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Investigating driver support systems in real traffic with the Instrumented Car for Computer Aided Driving (ICACAD)

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INTRODUCTION

Given the current efforts within several European research programmes to develop systems to support drivers in their driving task, there is a growing need to investigate how drivers respond to the use of such systems. One of these efforts was the Generic Intelligent Driver Support (GIDS) project. This project was carried out from 1989 until 1992 (for an overview, see Michon, 1993) and succeeded by the ARIADNE and GEM projects. The aim of the GIDS system is to filter and prioritise information from various applications in order to prevent overload of the driver. The information is presented by various systems aimed at supporting drivers in their task. As the GIDS system runs on a series of fast PCs and required various sensors and actuatators while it also had to be flexible in order to do research with it, there was a need for an instrumented vehicle which would be able to carry much equipment and which would be able to communicate with the driver through a number of man-machine interface elements. The car would also have to be able to measure and register the behaviour of the driver. With these goals in mind a number of criteria were set up.

(1) The car would have to contain enough space to carry all instruments and computers but it would also have to have a «feel» like an ordinary passenger car. (2) An experimenter would have to be able to interrupt driving and (3) the car would have to contain a number of sensors for measuring driver behaviour and for providing the GIDS system with necessary information. (4) The driver-car interface, including the active controls, had to be developed and installed and (5) the car would have to be able to carry the set of computers on which the GIDS system would run. Also, (6) a computer was required for data registration, and communication between the GIDS system and the car sensors and elements of the driver-car interface. Finally, (7) the car would have to contain on-board power supplies to make everything work.

The TNO Human Factors Research Institute (the former TNO Institute for Perception) built this special purpose instrumented car and called it ICACAD (Instrumented CAr for Computer Assisted Driving). ICACAD is depicted in Figure 1. The use of instrumented vehicles as a means to study driver performance is not new

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FIGURE 1
Instrumented Car for Computer Aided Driving ICACAD

and has gradually increased since the sixties. At the TNO Human Factors Research Institute there is considerable experience with instrumented vehicles as three instrumented cars have been developed there before (Blaauw, & Burry, 1980; Van der Horst, & Godthelp, 1989; Michon, & Koutstaal, 1969). Furthermore, the institute has experience with equipping various other types of vehicles with measurement devices. Since prototypes of in-vehicle systems are usually not adapted to the automotive environment, ICACAD is designed to be very flexible in that it can carry a variety of equipment including prototypes of various in-vehicle systems and supply them with power and information. This flexibility is an important feature because is allows human factors research of systems that are still under development and that are not commercially available. In other words, ICACAD allows human factors research to become an integral part of the system design process thereby considerably reducing the risk that a system will fail either commercially because the public does not accept it or because it jeopardizes traffic safety resulting from sloppy system ergonomics.

This paper presents a general description of how a GIDS system (or similar sophisticated in-vehicle systems) can be tested on the road. It describes what information can be registered but also what kinds of messages can be presented to the driver of ICACAD. Finally, it gives an overview of the system architecture and the hardware used for ICACAD.

GENERAL RESEARCH PROCEDURE

In general, drivers' performance in instrumented vehicles is assessed by registering their behaviour while they are performing certain driving tasks. Sometimes drivers are required to conduct additional tasks while driving such as controlling on-board support and entertainment systems so that the effect of these tasks on their driving behaviour and performance can be analyzed. With ICACAD, such studies can be done on isolated test tracks as well as on public roads with normal traffic.

The driver (i.e., the subject) is usually accompanied by an experimenter and a technician. The technician takes care of the equipment and supervises data acquisition. The experimenter gives instructions to the subject and governs the experimental procedures. When working with inexperienced drivers (e.g. without a driving licence) or under dangerous driving conditions, a driver-training instructor acts as experimenter who can take over with a second brake pedal or by shutting down the engine with an emergency button.

FUNCTIONAL DESCRIPTION

Variables captured during experimentation allow distinction among variables related to driver input, driver output (corresponding to system input), vehicle output and physiological parameters (Blaauw, & Burry, 1980; Van der Horst, & Godthelp, 1989).

Input to the driver

A major source of input to the driver is visual information from the traffic environment. This information can be registered directly using video equipment. In addition, subjects' eye and head movements can be registered with a dashboard mounted camera. Together these data can be analyzed in order to know where subjects have been looking while driving. For example, Verwey (1993) distinguished between looking left, right, in the mirror and at an in-car visual display. Problematic with regard to registration of driver eye-movements is the fundamental difference between «looking» and «seeing»: the direction of the drivers' viewing direction does not necessarily correlate with their object of attention. Therefore, one can also have the experimenter label critical events during experimentation by pushing specific buttons and assume that the subject will attend to these events. The behavioral responses in these situations can then be analyzed later in the laboratory. Examples of events that can be analyzed in this way are overtaking, running red and the presence of specific road signs.

A second source of driver input which is especially important when evaluating the human factors of in-car systems is the information these systems present. In order to evaluate the effects of these systems on driver performance ICACAD has been provided with additional displays and controls. Logging and time-stamping the messages allow for assessment of the immediate and delayed effects of interacting with telematic applications on driving performance. Again, the assumption is that the system messages are noticed and used by the driver. When the driver has been instructed to attend and respond to these messages only when the driving task allows to do so this task actually becomes a secondary task and performance on it can be used as indicator for driver workload (Verwey, 1993; Verwey, & Kaptein, 1994). The displays in ICACAD encompass visual, auditory and tactile displays. For information presentation a colour hind-lit Liquid Crystal Display (LCD) was built into the dashboard while keeping the original displays in their usual place (Figure 2). Three speakers have been mounted, two in the normal positions at the left and right of the dashboard allowing stereo sound and one just below the LCD. Six dimly-lit push- buttons and one rocker switch are located around the LCD for driver input to the system. In order to give direct feed-back to the driver, which is related to the driving task and highly compatible to an optimal response action, an active accelerator pedal and steering-wheel have been mounted. These are active in the sense that they allow for presentation of tactile vibrations and force pulses on the wheel and the accelerator (see below).

Driver output/vehicle input

Driver actions usually serve as input to the vehicle and can also be registered. Steering-wheel and accelerator movements are measured by a potentiometer attached to them. Braking pedal actions are measured by a pressure transduce in the hydraulic circuit. Usage of other control such as the indicator and head light switches can also be registered.

Visual output

Another possibility to investigate driver beha-

FIGURE 2

The common driver-vehicle interface has been extended with a multi-purpose hind-lit CGA Liquid Crystal Display with buttons

viour is registration of vehicle movements: there are sensors for lateral position (in the presence of road delineation), lateral acceleration, longitudinal speed, position and acceleration, and yaw and roll rate. Headway can be measured with an infrared radar or through a wireless dat link between ICACAD and another car that is supplied with the necessary equipment. Usually, the institute's other instrumented vehicle ICARUS (Instrumented CAr for Road User Studies, see Van der Horst & Godthelp, 1989) is used for this. For accurate position information on-line calibration of the current position is possible by use of active infra-red sensors which are triggered by reflecting material at given locations along the roadside.

Physiological variables

Indicators for driver performance and workload may be derived from variables describing the driver's physiological state. Several physiological variables can be measured, for example, heart rate and its derivatives, respiration rate, skin conductance responses (SCR), and special features of the electroencephalogram (EEG).

Cooperative and autonomous driving

ICACAD is provided with possibilities for cooperative driving. First, speed control can be supported or controlled by the test system through activation of the accelerator pedal. This is done by adding a force to the accelerator in one or the other direction. The maximum force in either direction is 500 N. This accelerator allows several ways to affect choice of speed. With low levels of counter-force the accelerator operates as tactile display giving speed advice. Reducing the counter-force, which may even become negative, indicates that speed should be increased. An increasing counter-force indicates that one should lower speed. With higher force levels the advice gets more difficult to ignore until, at the maximum force level, it becomes hard to overrule. In this way the active accelerator can be used to limit speed in low speed areas as well as to warn drivers with several levels of persuasiveness when, for example, distance to the lead car is to small or when the driver attempts to overtake while this is dangerous. Because the accelerator can be activated in both directions the speed of the vehicle can also be controlled by the on-board system in the sense of autonomous driving. One example of autonomous speed control is to have it controlled by the current distance to the lead vehicle. This turns the system into an intelligent cruise control.

In addition to cooperative and autonomous speed control ICACAD also allows cooperative and autonomous lane keeping control through the active steering wheel. As with the accelerator, the active steering wheel can serve as tactile display by presenting a small torque on the wheel but the advice becomes more persuasive with increasing torque levels (up to 15 Nm equalling 77 N at the outside of the wheel). The maximum torque level is not sufficient for overruling the driver and autonomous driving is possible when the wheel is released. For example, one may link the active steering wheel to the lane position sensor in order to get autonomous steering.

The test system

As stated before the major aim of ICACAD is to evaluate the ergonomics of sophisticated in-vehicle systems. The first system tested in ICACAD was the GIDS system (Janssen, Kuiken, & Verwey, 1994; Michon, 1993). This system is aimed at integrating and prioritizing information from several information sources and presenting it to the driver in a suitable manner at the appropriate time. ICACAD provides information to the GIDS system on current location at a specific test route and distance to a lead vehicle. It has also been also equipped with a radio and a car-telephone. Both have been linked to the GIDS system so that the driver can use speech and, when standing still, pull-down menus on the LCD for control.

TECHNICAL DESCRIPTION

In order to be able to adapt ICACAD to a wide variety of test systems a DODGE RAM van was chosen. This car contains much space and drives more or less like an ordinary passenger car. In order to give the experimenter possibilities to take over car control an additional braking pedal has been mounted on the floor in front of the passenger seat. On the dashboard in front of the experimenter an emergency button allows him to shut down the engine.

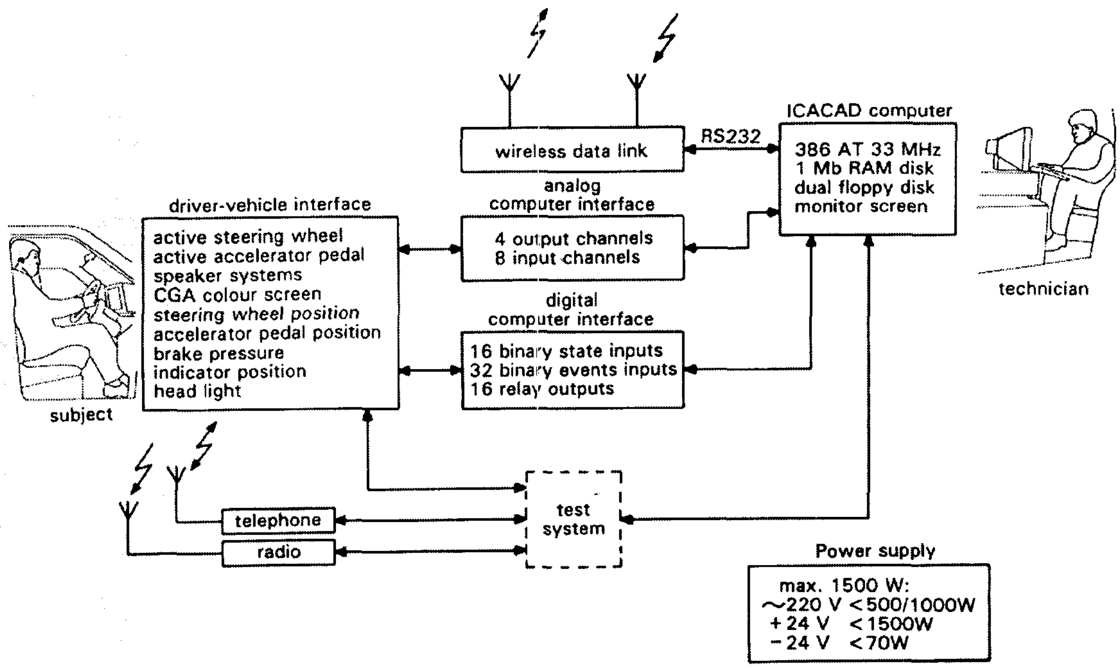
The translational accelerations are measured with two sensors, one measuring lateral acceleration, the other measuring longitudinal acceleration. These sensors are mounted just behind the driver seat so that the accelerations are measured as they are experienced by the driver. Longitudinal velocity is obtained with a binary rotation sensor mounted directly on the left back wheel. Longitudinal position (distance) is derived from this. Distance can be calibrated using active infra-red sensors mounted on each side of the vehicle. Passing a piece of infra-red reflecting material along the road will trigger a sensor and allows for the calibration. For rotational velocity in the horizontal plane (yaw rate) and around the longitudinal axis (roll rate) a small gyro has been installed. Lateral position is measured using a special device developed for earlier versions of the institute's instrumented vehicles (Blaauw, & Burry, 1980; Van der Horst, & Godthelp, 1989). This device measures the distance between the vehicle and a reference line. Usually the roadway delineation is used as reference. The device is mounted at the roof of the vehicle.

Figure 3 shows a schematic diagram of the data-management configuration of ICACAD. The core of the standard equipment is a 33 Mhz 386 AT PC with two 3.5 inch 1.44 Mb floppy drives and a 1 Mb RAM disk. The RAM disk is used instead if harddisks to prevent risk of disk crashing during driving. Its capacity is enough to run experiments without the need for storing data on floppies. For example, eight 16 bit analog channels can be registered for about 1.5 hours in RAM disk.

The ICACAD computer serves five major functions. a) It registers data on driver and vehicle behaviour, b) it links the test system to

FIGURE 3

Basic configuration of the data-management system in ICACAD



the sensors and to most elements of the driver-vehicle interface, c) it keeps track of the current position of the vehicle in the road network, d) it provides a graphic display of the data flow for monitoring purposes, and e) it enables the technician to communicate with and exert control over the computers of the test system. The latter function reduces space, weight, power consumption and control efficiency because it makes peripherals of the test system such as keyboards and monitors superfluous.

CONCLUSIONS

In ICACAD the TNO Human Factors Research Institute possesses a flexible on-the-road laboratory to investigate drivers' responses to new sophisticated systems in the car while driving in the real world. ICACAD's flexibility enables evaluation of systems that have not yet been fully developed and, hence, allows human factors research to become an integral part of the system design process. Therefore, ICACAD increases the chance of success of almost any kind of sophisticated in-car system because driver load and driver acceptance can be evaluated under real driving conditions.

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ABSTRACT

This paper describes the Instrumented Car for Computer Aided Driving (ICACAD) and how it is used for conducting behavioural research in traffic. Its primary aim was to investigate the effects of telematics applications on driver performance, which is important for making such applications a success. However, the general set-up of ICACAD makes it suitable for other types of experiments possible as well.

RESUMO

Neste artigo é descrito o Carro Instrumentado para Condução Auxiliada por Computador (Instrumented Car for Computer Aided Driving, ICACAD) e a forma como ele é usado para investigações comportamentais em tráfego rodoviário. Este automóvel foi desenvolvido com o objectivo inicial de estudar os efeitos de sistemas telemáticos no desempenho de condutores, o que é importante para assegurar o êxito desses sistemas. Porém, as características gerais do ICACAD tornam-no também adequado para outros tipos de investigações.