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Human-Centered Intelligent Vehicles: Toward Multimodal Interface Integration

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As a general rule, the development of innovative systems based on new technological advances cannot be considered complete until they integrate a sufficiently friendly user interface with the average end user. The same consideration applies to intelligent transportation systems, and more precisely to intelligent vehicles, where an easy, effective, and immediate form of dialog with the vehicle equipment could make driving safer and more efficient. Many prototypes of intelligent vehicles integrating extremely advanced information and control subsystems have been built and proposed, each with its own interface. This installment of the ITS department provides an essential overview of the concepts and principles of, and approaches to, the design of interfaces for equipment in future intelligent vehicles.

If you have any comment on this department, feel free to contact me. I also seek contributions on the current status of ITS projects worldwide as well as ideas on and trends in future transportation systems. Contact me at broggi@ce.unipr.it; www.ce.unipr.it/broggi.

—Alberto Broggi

ITS technologies provide vehicles with different types and levels of intelligence to complement the driver. Information systems expand the driver's knowledge of routes and locations. Warning systems, such as collision-avoidance technologies, enhance the driver's ability to sense the surrounding environment. Driver assistance and automation technologies simulate the driver's sensorimotor system to operate a vehicle either temporarily during emergencies or for prolonged periods.

Such new information and control technologies that make vehicles smarter are arriving on the market as optional equipment or specialty after-market components. These technologies are being developed and marketed to increase driver safety, performance, and convenience. However, these disparate components require further significant integration efforts to create a coherent intelligent vehicle that complements the human driver, fully considering his or her requirements, capabilities, and limitations.

A fully intelligent vehicle must work cooperatively with the driver.[1] New, uncoordinated technologies could deliver excessive, competing, or contradictory messages and demands that might distract, confuse, and overwhelm the driver. This could cause an overload of the driver's limited cognitive resources, thereby decreasing the driver's performance and safety. An intelligent system senses its environment and acts to reach its objectives. So, its interaction and communication channels—that is, its interface—greatly influence the type of intelligence it can display.

Primary requirements for a definition of a coherent intelligent system therefore include *intrasystem integration* (among all subsystems, including input/output if applicable) and *intersystems integration* (among the systems and environment, including the user if present). An integrated, coordinated system is thus a defining feature of a *human-centered* intelligent vehicle. Without it, the vehicle would simply be a container of potentially overlapping or conflicting technologies.

The quest for human-centered interface design

Recognizing the importance of smart vehicles and the potential unintended consequences if human factors are not at the center of their design, the US Department of Transportation launched the *Intelligent Vehicle Initiative* in 1997. "The nation that develops and integrates an architecture that provides a seamless interface to the driver will dominate the automobile industry for many years to come," stated the US National Science and Technology

1094-7167/01/$10.00 © 2001 IEEE

Council.[2] Among near-term measurements and standards needs for developing intelligent systems, the US National Institute of Standards and Technology has underlined the importance of architecture and interface standards to enable adding intelligence to technology effectively.

The EU as well has identified *human-technology interaction* (HTI) as a short-term priority for the deployment of road transport technology in Europe. The Japanese government has also provided excellent organization and funding for such standardization.

In this direction, the IT industry has begun promoting PC software platforms as a standard, flexible, and integrated solution for coordinating in-vehicle information and control technologies. Such technologies will include systems for security (warning, assistance, and automation), information (navigation assistance and traffic news), communication (Internet access, email, cell phones, faxes, and pagers), and entertainment (backseat movies, video games, and news). Furthermore, personalization, a basic principle in PC technology development, is strategic from an overall market perspective, because customization is attractive to both developers and end users.

Interface design issues

The integration of individual in-vehicle technologies will be reflected in coordinated and streamlined displays and controls. Over time, the vehicle will become increasingly sophisticated in how it communicates information to and accepts commands from the driver.

This increasing complexity has underscored the importance of providing system developers with human factors guidance early during design. Driver-centered design, however, means more than the ergonomics of "knobs and dials." It also requires that designers adopt what the Japanese call *kansei*, the infusion of human sensibility.

A key criterion for the development and introduction of an innovative technology is that it provides the intended benefits without unintended adverse consequences. Driving is potentially dangerous. Although in-vehicle technologies can enhance the driver's capabilities and comfort, the distinctive and complex nature of these systems suggests that they could further strain driver capacities and, if not carefully implemented, actually exacerbate existing traffic problems. The design of the driver–vehicle interface, where the driver interacts physically and cognitively with the vehicle, is therefore critical.

When giving drivers access to such systems inside the vehicle, designers must consider not only safety (that is, not overloading the driver's information-processing resources) but also driver acceptance and usability.[3] Driver acceptance will play a critical role in how intelligent vehicles look and perform, and the system interface will strongly influence how a user views and understands the system's functionality. Interfaces must be intelligent, user friendly, effective, and transparent to use.

> Drivers will soon face a mass of new visual, auditory, and tactile information. In an intelligent vehicle, drivers will have access to more information than they are traditionally accustomed.

Careful HTI design can address these concerns, although many ITS technologies will likely still require additional driver education and training. Accurate HTI design lets users easily and naturally decompose a task into subtasks and map them to the system's functions.[4] So, the first step in the design process is to outline the potential information requirements for a given hypothetical system. This involves understanding the nature of users' tasks, the ways in which users most naturally decompose them, and the information required to perform these tasks.

Recent development of intelligent transportation systems suggests that drivers will soon face a mass of new visual, auditory, and tactile information. In an intelligent vehicle, drivers will have access to more information than they are traditionally accustomed. So, the vehicle itself will have to filter information, by selecting and enhancing relevant information only. Therefore, designers will have to make many decisions concerning what information to present and how, where, and when to present it.

Information display issues that will directly and significantly affect the system's safety, usability, and acceptance include

- *modality* (for example, auditory, visual, and or tactile),
- *format* (for example, text, map, tone, or voice),
- *location* (for example, concentration and distribution, and head-up or head-down), and
- *time* (for example, start time, duration, and frequency).

Multimodality

Most research on information displays has focused on the acceptability of the visual or auditory modality. Traditionally, drivers depend largely on vision for driving-related information. However, with an *in-vehicle information system* (IVIS), drivers must perceive many different types of information, and a system's exclusive use of one modality might lead to driver overload.

The lack of coherent and specific guidelines and standards for multimodal in-vehicle displays has resulted so far in design by consensus, because similar studies often present contradictory results or general theoretical principles too difficult to apply directly.

With the overall goal to develop a comprehensive, usable set of guidelines, the US Department of Transportation has recently begun conducting simulator experiments that relate display modality, format, and location to additional critical variables such as

- information type, priority, and complexity;
- trip status and driving load; and
- the driver's age and subjective workload.

Overall, in virtually every circumstance, carefully designed multimodal displays appear to be more beneficial than any single-modality display. Multimodal displays have exhibited safer driving behavior under every driving condition, have been more effective in route guidance and emergency response, and have exhibited better scores on many subjective workload measures.[5]

Generally, the information architecture should be as simple as possible. If complex information is inevitable, a multimodal display will lower the driver's workload and will result in better driving performance.

An Autonomous Vehicle Interface Prototype

A recent collaboration between the University of Pavia's Computer Vision Laboratory and the University of Parma's Department of Information Engineering has lead to an integrated, multimodal interface prototype developed for the ARGO autonomous vehicle. ARGO is a passenger car with a real-time vision-based control system for extracting road and environmental information (lane markings, vehicles, and obstacles) and for autonomously steering the vehicle.[1]

The automatic driving system's interface (see Figure A) lets the driver adjust various driving parameters and select one of these driving modes:

- *Manual*: The system monitors the driver's activity and warns the driver of potentially dangerous situations (options: lane departure warning and vehicle or obstacle detection).
- *Supervised*: The system temporarily controls the vehicle to keep it safe in dangerous situations (options: lane keeping and vehicle or obstacle collision avoidance).
- *Automatic*: The system controls the vehicle for an extended period (options: lane or vehicle following).

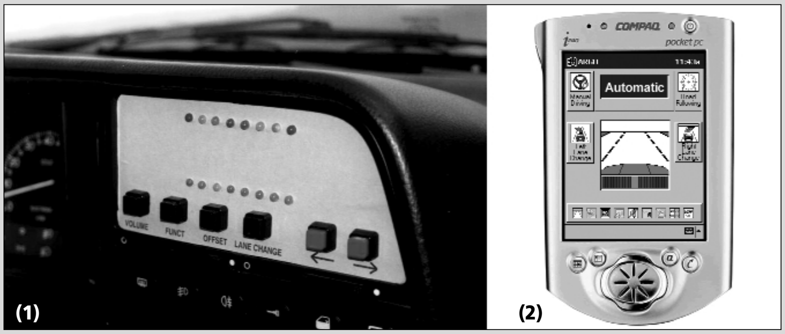

Figure A. Two interface prototypes for the ARGO autonomous vehicle: (1) the first prototype, a dashboard-integrated control panel; (2) the current prototype, a GUI on a Pocket PC (a sample screen shot showing automatic mode and the lane-following option).

In the first prototype (see Figure A1), a dashboard-integrated control panel provided buttons for setting the system's driving mode and other parameters for the developer. An LED-based display indicated the car's position relative to the lane's center. Audio messages warned the driver of detected dangerous conditions and confirmed a command's reception and execution through vocal messages, simple tones, or special-purpose "earcons" (auditory icons such as an alarm siren). An onboard video monitor functioned as a debugging tool, providing full visibility of all system data as well as vehicle status.

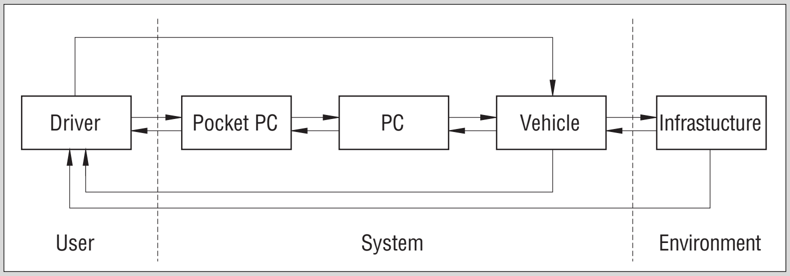

Figure B. The driver–vehicle–infrastructure interaction framework (a user–system–environment human–technology interaction scheme) for the second interface prototype (see Figure A2). A satellite handheld device (a Pocket PC) mediates driver interaction with the core automation system (a PC); existing additional driver–vehicle relations remain unmodified.

Although this first interface proved effective and simple enough for anyone to use, the limitations of its hard-coded interaction paradigm led us to develop a second prototype (see Figure A2). Although we still principally intend the new interface architecture to support the developer (and only partially to support an eventual end user), we have designed and implemented it as an integrated, coherent, and flexible interaction framework (see Figure B). Such a framework is suitable for both automation system testing and further human-factors experiments in driver–vehicle interaction. In particular, we have implemented a client-server architecture on ARGO's core Linux-PC system (the server) and on a Windows CE–Pocket PC subsystem (the client)—a personal, configurable, and mobile platform.

The prototype implements a simplified information architecture onto a basic and essential multimodal-interaction paradigm: a simple "windows–buttons" metaphor on the Pocket PC touch screen lets the driver easily select the system's driving modes and options while providing essential visual and auditory control feedback (for example, warning messages and command confirmations).

As I previously stated, the PC-based architecture provides a practical and flexible way to coordinate existing in-vehicle information and control technologies. It also lets us easily expand the system's capabilities uniformly and coherently. Furthermore, the Pocket PC's graphical user interface is an attractive feature for developers (who can easily redesign the interface and evaluate different interface languages) and end users (who can adapt the interaction dialogue to their preferences). The device's mobility and extensibility (the ability to integrate different functions and programs) offer additional, distinctive advantages for developers and users.

Future development of ARGO's system interface will focus on advanced human-centered multimodal integration, gradually shifting the interaction paradigm toward the average end user. We'll explore and evaluate innovative in-vehicle interaction languages and devices, paying particular attention to alternative visual, auditory, and tactile input–output metaphors (for example, different graphical solutions, directional sound, steering wheel feedback, speech recognition, and gaze and gesture recognition).

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However, to avoid annoying the user, multimodal information presentation should be conservative and carefully balanced according to the capacity and limits of human sensory channels. (For example, balanced visual and auditory information redundancy might reinforce message effectiveness, whereas excessive redundancy might result in a frustrating and unusable system.) A full understanding of the subtle trade-offs of multimodal information display will require significant research.

Additionally, most research on in-vehicle systems has concentrated on the presentation of navigation and warning information, resulting in accurate and detailed comparative literature about past and present interface prototypes.[6] On the other hand, research and documentation on automation systems interfaces (and on comprehensive multifunction systems integration) is relatively rare. At the Universities of Pavia and Parma, my colleagues and I are developing a prototype for an automation system interface as a flexible framework suitable for further multimodal ITS functions integration and testing (see the sidebar).

As more applications are developed and integrated into working systems, researchers should continue to reevaluate how different modalities and modality combinations affect driver performance.

The vision of a human-centered intelligent vehicle is not fixed; it will continuously evolve along with technological innovation. A forward-looking approach to technology, however, will always focus on the human–machine interface, the medium through which a user communicates with a system, the point of contact between people and technology.

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