VEHICLE INTEGRATED NON-DISPERSIVE INFRARED SENSOR SYSTEM FOR PASSIVE BREATH ALCOHOL DETERMINATION

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ABSTRACT

The objective of the present investigation performed within the Driver Alcohol Detection System for Safety (DADSS) program is to demonstrate the effect of further recent improvements of the breath-based nondispersive infrared sensor technology in realistic settings. More specifically, sensor systems installed in vehicles have been tested by: a) exposing them to a controlled, realistic breathing pattern from artificially generated gas pulses mimicking that of an intoxicated driver and b) human subjects entering a test vehicle and performing a simulated drive while under the influence of alcohol. The tests with artificial gas pulses correspond to human directed forced exhalation from positions up 70 cm from the sensor. The tests provide experimental evidence that in-vehicle, driver breath alcohol determination is feasible with a single sensor positioned at the top of the steering column. The human subject study was designed to test both active and passive detection modes. Good correlation to the breath alcohol reference instrument was found in both cases over the full range of alcohol intoxication exceeding 0.08 percent (the legal limit in most U.S. states). Time to detection is a remaining challenge of the passive mode but is manageable by requesting an active breath in the absence of reliable data. The results illustrate the feasibility of using breath-based NDIR based sensors in different operational modes. In the active mode, a simple exhalation directed towards the sensor is enough for a test to be approved and the alcohol content quantified. In the passive mode, the operator does not actively interact with the sensor. In a real-world scenario, sensors set to a passive mode could be used for driver monitoring and to assist the driver to choose a smarter option when alcohol is detected. The overall conclusion from the present investigation is that in-vehicle breath-based alcohol determination is feasible with the current state of the art sensor technology.

INTRODUCTION

Driving under the influence of alcohol increases the likelihood of being involved in a car crash, and the risk increases dramatically with increasing blood alcohol concentration (BAC) [1]. Statistics from the U.S. National Highway Traffic Safety Administration (NHTSA) indicates that almost 11,000 people were killed in the US in 2017 alone due to drunk driving [2]. The Driver Alcohol Detection System for Safety (DADSS) program is addressing the challenge of preventing drunk driving by means of non-intrusive sensors installed in vehicles [3]. The ideal DADSS system would prevent the vehicle from being driven when alcohol at or above 0.08 percent is detected in the driver's breath. On the other hand, it would not inconvenience the sober driver in any way.

A principle for contactless determination of breath alcohol concentration (BrAC) using simultaneous measurement of alcohol and carbon dioxide (CO_2) at one point in the vicinity of the test subject has been demonstrated [4] and validated [5]. The CO_2 signal is used for detection of a breath and to compensate for the dilution of the breath sample. A prototype sensor system based on this principle using non-dispersive infrared (NDIR) sensor technology was reported [6]. Improvement of system performance and usefulness for in-vehicle contactless and even passive breath alcohol detection have been demonstrated [7, 8].

The objective of the present investigation is to demonstrate the effect of further improvement of the NDIR sensor technology in realistic settings. More specifically, sensor systems installed in vehicles have been tested by exposing them to: a) controlled 'breathing pattern' from artificially generated gas pulses mimicking that of an intoxicated driver b) human subjects entering a test vehicle and performing a simulated drive while under the influence of alcohol.

METHODS AND TECHNOLOGY

The sensor system is based on an infrared measurement cell, simultaneously measuring CO_2

and ethanol. The CO_2 measurement is used as an indicator of an exhalation and to account for the dilution of the breath sample. Details of the sensor technology and vehicle integration have been reported earlier [7, 8]. A major issue with earlier implementations was the resolution of the alcohol sensor. The present investigation has been performed using alcohol sensors with significantly improved resolution.

A test of the alcohol sensor resolution was performed by recording sensor signals with zero input during an extended period of time. The resulting plot of the calibrated output root mean square (RMS) signal as a function of the time window, called the Allan deviation, is a useful characterization of the noise behind the observed resolution [9].

The test equipment for generating artificial breathing patterns includes gas cylinders containing air and CO_2, valves to control the gas flow bubbling through tanks with water and ethyl alcohol at accurately controlled concentration heated to body temperature. Exterior and interior views of the equipment are shown in Figure 1 and 2. More technical details of the equipment can be found in previous reports [7, 8]. The distance between the orifice generating the gas pulses and the sensor located at the top of the steering column was varied between 10 and 70 cm. Four alcohol concentrations were tested: 0.0, 0.1, 0.25 and 0.4 mg/L (0.4 mg/L corresponds to the legal limit in most U.S. states of 0.08% BAC). Each one of the three liquid tanks shown in Figure 1 generated gas pulses with one of these alcohol concentrations. The volume of each gas pulse was 1.5 L corresponding to a forced human exhalation.

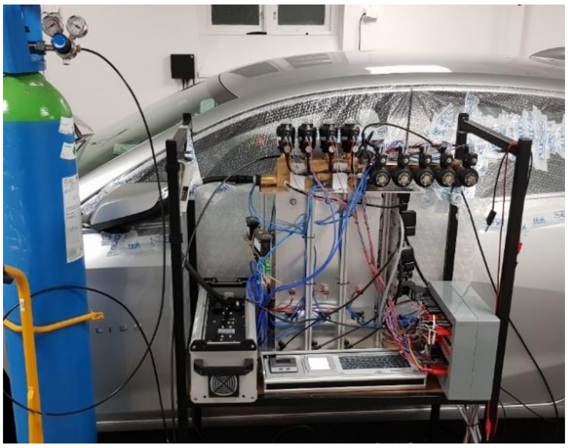

Figure 1: Exterior view of the experimental setup used for tests with artificially generated breathing pattern. The sensor is positioned on top of the steering column.

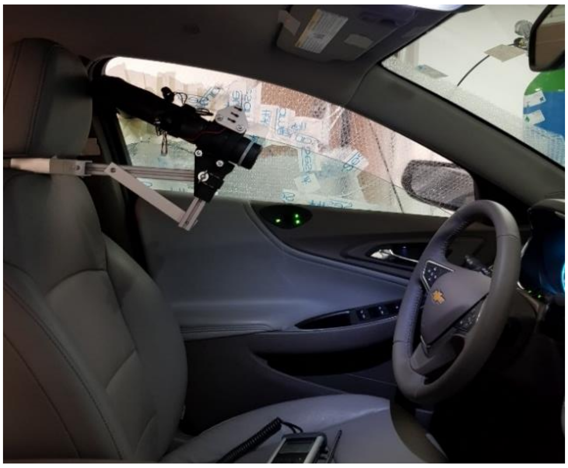

Figure 2: Interior view of the experimental setup used for tests with artificially generated breathing pattern. The sensor is positioned on top of the steering column.

Also shown in Figure 1 is the reference instrument (Evidenzer, Nanopuls AB, Sweden) used for verification of the gas pulse concentration. The hosing carrying the gas to the orifice outlet shown in Figure 2 was heated to above body temperature to avoid water condensation. The orifice position shown in the right-hand photograph was at a measuring distance of 50 cm to the sensor.

The human subject study was performed with ten subjects recruited from outside the project team. In Table 1 some characteristics of the population and the study format are summarized. The study was approved by the Regional Swedish Human Ethics Board in Uppsala (ID 2018/148).

Table 1: Population characteristics and study format of human subject's study. In total 10 subjects were recruited, including 6 males and 4 females.

	Min	Max	Mean	Median
Age	25	71	46	53
Height (cm)	162	187	176	178
Weight (kg)	48	140	86	87
Session (h)	6	10	7.5	7.5

The study protocol involved an initial inquiry about the subject's present health condition. Initial breath tests were performed first with the reference instrument (Evidenzer, Nanopuls AB, Sweden) then within the test vehicle while performing a simulated driving task lasting approximately ten minutes. The in-vehicle breath tests included both active breath tests directed towards the sensor and passive tests without active involvement of the subject. The subject then consumed alcohol 0.8 g / kg body weight with the objective of peaking above 0.08

percent. After thirty-five minutes, breath testing was resumed while the subject was performing a simulated driving task. The procedure was repeated every 45 minutes until the subject's reference BrAC was below 0.03 mg/L). Figure 3 and 4 shows a subject demonstrating active directed breath while leaning forward (Figure 3) and from a relaxed position (Figure 4).

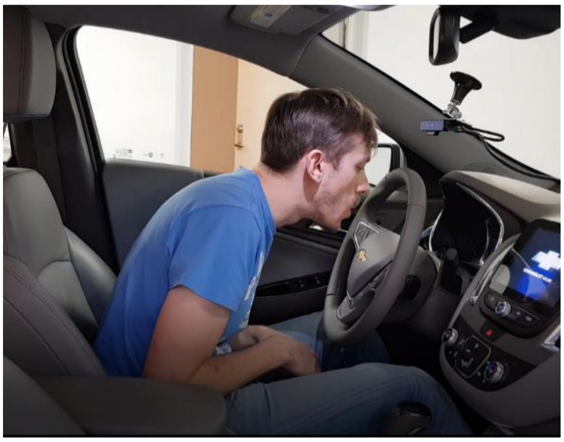

Figure 3: Human subject demonstrating active modes of detection while leaning forward.

Figure 4: Human subject demonstrating active modes of detection while in a relaxed position.

RESULTS

In this section, the experimental results of the present investigation will be summarized. Figure 5 shows the resolution of the present implementation of the NDIR sensor technology. The graph shows a logarithmic plot of the Allan deviation as a function of the time window $\tau(s)$ [9], and the curve exhibits the characteristic V-shape. The resolution at $\tau(s)=1$ second of $3.5*10^{-4}$mg/L is representative for a single breath. It is an improvement by a factor of 2.9 between the present and previous implementation [10]. The minimum value $8.5*10^{-4}$ mg/L occurring at a time window of 53 seconds represents the ultimate resolution of the current implementation.

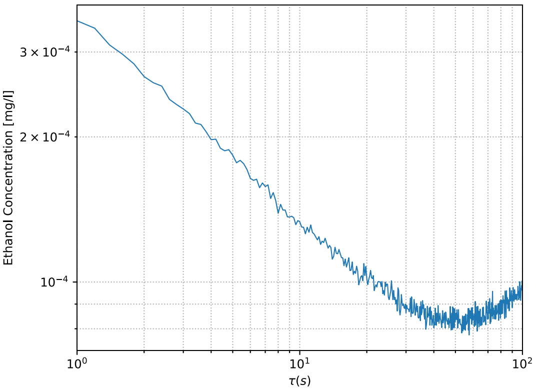

Figure 5: Allan plot of the sensor resolution according to the present NDIR implementation.

The results of the tests with artificial breathing are summarized in Figure 6. The four graphs show BrAC determined by the sensor after dilution compensation at three nominal concentrations, 0.0, 0.1, 0.25, and 0.4 mg/L as a function of the distance between the source of the gas pulse and the sensor. The calculated BrAC values range from a distance of 10 to 70 cm for each concentration. At all distances, the sensor output result is close to the nominal concentration of the gas pulse with a standard deviation of less than 0.01mg/L in each group.

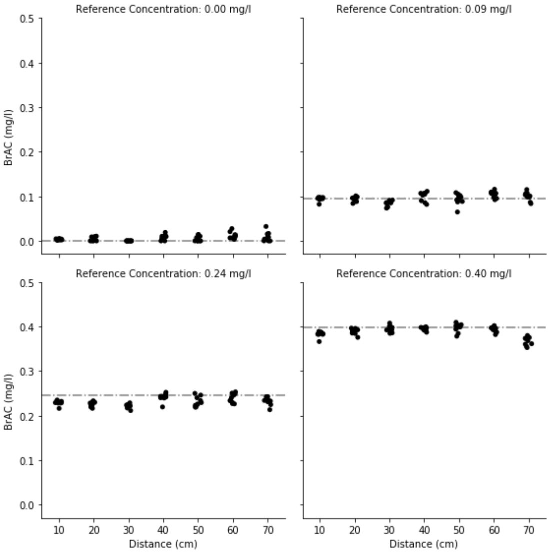

Figure 6: Test results of artificially generated breathing patterns at four nominal breath alcohol concentrations.

The results of the human subject study are summarized in Figures 7 to 10. The graphs depict 'true' BrACs determined by the reference instrument at the abscissa, and BrAC determined by the sensor system with various types of breath tests. Figure 7 and 8 shows BrAC determined after directed breaths from a leaned-forward position (Figure 7) and from a relaxed position (Figure 8). Both graphs show good correlation between the reference and sensor system BrACs over the full range of 0-0.6 mg/L. The error band is relatively straight over the concentration range in Figure 8 with a standard deviation of approximately 0.05 mg/L. In the lean-forward mode (Figure 7) the error band is smaller at low concentrations and somewhat diverging.

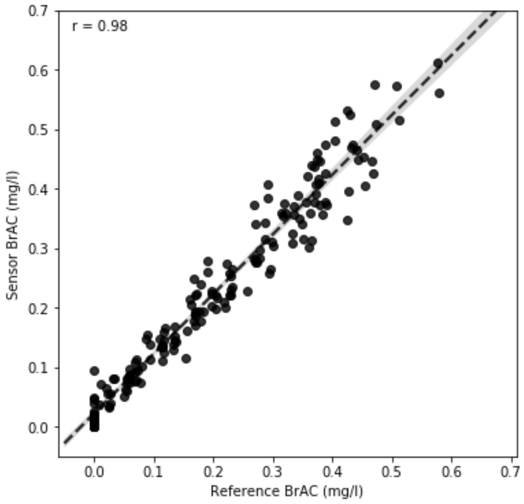

Figure 7: Results from the human subject study with active breathing leaning towards the sensor.

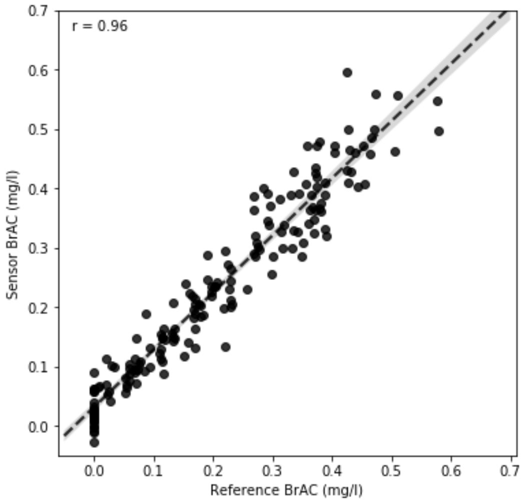

Figure 8: Results from the human subject study with active breathing at a relaxed position.

The results of the passive BrAC determinations in Figure 9 and 10 show a pattern similar to the active breath tests in Figure 7 and 8. The graph in Figure 9 shows the results of the first classified breath sample during the session, and Figure 10 shows the accumulated values of the whole session. In five of the ten subjects, the first breath classification occurred after less than one minute from stepping into the vehicle. The correlation between ‘true’ and test system BrAC was good. The error bandwidth of the accumulated BrAC values (Figure 9) is reduced from 0.05 mg/L (1σ) for the corresponding first detection values (Figure 10) to 0.04 mg/L.

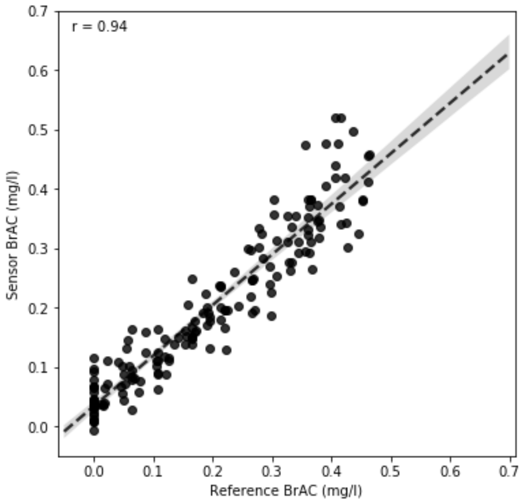

Figure 9: Results from the human subject study with passive breathing after first detection.

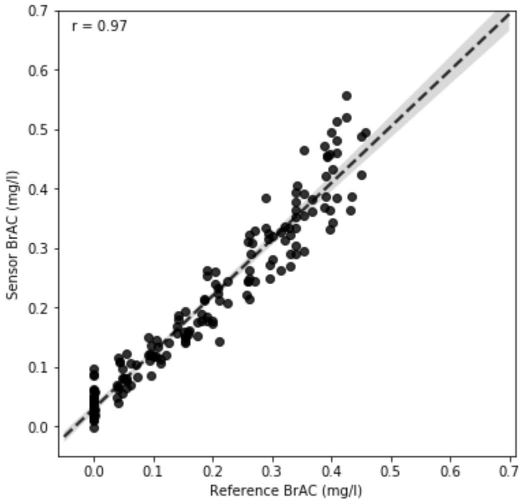

Figure 10: Results from the human subject study with passive breathing showing accumulated results of the current driving session.

The field operational test provided vital information of sensor functionality in a real-world scenario but at the time of writing the data has not yet been analyzed.

DISCUSSION

The Allan plot in Figure 5 shows that the resolution of the present sensor system has been improved by a factor of 2.9 compared to the previous sensor implementation. The downslope at small values of the time window indicates that the noise in this region is stochastic. The minimum indicates the ultimate resolution of the specific implementation, reachable by time averaging over several measurement cycles. The positive slope at large values of the time window is an effect of slow offset signal variations which could be either circumstantial or due to some inherent cause. The results represent good progress based on the best components available today. Further progress can be expected due to the current rapid rate of technology development.

The tests with artificial gas pulses correspond to human directed forced exhalation from positions as large as 70 cm from the sensor. The tests provide experimental evidence that in-vehicle, driver breath alcohol determination is feasible with a single sensor positioned either at the steering column or the door rim. The reduced accuracy at very large distance is manageable by requesting another breath sample at a shorter distance.

The human subject study was designed to test both active and passive detection modes. Good correlation to the reference instrument was found in both testing conditions when alcohol intoxication exceeded 0.08 percent. The lean-forward case (Figure 7), with a moderate sample dilution, exhibits a slightly diverging error band indicating heteroscedasticity, as reported earlier [11]. In the other three graphs from the human subjects' studies (Figure 8, 9 and 10) there is no clear concentration dependence of the total error bandwidth, which amounts to approximately 0.08 percent. In the passive mode, only spurious exhalations directed towards the sensor will be detected. Therefore, it may take some time before sufficient data has been accumulated to enable a useful BrAC estimation. This issue is manageable by requesting an active exhalation from the driver.

In the near future, field tests with sensor systems installed in vehicles will be performed. Scenarios including varying climate conditions and human behavior aspects of both drivers and passengers will be targeted.

CONCLUSIONS

The results of the performed investigations clearly illustrate the feasibility of using NDIR based sensors in both active and passive operational modes. In the active mode, a simple exhalation directed towards the sensor is enough for a test to be approved and the alcohol content quantified. In the passive mode, the operator does not actively interact with the sensor. However, sensor signals need to be collected over a period of time before the alcohol content of the drivers' breath can be classified. In a real-world scenario, sensors set to a passive mode could be used for driver monitoring and to assist the driver to choose a smarter option when alcohol is detected. The overall conclusion from the present investigation is that in-vehicle breath-based alcohol determination is feasible with the current state of the art technology.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Blomberg RD, Peck RC, Fiorentino D, Crash risk of alcohol involved driving: A case-control study. Stamford, CT: Dunlap & Associates, 2005.

[2] National Highway Traffic Safety Administration. 2018. Traffic Safety Facts. Alcohol-Impaired Driving. DOT HS 8124450. Washington DC.

[3] Zaouk, A. Driver alcohol detection system for safety, Paper presented at Transportation Research Board 90th Annual Meeting, January 25, 2011; Washington, DC.

[4] Hök B, Pettersson H, Andersson G, Contactless measurement of breath alcohol. Paper presented at the Micro Structure Workshop 2006, MSW2006; May 9-10, 2006, Västerås, Sweden.

[5] Kaisdotter Andersson A, Improved breath alcohol analysis with use of carbon dioxide as the tracer gas, PhD Thesis No. 83, 2010, Mälardalen University, Västerås, Sweden.

[6] Hök B, Pettersson H, Kaisdotter Andersson A, Haasl S, Åkerlund P, Breath analyzer for alcolocks and screening devices, IEEE Sensors J. 2010; 10:10-15.

[7] Ljungblad J, Hök B, Allalou A, Pettersson H, Passive in-vehicle driver breath alcohol detection using advanced sensor signal acquisition and fusion, Traffic Injury Prevention, vol. 18, 2017, No. S1, S31-S36.

[8] Ljungblad, High performance breath alcohol analysis, PhD Thesis No 240, 2018, Mälardalen University, Västerås, Sweden.

[9] Allan D, Statistics of atomic frequency standards, Proc. IEEE 54, 1966, 221-230.

[10] Ljungblad J, Hök B, Ekström M, Critical performance of a new breath alcohol analyzer for screening applications, 2014 IEEE Ninth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), Singapore, April, 2014.

[11] Hök B, Ljungblad J, Kaisdotter Andersson A, Ekström M, Enlund M, Unobtrusive and highly accurate breath alcohol analysis enabled by improved methodology and technology, J Forensic Investigation, vol 2, 2014, Issue 4, 8-16.