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An Automobile-Integrated System for Assessing and Reacting to Driver Cognitive Load

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ABSTRACT

A highly integrated system was constructed to assess, and react to, a driver's cognitive load. Sensors embedded throughout the car track a wide variety of driver activities, including driving conditions, driver reactions, control usage, driver reflexes, passenger interaction, and driver attention. The raw sensor readings are compiled and parsed, and used to assess the cognitive and stress load on the driver based on affective computer modeling. Various outputs to the driver, including alarms, warnings, and communications, are selectively suppressed or dynamically reconfigured to maximize driver attention on the road scene and avoid cognitive overload.

INTRODUCTION

Modern automobiles contain a wide variety of interactive accessories. Although these accessories are designed to enhance the driving experience, they can sometimes draw attention away from the real job behind the wheel, piloting the vehicle. While elaborate stereo systems, climate controls, and even cellular telephones can be used safely during most driving situations, in demanding situations these accessories can possibly become an untimely distraction [1]. However, drivers have grown up with these accessories over time and are accustomed to using the systems found in automobiles today. They have also found a responsible way to manage these systems on their own, and in most situations, they do a good job.

Intelligent drivers also realize the importance of non-contact driving. With experience, the driver learns the best time to change the radio station or to put in a CD. Now, with the recent proliferation of cellular telephones into the vehicle and the social impact of this behavior, drivers must once again adapt their management techniques for these devices. Until now, that job has been left up to the driver alone to make the device management decisions. But in the future, it may be possible for the on-board computer systems to assist in the process.

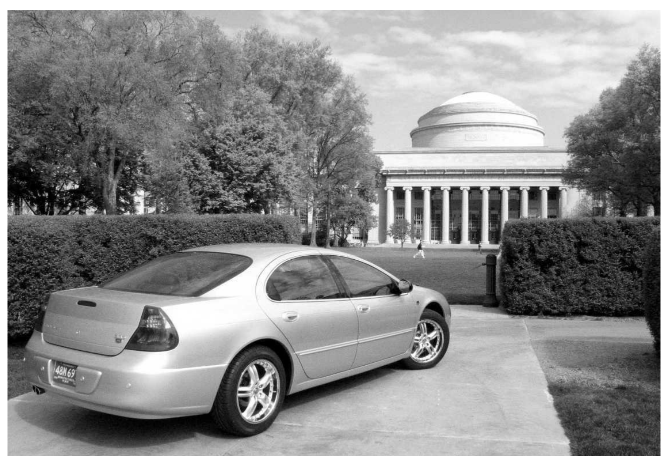

Figure 1. - 300M IT-Edition

While vehicles currently have substantial processing power to control on-board systems such as the engine, suspension, climate control, and convenience features, driver activity is rarely part of the control algorithm. Focusing on the future towards computer systems that "think" as well as "process" will help change this situation. To bring the driver into the processing equation, a car was constructed to monitor as much as possible about the driving environment, the driver's activity state, and the driver's information sources. The research vehicle, labeled the Chrysler 300M IT-Edition (Figure 1), was built using a compiled team from DaimlerChrysler, Motorola, and the Massachusetts Institute of Technology (MIT) Media Laboratory [2]. The goal was to develop and test innovative human-machine interface approaches that interact with the driver in a safe, non-intrusive manner. This non-intrusive approach is important for both driver acceptance and eventual product feasibility. It should also be noted that the 300M IT-Edition is strictly a research vehicle and the technology used in this vehicle is experimental.

The 300M IT-Edition was built as a rolling test-bed for researchers to develop control theories. It is expected that, by monitoring the state of the driver and the driving situation, the car can "think" and choose to suppress information from controls, accessories, and alerts, and activate them only during periods of light cognitive load on the driver. An example of a project is the cell phone project, that seeks the proper method of controlling the flow of information in the vehicle and regulation of cell phone usage in a manner that minimizes distraction during busy driving activity. Of course, this must be done in a non-intrusive manner that does not aggravate the driver or disturb the driving process. Another significant benefit that the car will provide is improving the skills of the driver in a timely manner, when the driver is not overloaded.

It should also be noted that, at this time, the vehicle does not contain a navigation system or any other advanced telematics hardware. There has only been the addition of a hands-free cellular telephone to the package. The goal is to assess the current level of complexity found in a typical customer owned vehicle as a baseline. It is generally agreed that most drivers themselves can manage the information sources found today in a standard Chrysler 300M automobile without intervention (although the phone is not standard). So any improvements that can be made to reduce the current level of distraction in the standard vehicle could be viewed as creating some headroom to add new features based on future customer demand. Therefore, the scope of work in the future is to include additional sources of information and activity for the driver once the basic control algorithms have been established.

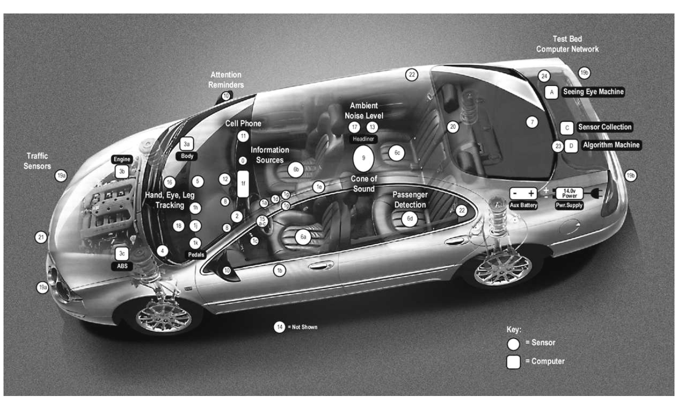

Figure 2. - Sensor locations on the prototype car.

IMPLEMENTATION

SENSORS

Because there is little known about measuring features that constitutes a 'busy' driver, the test-bed vehicle was outfitted with almost every sensor conceivable (Figure 2). This provides an extremely comprehensive impression of all the driver's activities. Sensors track features such as the driver eye gaze, hand position and pressure on steering wheel, foot position, hand position near accessories, cabin air quality, and road conditions. Other sensors monitor the state of the brake system, engine, surrounding traffic, passenger presence, and ambient noise level in the passenger cabin.

Figure 3. - 300M IT-Edition Driving Environment

SYSTEMS BEING SENSED

- Multiple optical cameras [3] used to track driver's eye and head movements (Figure 3).
- Multiple contact sensors to determine position of driver's hands – including grip force sensors on the steering wheel and gear shift knob.
- Sensors to determine the position of the driver's arms on the arm rests and console.
- Sensors in the cup holder to sense drinking activity.
- Sensors on the pedals to determine the position of the driver's feet (for example, "ready to brake").
- Vehicle communications network (J1850) monitor to acquire speed, throttle position, on-board system status, etc.
- Accelerometers and GPS receiver to determine vehicle position, motion, road quality.
- Ultrasonic sensors on bumpers to determine proximity to other vehicles in traffic conditions.
- Seat sensors to indicate whether other passengers occupy seats, as potential human distractions.
- Microphones to measure the level of passenger conversation.
- Carbon monoxide solution sensor to sample air quality level.

DATA ACQUISITION

Overview:

The original definition for the 300M vehicle called for interfacing the following I/O as presented in Figure 4:

- 20+ Digital Inputs
- 6 Digital Outputs
- 8 Analog Inputs
- 3 Proportional LED Diver Outputs
- 6 RS232 Smart Devices

The first design of the architecture was to interface all the I/O to a laptop in the trunk of the vehicle. The plan was for the interfacing laptop to run some kind of software to read all the I/O and then make that data available on a network. A researcher-based algorithm computer would then connect via this network to acquire the data. The data I/O concentrating laptop idea had several flaws. There would be a multi-minute delay each time the system was started as the laptop booted all the software required. Interfacing six serial devices to the laptop was possible using dual PCMCI cards, but was problematic because all the PCMCIA slots have already been used. An alternative of using this a USB style I/O would have been slow. Moreover, a client/server application software would have been needed to access these, which would have complicated the interface. After searching for alternatives, an embedded Ethernet controller solution was chosen from Netburner [4].

System Advantages

The embedded Netburner boards architecture has the following advantages:

- Each board has it's own IP number on the network (also has DHCP)
- Each board runs a real-time OS called uC/OS-II.
- Each board is accessible via HTTP while still performing its primary task (uses real-time OS).
- The Netburner uses GNU development tools.
- The boards are low cost ($140 for the SB72, which is used for the smart sensors).
- The smart sensor I/O board (model SB72) is ready to be used as a RS232 to Ethernet converter right out of the box.
- The system is scalable; additional boards can be added as necessary.
- The boards software can be updated over the Ethernet network very quickly.
- The system architecture supports wireless 802.11b to ease development.
- All smart sensors use TCP/IP to transfer their data. This allows two-way communication through a telnet connection.
- All analog and digital data is streamed using UDP protocol over the Ethernet network.
- Quick startup after power is applied (typically within 5 seconds).
- Allows custom algorithms to compensate for other system problems.
- The SB72 interface board, through custom software, compensates for the non-custom baud rate of 10.4K of the J1850 vehicle interface.
- The boards enable any custom analog, digital, or serial device to be connected to the Ethernet network.
- The smart sensor I/O board (SB72) connects to the network at 100 Mbit. Therefore throughput is not a problem.
- Data processing is distributed among the boards.

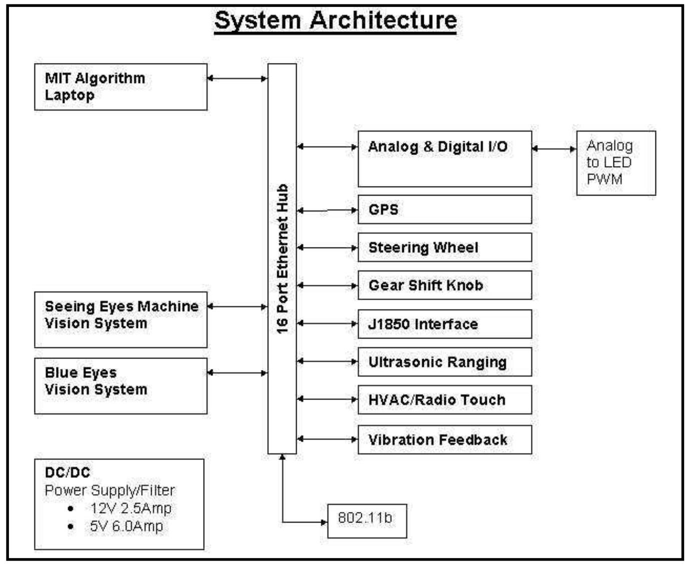

Figure 4. - 300M IT-Edition System Architecture

INTERPRETING SENSOR DATA

A separate computer is used to collect and interpret received sensor data. Each sensor input is continuously monitored, and its signal entropy is calculated to arrive at an estimate of 'activity'. Each singular entropy calculation is weighted, and summed to assess overall system entropy, which is used to control information available to driver. The specific weights for each sensor are the subject of continuing research. The special architecture allows multiple individual studies. Each researcher can develop a separate strategy or theory to control the human-machine interface or information flow. This algorithm can then be run on the each researcher's own development computer and connect to the in-vehicle network for testing. At the end of one researcher's testing, a second researcher can then plug into the network for its own algorithm's testing. This allows for the unique development of several activities in parallel, although testing is done in a serial fashion.

CONTROLLING DRIVER FEEDBACK

The compiled and interpreted sensor data is used to control the delivery of diverse information to the driver. This information includes, but is not limited to: incoming cellular telephone calls, warning lamps in the instrument cluster, messages on the overhead electronic vehicle information center (EVIC), and non-critical auditory alerts (such as fluid level warnings). Suppression of driver alerts is maintained for the duration of high-activity driving. During the periods of high activity driving, the computer system signals this condition to the driver by illuminating the "Busy" lamp (see next section, special features). Of course, the master algorithms developed by MIT Media Laboratory's researchers determine the periods of time that are considered "high activity" driving based on critical sensor information.

Special Features and Applications

Special applications and features are planned to be implemented as part of the research framework of the car and is described hereby.

Stress Management. Anger during driving was found to have strong association with the number of near accident events [5]. Some of the research work on the 300M IT-Edition is inspired by previous work accomplished at the MIT Media Laboratory in the field of Affective Computing [6]. Affective means "influenced by or resulting from the emotions". This is a new research area in the field of Human Computer Interaction (HCI). Affective Computing takes the emotional state and stress levels of the operator (in this case, the driver) into account during interaction.

Previous applications of detecting driver's stress such as SmartCar [7] used an on-board computer that measures various biometric sensors. This implementation required the driver to "wire up" (physical attachment of sensors) and is therefore significantly intrusive. In the 300M, a different sensing technique is used. Following an implementation done in the Media Laboratory, in which grip sensors were placed on a computer mouse to detect user frustration [8], pressure sensors were placed on the steering wheel and on the gearshift knob. Both these devices monitor the grip the driver has on the devices. If the grip force is increased significantly, the user exhibited a change in frustration level.

The computer system in the 300M IT-Edition is planned to "think" about what to do next, and may present information in different forms to different drivers. This adjustment based on the driver's state attempts to prevent frustration or anger while driving, aiming for user satisfaction as well as safety.

Driver Road Attention. An important tool to determine driver activity is to monitor where the driver is looking. If the driver is looking out the front windscreen, it can be assumed that the driver is at least looking at the driving situation around them (although the driver may not necessarily be aware of what is happening). If the driver is looking down at the controls, or sideways at the passenger, it can be assumed the driver is not aware of the immediate situation outside of the vehicle. Therefore, monitoring the driver's eye direction is an important factor in determining the instantaneous attention given to the driving situation.

Eye tracking is accomplished by using an off-the-shelf computer and hardware system called the "Seeing Eye Machine" [3]. The system uses two cameras (shown in Figure 2) to generate a stereo image of the driver. These images are then used to determine where the driver is looking, if the driver is blinking, how long are the blinks (drowsiness detection). The system can also determine the general head position. However, the system must be calibrated to individual users and does not operate well with individuals wearing dark sunglasses. Once calibrated, however, the system tracks eye movement very reliably.

Besides the visual and graphical output of the Seeing Eye Machine on the display monitor (Figure 5), the output is also available on the Ethernet backbone of the vehicle. Thus, various algorithms can use this information to determine the driver's activity. Information can be presented to the driver when looking forward, or attention reminders can be used when the driver is not paying attention to the road scene. Detecting drowsy drivers is also another benefit of that system.

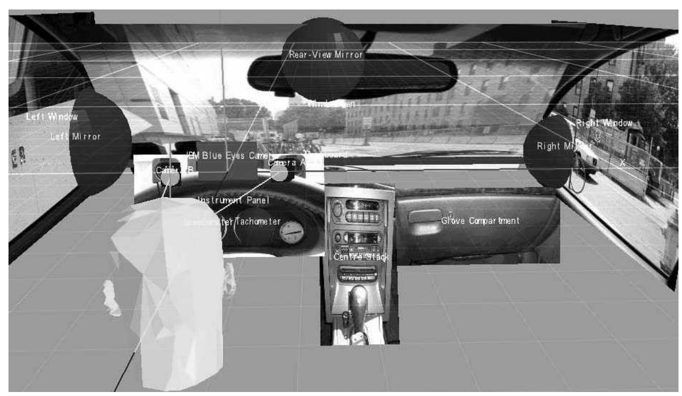

Figure 5. - Cameras track driver's eye position

Attention Reminders. Because the 300M IT-Edition can track the driver's head and eye position so closely, it is also able to help the driver avoid potentially hazardous developments. If, for example, using the eye tracking camera output (Figure 5), it detects that the driver has not glanced at the side mirrors for an extended period, the computer can blink an LED in the mirror (Figure 6) to attract the driver's attention directly to that mirror. Inadvertently, just by looking at the flash of the LED, the driver ends up checking their blind spots. This allows the computer algorithm to establish a minimum frequency for the driver to check the mirrors, and reminds them in a friendly way. The LED used in this application is a very narrow angle device so that other vehicles next to the 300M cannot see the light (blue in color). That way there is no false turn indication to other vehicles.

Figure 6. - Side view mirror attention reminders

Figure 7. - Vehicle speed visible in rear view mirror

CarCoach. The CarCoach is a car agent that is designed to give drivers immediate feedback on their driving performance. Coach refers to work previously published on COgnitive Adaptive Computer Help agent [9]. The CarCoach reads data from the steering wheel, gas and brake pedals, GPS, speedometer, and other car sensors. It uses the driver's environment to generate feedback on the driving quality, such as car seat, steering wheel and pedal vibrations, certain warning lights, etc. It also uses special LEDs that are designed for this purpose, and a physical embedded agent.

To demonstrate CarCoach, imagine the following scenario. The driver presses the brake pedal very strongly in order to stop the car. If this occurs once in a while, it may indicate good driving skills, as the driver responds to the changing environment - such as a need for an emergency stop. However, if it happens often, that might indicate insufficient brake sensitivity. Such a sudden stop could result in an accident, as the cars behind do not expect it. In this case, the CarCoach will trigger vibrations in the brake pedal to hint the driver on the excessive braking force that is being used.

The concept behind the CarCoach is different from simulators or driving teachers. The CarCoach is aimed to work on the road and is designed to improve the techniques of skilled drivers, rather than teach people how to drive. Hopefully, such system can improve the overall driving skills and prevent driving mistakes and will lead to more efficient and safer driving.

Audio Spotlight. A highly directional loudspeaker, called the Audio Spotlight [10], is used to limit the audibility of alerts and hands-free mobile phone to the driver alone. There is a single Audio Spotlight mounted in the headliner angled towards the driver's ear. This allows the driver to maintain a semi-private phone conversation with the individual on the end of the phone connection. In can also provide telematics messages (future content) directly to the driver without disturbing any of the other occupants. Lastly, it can provide discreet messages from the CarCoach agent so as not to embarrass the driver when he or she receives feedback.

Rear Speed Display. Based on previously published work at the MIT Media Lab [11], a "Rear Speed Display" (RSD) was also included in the vehicle (see Figure 7). The RSD is a digital speedometer display that is mounted on the rear package shelf or backside of the CHMSL facing forward in car. This permits the driver to discretely see the display by looking into the rear view mirror. The digits are constructed backwards on the display, but are corrected when looking into the mirror.

The RSD operates much like a heads-up display, and also permits the driver to view his or her speed without the need to look down and refocus on the instrument cluster. Objects viewed out either from the windshield or via the backlight (via the mirror) are at the same focal length as the RSD image. This allows rapid recognition of vehicle speed at up to 50 percent faster than a conventional speedometer [12], minimizing the eyes-off-the-road time. The RSD also has a secondary feature - it promotes rear view mirror usage because it is common practice for drivers to check their speed quite often.

Aviation Inspired Interface. There are two new controls that are influenced by controls found in most aircraft (see Figure 8). One is a warning lamp that illuminates amber or red, depending on the severity of the alert. The inspiration for this control comes from the Master Caution/Warning system found in aircraft. The Master Caution/Warning lamp illuminates in an aircraft to tell the pilot to check the caution panel for the specific fault condition. The pilot then acknowledges this fault by resetting the lamp condition.

Figure 8. - Warning and Busy Lamps on the I/P

The 300M control is similar to this aircraft warning system. The 300M driver must acknowledge the warning or caution condition by pressing the button after the lamp is illuminated. Using a single warning/caution lamp, which is mounted up high in the driver's primary sight line, commands immediate driver attention. After this primary lamp is lit, the driver may then locate the actual condition that set off the warning in the first place.

A second new control is the "busy" button and lamp. The busy button allows the driver to indicate to the vehicle that he or she wishes not to be interrupted with non-urgent warnings, cell-phone calls, etc., while preoccupied with tasks like negotiating traffic or parking. The busy lamp (green in color) also indicates to the driver when the on-board computer algorithm has made a determination that the vehicle or driver is currently too busy to accept calls or information based on sensor input. The busy lamp will extinguish and allow calls to pass and information to flow if conditions improve.

CONCLUSION

A platform for investigating the use of driver activity monitoring to control information flow in the vehicle and reduce distraction has been presented. At present, a comprehensive set of data is collected to determine driver activity, but it is expected that as we learn through experimentation, more about the dominant features, the sensors can be reduced to only a few simple items. Trying to identify all stressful driving conditions may also be as complex as driving is itself and impossible to capture all instances. However, it is a goal of this research to identify the most stressful driving conditions, as well as driving mistakes, as a logical first step towards reducing day-to-day driving distraction risks produced by the automobile. Further findings will be published as work progresses at the MIT Media Laboratory. Finally, the 300M IT-Edition findings discussed or expressed in this paper are a result of basic research taking place with the vehicle at the Media Lab and are a result of experimental equipment and technology.

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