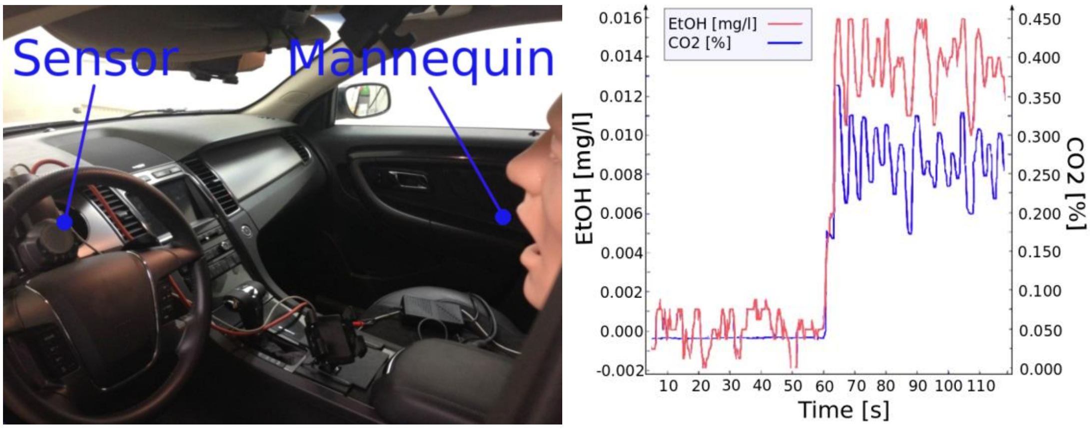

Figure 5. (a) Experimental setup in a vehicle compartment for investigations of the feasibility of unobtrusive testing. The sensor was located at the steering wheel and gas pulses were generated from a mannequin 65 cm from the sensor. (b) Recording of ten consecutive gas pulses starting at 60 seconds. The gas pulses contained 0.4 mg/l ethanol and 5 vol% CO_2, and had a total volume of 0.5 l during 2 sec, which is representative of human breathing at rest.

Combinations of in-vehicle sensor positions and human nose and mouth breathing are presently being studied. Placing the sensor on the steering wheel, as in Fig 5, appears to be one of the best positions for detection of mouth breathing. Fig 6 shows the measured CO_2 signal during an entering procedure. The set-up with artificial gas pulses, where ethanol was simultaneously detected, as well as the human normal breathing show a dilution factor of less than 20.

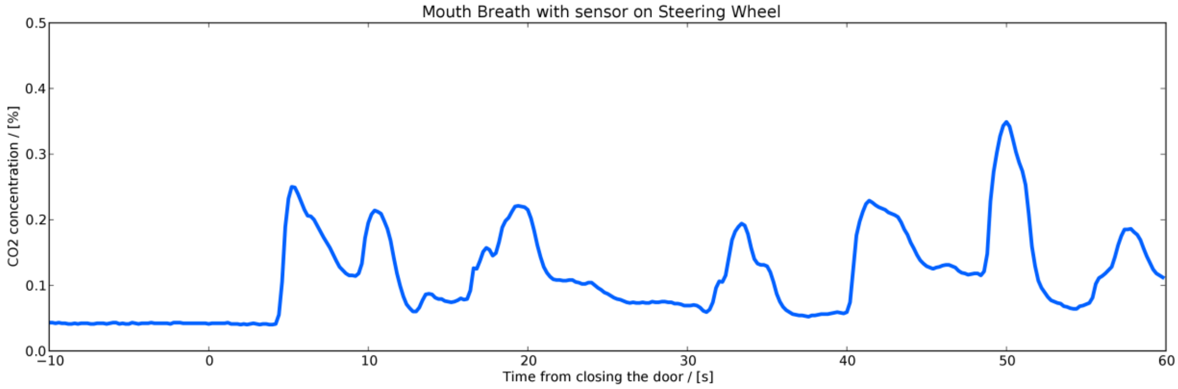

Figure 6. Recording of a test subject breathing normally through the mouth during an entrance procedure. The sensor is positioned near the steering wheel as shown in Fig 5.

Discussion/Future work

With a new gas sensor, proof-of-principle has been obtained for unobtrusive breath testing by measurements with artificial gas pulses in bench tests, and in a vehicle compartment with artificial pulses from a distance of 60 centimetres, and also with human subjects. With use of CO_2 as a tracer gas the correlation to human breath is secured and the factor of dilution is determined and used for estimation of the BrAC in undiluted breath according to eq. (1). To minimise the influence from background variations in CO_2 a breath sampling ensuring a dilution factor of less than 20 is desirable. The results from our in-vehicle test indicate that this is possible to attain.To further optimise sampling of the driver's breath, future work focuses on optimised signal acquisition and selection of positions within the vehicle compartment. Important input to this work will be the influence from external air flows (ventilation), difference in breathing pattern (mouth/nose), passengers, and e.g. wind shield fluid. The sensor also provides new possibilities to applications outside prevention of drunk driving, e.g. for access control and other screening applications.

Acknowledgment

We are grateful for the contributions from our colleagues and partners, especially Jonas Ljungblad and Mathias Granstam at Hök Instrument and Henrik Rödjegård and Hans Martin at SenseAir.

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