DRIVER ALCOHOL DETECTION SYSTEM FOR SAFETY (DADSS) – PILOT FIELD OPERATIONAL TESTS (PFOT) VEHICLE INSTRUMENTATION AND INTEGRATION OF DADSS TECHNOLOGY

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ABSTRACT

The Driver Alcohol Detection System for Safety Program – a joint effort between the National Highway Traffic Safety Administration and the Automotive Coalition for Traffic Safety since 2008 - has been developing unique, in-vehicle breath-and touch-based alcohol detection systems to address the problem of alcohol-impaired driving. The sensors under development are intended to be passive, seamless with the driving task, non-intrusive, accurate, fast, reliable, durable, and requiring little or no maintenance. When installed in vehicles, the technology is intended to prevent alcohol-impaired driving when the driver's blood alcohol concentration is at or above 0.08 %. Sensor technology, now in Phase III of development, is undergoing more extensive testing in real-world driving environments. Research vehicles are being fitted with breath-based alcohol sensors and comprehensive Data Acquisition Systems (touch-based sensors will be integrated once they have completed the requisite test protocols). Pilot Field Operational Trials have recently begun, and data are being collected. In this paper, an overview is provided of the instrumentation and integration of the test vehicles in readiness for field trials. Data is being collected from the DADSS alcohol sensors as well as from breath-alcohol reference sensors. Instrumentation also has been installed to track environmental conditions, vehicle system data, and test participant video. The data are uploaded via 4G and WIFI and stored in the cloud. These data will be critical in determining the effectiveness (accuracy, precision) of the DADSS sensors in real-world driving environments and when compared with breath alcohol reference sensors. They will also be used to evaluate the effects of repeated use and vehicle mileage on sensor function and in diverse environments, analyze driver behavior and user acceptance, analyze and assess the impact of the DADSS sensors using real-world data, improve awareness of in-vehicle alcohol detection systems and assess potential impact of the sensors on alcohol-impaired driving. The findings will be used to refine the DADSS Performance Specifications and ultimately for modifying the systems designs and enhance product development. The DADSS technology, if proven to be reliable and reproducible under diverse environmental and biological conditions, would represent a significant technological breakthrough in crash avoidance and a significant advance in driver monitoring technologies in vehicles.

INTRODUCTION

Alcohol-impaired driving (defined in almost all U.S. states as driving at or above the legal limit of 0.08 g/dL or 0.08 percent blood alcohol concentration (BAC), 0.05 g/dL in Utah) is one of the primary causes of motor vehicle fatalities on U.S. roads every year. In 2017 alone, crashes involving at least one driver with a blood alcohol concentration (BAC) of 0.08 g/dl resulted in 10,874 deaths of U.S. road users (NHTSA, 2018).

Although strong laws and enforcement have led to fewer alcohol-impaired deaths on the roadways (Ferguson, 2012), there are still large numbers of such deaths every year in the United States and around the world. To effectively reduce or eliminate the problem it will be necessary to prevent alcohol-impaired drivers from driving in the first place. In 2008, the National Highway Traffic Safety Administration (NHTSA) and the Automotive Coalition for Traffic Safety (ACTS)[1] began research to develop potential in-vehicle solutions to the problem of alcohol-impaired driving. The alcohol sensors under development are required to be seamless with the driving task, non-intrusive, accurate, fast, reliable, durable, and require little or no maintenance. Ultimately, the vehicle will not be able to be driven when the device registers that the driver's blood alcohol concentration (BAC) exceeds 0.08 g/dl (%), although other limits potentially are programmable. This cooperative research partnership, known as the Driver Alcohol Detection System for Safety (DADSS) Program, has identified feasible non-invasive technologies to prevent alcohol-impaired driving, both breath-based and touch-based (Ferguson et al., 2009, Ferguson et al., 2010, Ferguson et al., 2011, Zaouk et al., 2015, Zaouk et al., 2017).

Now in Phase III of the research and development effort, the breath-based sensors have undergone extensive laboratory and human subject testing (Lukas et al., 2017, Zaouk, et al., 2017). The latest generation sensors (Gen 3.2) are ready for pilot testing (PFOTs) in real-world driving environments (touch-based sensors will be incorporated at a later

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[1] Members of ACTS comprise motor vehicle manufacturers representing approximately 99 percent of light vehicle sales in the U.S.

stage when they have completed the requisite test protocols). After completion of the PFOTs, more extensive and comprehensive Field Operational Trials (FOTs) will be conducted. Results from these tests will be critical in determining the effectiveness of the DADSS sensors in a wide range of environments including the impact of environmental factors on sensor function over time, the impact of repeated use and vehicle mileage on sensor function, and user interactions with prototype devices in a vehicle environment, including driver behavior and user acceptance. The DADSS Program has submitted FOT test plans for review and is awaiting official approval to proceed.

SENSOR TECHNOLOGY

SenseAir Breath–Based Sensor technology

The breath-based approach uses sensors to measure the concentrations of alcohol and carbon dioxide (CO_2) in the breath simultaneously. The known quantity of CO_2 in the human breath is an indicator of the degree of dilution of the alcohol concentration in expired air. Diluted breath is drawn into the sensor by a fan, which directs infrared light beams on the breath sample and analyzes the wavelengths returned for both alcohol and CO_2. Breath alcohol concentration is then quickly and accurately calculated (Hök et al., 2006). See Figure 1 for the breath sensor block diagram.
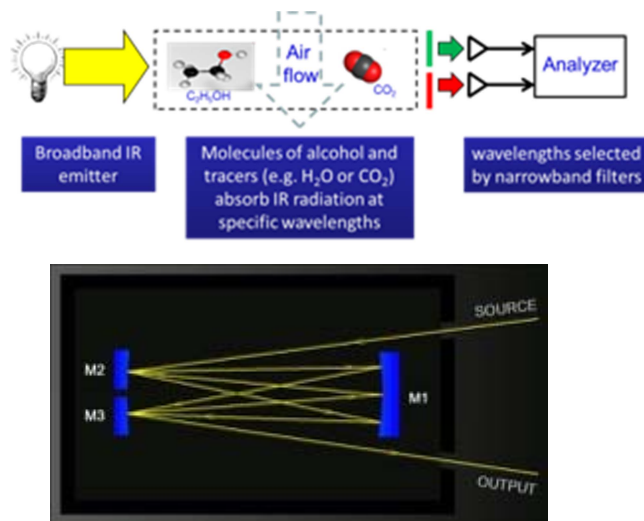

Figure 1. Breath-based sensor block diagram

The ultimate goal of the DADSS sensors is to measure breath alcohol within the vehicle cabin without direct input from the driver, that is, passively. The challenge with the breath-based system is to meet the performance requirements while measuring highly diluted breath. Thus, a significant component

of the research is focused on understanding expired breath aerodynamics within the vehicle cabin and identifying effective locations for the sensors. After comprehensive research that investigated optimal sensor placement in numerous locations within the vehicle, the sensor was adapted for installation in the DADSS research vehicles in four different positions: above the steering column, above the glove box, in the passenger's door panel and in the driver's door panel. These positions improved analysis of the impact of cabin air flow and the driver's position on alcohol measurements as well as optimized performance. It also allows a sober driver to operate the vehicle while a dosed passenger can provide samples for analysis.

The breath-based sensor has been updated in Phase III with the goal of improving this capability (see Figure 2 for evolution of sensor development). The latest, third Generation sensor (Gen 3), underwent a complete re-design to increase resolution for passive sensing, reduce the overall size, and obtain improved performance over the full temperature range of -40°C to +85°C as specified by the DADSS Performance Specifications. A major improvement of the Gen 3 sensor was the optical module configuration in which ethanol detection takes place over the full length of the chamber, whereas CO_2 is detected cross-wise. With this configuration there is no systematic timing difference between the two signals, thus enabling the possibility of passive in-vehicle sensing (Ljungblad et al., 2017).
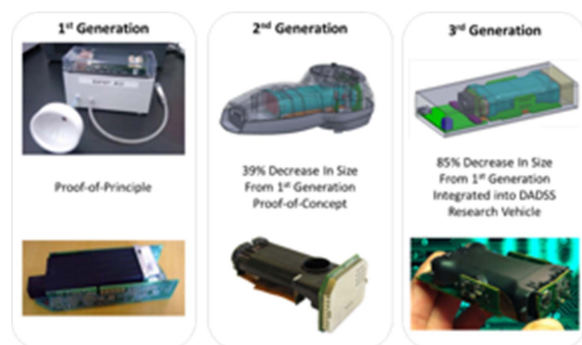

Figure 2. Evolution of Breath-based DADSS Sensor

TruTouch Touch-Based Subsystem

The tissue-based approach analyzes alcohol found in the driver's fingertip tissue (or more specifically, the blood alcohol concentration detected in the capillaries). The driver touches an optical module and a near infrared light shines on the driver's skin, similar to a low power flashlight, which propagates into the tissue. A portion of the light is reflected back

to the skin's surface, where it is collected by the touch pad. This light transmits information on the skin's unique chemical properties, including the concentration of alcohol (Ridder et al., 2005).

The shift from the Phase I prototype, which used a bulky spectrometer engine with moving parts, to a fully solid-state laser spectrometer (which better suited the automotive environment) has required extensive hardware and software research (Ver Steeg et al., 2017). The key enabling innovation is the ability to define an optimized subset of optical wavelengths which provide a high quality non-invasive alcohol measurement in humans (see Figure 3 for schematic representation). It was determined that the new approach required the use of modulated laser diodes to generate 40 unique wavelengths of light for optimal alcohol measurement. The necessary laser diode target specifications were derived from an analysis of the human subject system data with accurate comparative reference data.
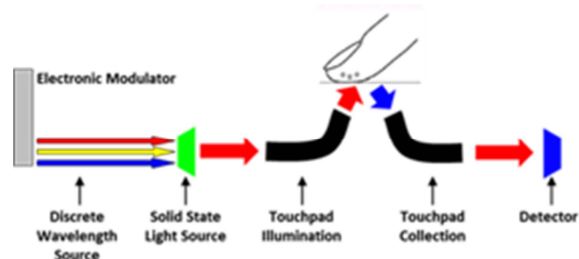

Figure 3. Touch-based solid-state laser spectrometer approach

The highest risk technical element of the touch-based system is the laser device fabrication which needs to meets target specifications. Extensive, cutting-edge research has been undertaken to develop the requisite lasers and to assemble them in initially multi-laser butterfly packages and most recently in a "stingray" shaped package. Many of these laser wavelengths had not been manufactured before. The combined light source generated by the laser packages in a touchpad, then has to illuminate the finger and is reflected back to the detector where alcohol measurements are made. After initial work to develop the laser diodes and packaging, a new supplier, Nanoplus, was selected with greater expertise in these areas. Each stage of the development process has required painstaking research which has been the subject of multiple patent applications. As with any new technology development, complications have been experienced along the way. For example, research on the fourth generation (see Figure 4), revealed a problem with laser intensity fluctuations resulting in unreliable tissue alcohol measurements. Once the various technical issues have been resolved,

a touch-based sensor will be incorporated into each of the DADSS research vehicles.
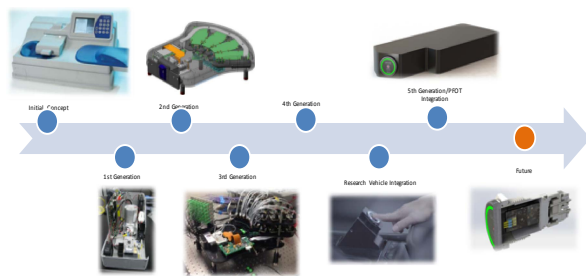

Figure 4. Evolution of touch-based DADSS Sensor

PILOT AND FIELD OPERATIONAL TRIALS

Study Design

The breath-based alcohol Gen 3 sensors have undergone significant laboratory testing and human subject testing. The next phase will be to evaluate them in extreme real-world environmental conditions, heat, cold, varying humidity, etc. to ensure that they will be operational for the harshest real-world conditions that they are likely to encounter. Research vehicles have been developed for use in PFOTs, and later in more extensive FOTs, to gather sensor validity, reliability, and durability data as well as to assess the real-world use of the sensors with human participants in varying environmental conditions.

Prior to the PFOT, the vehicles have undergone a "shakedown" stage, in which DADSS Program researchers are driving five fully-equipped test Chevrolet Malibu vehicles on a daily basis, to and from work, to ensure that the sensors, Data Acquisition Systems (DAS), cameras, and communications systems etc. are fully operational. These initial tests will provide a detailed insight into the necessary requirements of the PFOT test site set up and will be used to complete the development of the PFOT Test Plan (test routes, number of starts/stops, number of samples required, etc.). These initial vehicle tests are being conducted in Marlborough, MA, and Sterling, VA. Once approval has been given from OMB to move forward the FOT will commence.

The PFOT will be conducted in two phases. PFOT 1 and 2 will be comprised of vehicles equipped with four Gen 3.2 breath sensors – two on driver side (driver door and steering column), and two on the passenger side (above the glove box and passenger door). A touch-based sensor can be added once it is ready for field testing (for more details see PFOT

Vehicle Integration Layout and Systems, next section).

The FOT will utilize fully-equipped Chevrolet Malibu vehicles, donated by General Motors. These vehicles currently are going through vehicle fit out at the KEA Technology laboratory in Marlborough, MA.

Required climatic conditions for FOT:

- Site 1 Low Humid, Low Temp
- Site 2 High Temp, Low Humidity
- Site 3 High Temp, High Humidity
- Site 4 High Elevation, Low Temp
- Site 5 Corrosive, Low Temp (High salt)

PFOT 1 and 2 will involve drivers and passengers in Marlborough, MA, and Sterling, VA. The ensuing FOT will involve both drivers and passengers at sites that cover the above required climatic conditions. Drivers will not be permitted to consume alcohol and only alcohol-free measurements will be obtained from the driver side sensors. Passengers will be asked to consume two different amounts of alcohol, approaching a breath alcohol concentration (BrAC) of 0.02-0.03% and 0.04-0.05%, respectively. It was found during human subject testing that once subjects' reached BACs in excess of 0.05% they experienced some difficulty in properly using the sensors. Thus, the design of the passenger user interface was designed to accommodate the perceptual and information processing limitations associated with a BrAC at the maximum dosage (0.05%). In that way, errors in user interface issues due to alcohol consumption will be mitigated. It will also help to provide a safer environment for the driver.

Assignment of the passenger roles will be alternated so that no given participant will be required to consume alcohol every test day. Moreover, the test protocol will ensure that adequate time elapses between the end of a test day and the beginning of the next test day, so that a drinking passenger's BrAC returns to zero BAC.

When a passenger is included, each dosed passenger will provide a minimum of 3 breath samples every 10 minutes or 18 per hour. This will result in a minimum of 72 samples per day per vehicle. For two vehicles over 40 days this will result in a minimum 5,760 samples. Each breath sample to the SenseAir breath sensors will be directed, but the sensors will also be operating in sniffer mode throughout the day.

The initial trials involving passengers will be conducted in the winter in the North East to test the sensors in a cold climate. Each of the daily drives

will last 4 hours and will follow a different route each day.

Participant Details

Adult male and female volunteers (age 21-55 years) will be recruited in the Boston Metropolitan area via web sites, newspaper ads and flyers. Participants must not meet DSM-IV criteria for any psychiatric disorder or substance dependence. Reasons for exclusion include: unstable or uncontrolled medical illness, serious central nervous system disease (e.g. multiple sclerosis or cerebral vascular accident), major depression, bipolar disorder or a family history of bipolar disorder, schizophrenia, psychosis, or organic mental disorder. Participants will also be excluded if they take any regularly prescribed prescription medications, have a history of head trauma, seizure disorder, or other intracerebral pathology or have a pacemaker, metallic surgical hardware or other metal in his/her body. Women of childbearing potential must be using a method of birth control throughout the study. Participants will be screened prior to participating for drug use and pregnancy.

FOT Vehicle Integration

The DADSS vehicles will be equipped with four Gen 3.2 breath sensors. Prior to installation, all of the sensors are put through a detailed characterization regimen in the KEA Technology laboratory. Standard calibration testing is conducted at temperatures of $+40^{\circ}C$, ambient (approx 22 $^{\circ}C$, and $+85^{\circ}C$ using breath samples at concnetrations of 0.0, 0.05, 0.08, and 0.10 % BrAC. In addition to the SenseAir breath sensors, the vehicles are equipped with a breath-alcohol Reference sensor, two video cameras, a Web interface, the DAS, Data and video storage, and the ability to accommodate one touch sensor (when available). The vehicles with four breath sensors will also have a user interface for use by the passengers.

The first DADSS breath sensor on the driver's side is mounted into the steering column clamshell, directly in front of the driver's face. The second sensor is mounted on the driver's side door (see Figure 5 for driver-side sensor placement).

Figure 5. Driver-side Breath sensors; driver-side door (top) steering wheel (bottom)

On the passenger side, sensors will be located above the passenger glove box and the passenger-side door.

The "reference" handheld breath sensor that the driver and passenger are required to blow into to obtain an accurate BrAC reading is situated on the left side of the center stack (see Figure 6).

Figure 6. Smart Start Reference sensor

In addition, each vehicle is equipped with an automatic data collection system, (DAS). The DAS is the central brain of the DADSS system. It takes in power from the vehicle battery, and distributes this

power to all other components of the system. Utilizing a wake signal from the 12V inverter in the car, the DAS will activate upon the turn of the key. The DAS powers the reference sensor as well as collects the serial data it captures. The DAS also relays power to the SenseAir breath sensors, as well as receives the Control Area Network (CAN) data coming from the sensors. Along with the sensors, the DAS provides power to the router and the DVR, for network and video capabilities. All these data are stored by the DAS. In sum, the DAS will record sensor, vehicle and participant data without requiring any input from the participants and will automatically transmit data to the research team. Objective data collected will consist of numerical and video data that capture host vehicle states and maneuvers, surrounding traffic, system operation, and driver behavior. Subjective data collected will include driver background information before participation in the FOT and at the conclusion of each FOT day.

The majority of the hardware for the DADSS system is mounted onto a plate that resides in the trunk of the Chevrolet Malibu (see Figures 7 and 8). The three antennae are located on the rear deck (see Figure 9).

Figure 7. Location of DAS, Network Switch, and DVR in trunk

Figure 8. From left to right, DAS, WIFI LTE, network switch, and DVR

Figure 9. Rear deck view of the 3 antennae with seats down

The research vehicles also are equipped with video recording systems. The video data will be used for a number of different purposes. The study requires physical verification of the participant's three-dimensional position in the vehicle interior space so that their position may be correlated with sensor data from the breath-based sensors as well as height and weight data collected from the demographic interview. Video verification also can be used to correlate touch-based sensor interaction with the data collected from those sensors in the event that there are data artifacts and/or anomalies. Each video system is comprised of two cameras, a digital video recorder, a DAS, and two data transmission technology systems (i.e., WIFI and 4G). The two camera locations are shown in Figure 10, and the camera angles in Figures 11 and 12.

Figure 10. Video cameras to record driver interaction with the sensors.

Figure 11. Camera 1 view

Figure 12. Camera 2 view

CONCLUSIONS

Significant progress has been made in the development of DADSS in-vehicle alcohol sensors. Two specific approaches are under development; breath-based and touch-based sensors. Now in Phase III of the research and development effort, the SenseAir breath-based sensors have undergone extensive laboratory and human subject testing to ensure that they are approaching or meeting the stringent performance specifications (accuracy, reliability, durability) outlined in the DADSS Performance Specifications. The critical next stage is to test how they function when installed in vehicles in a diverse range of real-world driving environments (hot, cold, dry, humid, corrosive etc.).

Research vehicles have been fitted with the latest generation, Gen 3.2, breath sensors in both the driver and passenger positions (touch-based sensors will be incorporated at a later stage when they have undergone the requisite testing protocols). Pilot Field Operational Trials are underway and comprehensive DAS including a video recording

system are collecting data from the alcohol sensors as well as from instrumentation designed to track environmental conditions, vehicle system data, test participant video, and breath-alcohol reference sensors. The PFOTs and subsequent FOTs will be key in determining the effectiveness of the DADSS sensors in a wide range of real-world driving environments including the effects of repeated use and vehicle mileage on sensor function. Of equal importance, driver behavior when interacting with the sensors and user acceptance will be evaluated with the potential to assess future impact of the sensors on alcohol-impaired driving. The findings will be used to refine the DADSS Performance Specifications and ultimately to modify the systems design and enhance product development. The DADSS technology, if proven to be reliable and reproducible under diverse environmental and biological conditions, would represent a significant technological breakthrough in crash avoidance and a significant advance in driver monitoring technologies in vehicles.

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