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# Ubiquitous computing within cars: designing controls for non-visual use

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Increasingly, computing and communications-based technologies are being implemented within cars. There is a need for fundamental research and development to ensure that the control interfaces for future cars require minimal visual demands. The needs, abilities and preferences of drivers (in particular older drivers) are clearly a prime focus, as part of a user-centred design approach. In addition, it is argued that much can be learnt from the experience and strategies adopted by people who are blind or have low vision (a non-user group). The paper sets out a number of research questions regarding the inclusion of such people in the design process of future automobiles.



KEYWORDS: vehicle ergonomics; design; controls; haptic interfaces; visual impairments.

## 1. Introduction

At the beginning of the 21st century, we are starting to experience a substantial increase in the complexity of the driver–vehicle interface. Over the next 20 years, a number of novel display and control operations (data entry, menu item selection, repeating messages, etc.), will be generated as a result of the widespread introduction of advanced computers and communications-based systems (Barfield & Dingus, 1998).

Many terms (and their associated acronyms) have been used in the last 15 years to refer to this collective group of technologies, e.g. Road Transport Informatics (RTI), Intelligent Vehicle Highway Systems (IVHS) and Advanced Transport Telematics (ATT). At present, two terms appear to be in vogue: Transport Information and Control Systems (TICS) and Intelligent Transport Systems (ITS). For the purposes of consistency, the label "ITS" will be used for the remainder of this paper.

The central ethos of ITS is that it is the application of information technologies, rather than basic road building, that is the key to meeting many of transportation's needs. As noted by ITS America, "ITS provides the intelligent link between travellers, vehicles, and infrastructure" (http://www.itsa.org). In this respect, in-vehicle information and support

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systems are an important facet of ITS. According to Galer Flyte (1995, pp. 159–160), such systems can be broken down as follows.

(1) Those which "Directly impinge on the driving task"—e.g. collision avoidance, intelligent cruise control, lane keeping.
(2) Those which "Provide information relevant to components of the driving environment, the vehicle or the driver"—e.g. traffic and travel information, vision enhancement, route guidance/navigation.
(3) Those which "Are unrelated to driving"—e.g. entertainment devices, office-based facilities, such as email, fax and web-browsing capabilities.

Of these systems, GPS-based route guidance/navigation is the most mature, and there is every likelihood that Satellite Navigation systems "SATNAV" will become commonplace as the market matures and costs fall. It has been estimated that by the year 2005 more than 5 million navigation systems will be sold per year throughout Europe (Rowell, 1999).

The application of much of ITS within vehicles can be seen as good illustrations of "ubiquitous computing" (Wieser, 1991). To the users (drivers and passengers), they do not resemble computers in the "box on your desk" sense. Much of the technology is hidden, either within the car or the infrastructure, with the ultimate goal of making the task of driving safer, and more effective and comfortable (Barfield & Dingus, 1998).

## 2. Human factors concerns

Clearly, there is a danger that drivers of the future will be overwhelmed by all the functionality on offer within their vehicles. At best, except for safety sub-systems, the outcome might be that drivers choose not to use particular systems (or sub-systems). In the worst case, the attentional demands of interacting with numerous systems may adversely affect drivers' abilities to control their vehicles safely. Lack of attention on the road and distraction are already major contributing factors in many road accidents (Wierwille, 1995), so systems which have the potential to add to this problem must be carefully designed. In this respect, studies with current technology navigation systems indicate the lack of application of human-system integration principles. By means of illustration, in a test track study (Tijerina, Palmer & Goodman, 1998), participants performed destination entry tasks using one of four different commercially available navigation systems whilst on the move. The mean entry time was 40 s to 2 min (dependent on the age group), and the mean number of lane departures was 0.9 (i.e. when entering a destination, drivers typically left their lane). As a comparison, when dialling a phone or tuning a radio, drivers' average task times were 15–20 s and the mean numbers of lane departures were 0.1–0.2.

It is sobering to reflect upon the rapid growth of in-car technology and the changing age profile of the driver population. In the UK, there are currently over 2 million people aged 70 plus who hold a driving licence. It has been estimated that within the next 15 years this figure will double to about 4.5 million (DETR, 2000). Similar trends can be observed across the developed nations (Barfield & Dingus, 1998). As noted above, the increased functionality available to drivers is often at the cost of increased visual and mental demands. At the same time, longer life expectancies mean that an increasingly large population of drivers will potentially be unable to cope with these additional demands, as a result of their reduced visual capabilities, declines in manual dexterity, limited ability to divide attention, etc. (Waller, 1991). In this respect, a range of empirical studies have demonstrated the negative effects of new technology on driving performance for older drivers (Fox, 1998; Reed & Green, 1999).

There has been considerable research in the last 15 years regarding the human factors issues of ITS. Major research programmes within Europe, North America and Japan have included large-scale collaborative projects tackling a wide variety of topics. For instance, methods and tools for designing and evaluating new systems, application-specific guidelines for interfaces, and the attentional and behavioural effects of the technology have all been studied (Michon, 1993; Carston, 1999). Much of the work has focused on design and development of displays (primarily visual and/or auditory) particularly for the route guidance/navigation function [see Ross, Vaughan, Engert, Peters, Burnett & May (1995) and Green, Levison, Paelke & Serafin (1995) for a summary of guidelines]. However, there are critical issues related to the control interface, that is the mechanisms for *entering* data, *selecting* from options, *requesting/ repeating* information and *moving* through the system (Burnett, 2000).

## 3. In-vehicle control design: current situation and trends

The average car of today possesses a large number of manual controls (stalks, switches, buttons, knobs, thumbwheels, etc.), used for operating secondary (e.g. windscreen wipers, indicators, headlights) and ancillary (e.g. air conditioning, entertainment) functions of the vehicle. Whilst there are few empirical studies specifically on this subject, it is clear from everyday experience that, for many cars, it can be problematic to find the required control quickly, carry out the appropriate operation and be confident that the correct action has been made. Indeed, numerous examples of poor design can be observed in present dashboards (e.g. small, identical buttons that are closely spaced, rows of identical rotary knobs that are poorly labelled)—see Figure 1. As noted by Prynne (1995), it is apparent that many car dashboards are designed "more for the eye than the hand" (p. 30).

To cope with the increasing levels of functionality on offer, there is a particularly worrying trend by many car manufacturers towards using multi-function screen-based interfaces. For example, "scroll and select" which involves scrolling within and between menus using rotary knobs, 4-way switches, etc. or touchscreens. It is inevitable with screen-based interfaces that the driver's eyes are taken off the road in order to locate and select required inputs. Touchscreens are of greatest concern because they are likely to require significant visual attention on the part of the driver, as a consequence of the basic lack of tactile and kinaesthetic feedback.

In many cases, screen-based interfaces are being employed to enable the driver to interact with many established functions of the vehicle, as well as the novel ITS-related functions. As a result, previously simple control operations (e.g. using a rotary dial for fan speed selection) have become considerably more complicated, requiring a number of discrete steps (e.g. mode selection, option choice, adjustment setting)—Porter (1999). An example of such an interface is shown in Figure 2.

FIGURE 1. Examples of current car dashboards.

FIGURE 2. An example of an integrated screen-based control interface.

Whilst there have been few specific research studies on the safety-implications of touchscreens in cars [the influential work of Zwahlen, Adams & Debald (1988), being a notable exception], there has been considerable research concerning the use of in-vehicle displays, in general, for presenting ITS-related information [see Barfield

& Dingus (1998) and Srinivisan (1999) for some recent reviews]. A basic conclusion that can be drawn from such work is that driver-system interactions should make minimal use of the human visual sense. For any in-vehicle display that extends beyond a basic complexity (e.g. simple left/right arrows), the ability of drivers to control their vehicles safely and maintain situational awareness degrades severely (Burnett & Joyner, 1997; Zaidel & Noy, 1997).

The use of screen-based interfaces raises a further research issue regarding the design of controls for future cars, namely: to what extent should integration occur? If we assume that many of the additional features within cars are a "good thing", and thus future cars should have greater embedded functionality, then the use of multiple single-function controls (no integration) is likely to cause problems for drivers (e.g. excessive time to locate correct control). Conversely, small numbers of multi-function controls may cause a different set of difficulties (e.g. remembering which mode one is in). A balance has to be sought, but it is far from clear what this might be, and whether novel control types (e.g. joysticks as used currently in aircraft) may aid drivers.

Recently, automatic speech recognition (ASR) has become a commercial reality within cars. There are clearly benefits in such a "hands-free, eyes-free" method of interaction for ITS within cars. Laboratory and simulator-based studies (Graham & Carter, 1999; Gellatly & Dingus, 1998) have realized such advantages in empirical terms. Nevertheless, recognition rates for ASR may well always be less than 100% (Russell & Harvey, 1995), and certain drivers are likely not to wish to "talk to their car" (Prynne, 1995). As a result, two recommendations exist. First, that ASR should only be used when operating a restricted range of non-safety-related functions and second, that supplemental manual controls will always be necessary.

## 4. The potential for haptic cues

There is an increasing interest within the human–computer interaction (HCI) field for new interfaces that make use of haptic (tactile and kinaesthetic) information. Studies are being conducted within diverse application domains such as virtual reality (e.g. to provide a greater sense of immersion), aerospace (e.g. to maximize pilot performance, when under high *G* forces) and textiles (e.g. to give a sense of material texture for on-line shopping)—see the on-line proceedings of the First International Workshop on Haptic HCI in 2000 for more information (http://www.dcs.gla.ac.uk/haptic).

In the ITS field, there have been no specific studies reported in the open literature concerning the potential for haptic control interfaces within cars. Nevertheless, it is argued on the basis of background research that there can be considerable gains from making greater use of haptic information within cars. The following reasons are proposed.

(1) The human body (in particular the hands and fingers) is capable of sensing a wide variety of haptic features, such as edges, textures and contours (Prynne, 1995). This enables traditional manual controls to provide considerable information concerning their function, mode of operation and current status which can be acquired without using the visual system. This information coding can be provided by the

physical design of the control in terms of its size, shape, texture, orientation and tactile/force feedback characteristics (Sanders & McCormick, 1993).

(2) Older people potentially have most to gain from an increased availability of haptic cues within cars. Visual and auditory capabilities decrease quite markedly with age, whereas studies have shown that the ability to discriminate using the sense of touch is relatively resilient to the effects of age (Steenbekkers & van Beijsterveldt, 1998, p. 159). Since older people constitute a rapidly enlarging segment of the driving population, this is evidently an important advantage.

(3) Given that the sense of touch can only be used when a person has established direct physical contact with an interface, there is a natural emotional "closeness" to the interaction. Such an effect is largely absent from visual and auditory-based human—machine interactions. In a recent virtual reality study (Sallnas, 2000), the addition of haptic feedback when people were collaborating on tasks significantly improved the feelings of trust and perceived "togetherness". Such findings suggest that haptic interfaces within cars would lead to higher levels of user acceptability, as compared with visual and auditory-based systems.

Many guidelines exist for the coding of controls (e.g. Jenkins, 1947; Hunt, 1953; Bradley, 1967, 1969; Chapanis & Kinkade, 1972; Air Force System Command, 1980) but they all suffer from being out of date (e.g. in terms of materials) and not specifically applicable for use within a driving context (e.g. demanding primary task, limited space, effects of vibration, cold fingers, wearing of gloves and age not assessed). Furthermore, published studies have not systematically investigated the effectiveness of combinations of coding or novel designs using the latest technologies.

## 5. A novel approach: "non-user" requirements

An analogy can be drawn between drivers and people with severe visual impairments. The driving task places great demands on drivers to direct most of their visual attention to the road, other vehicles and road users. In a road-based study, Burnett and Joyner (1997) found that drivers spent an average of 87% of their journey time looking towards the road ahead when travelling in unfamiliar towns and directed by the informed passenger. The consequence of this focus in drivers' attention is that their visual capacity to search for and identify in-vehicle controls is severely limited. In essence, regarding the in-vehicle scene, drivers can largely be seen to be resource-limited with respect to their visual sense.

It is argued here that design-related benefits can be gained from considering the needs of blind people and those with low vision when developing future haptic control interfaces for vehicles. It is stressed that this would be additional information to supplement that gathered from users (drivers and passengers). Three basic advantages exist.

(1) Visually impaired people have considerable experience and insight regarding the use of haptic cues and residual vision, since their attention is inevitably focused towards these sources of information (in addition to audible cues). As such, they are well placed to verbalize what specific characteristics of a control facilitate non-visual use. Obtaining such data from sighted people can be more difficult due

to two reasons. Firstly, there is considerable evidence that the visual sense is the dominant sense for everyday life (particularly in the organization of spatial information), with hearing also of significance (Eysenk, 1993). Subsequently, sighted people do not have the same focus to their use of the skin senses, and may be unaware of what haptic cues they are using in control-based tasks. Secondly, studies have shown that the perceptual experience of many objects is multi-modal, that is, the senses are intertwined. As a result, people are generally poor at isolating single sense elements used in tasks (Hollins, 1989).

(2) Useful, but rarely used, knowledge already exists on the design of controls for non-visual use, based on research conducted for people with visual impairments (e.g. Vanderheiden, 1992; Gill, 2000). The Trace R&D Center in the US (see http://www.tracecenter.org) provides a number of examples of basic controls that incorporate universal design features providing accessibility for those with visual and other disabilities, but which benefit the wider population. An example is the tactile ridges/dots on specific keys of alphanumeric keypads to facilitate the finding of keys.

(3) By considering people who would not normally be consulted or involved in the design process, there is the potential to facilitate novel design. A keyword here is "potential", since one cannot prove or disprove this statement without first conducting a design exercise.

Such an approach is novel, in that it advocates the additional inclusion of "*non-users*" in the design process. It is common (perhaps universal) practice in Human Factors to advocate an understanding of the *users*' requirements early in the design process. In a wider view, the needs of "stakeholders" are also of concern, that is, those people/groups who may directly or indirectly be affected by the new technology (Eason, 1988). Such understanding aims to reduce the likelihood of problems late in the design process, and minimize the number of iterations involved in design (Eason, 1988). For the reasons given above, it is believed that the lateral research view proposed here has the potential to provide novel and important inputs to future designs.

Figure 3 depicts both the concept of user-centred design and the basic stages of any design process (requirements, design and testing). The arrow identifies where in the design process non-users can contribute, that is, purely within the requirements phase. Furthermore, the diagram highlights that the emphasis throughout the design process should remain on the abilities, expectations and opinions of users, in this case drivers (and potentially passengers). In terms of methods within the requirements stage, supplemental information from non-users can be obtained from specific research studies. As an example, experiments could establish the range and combination of haptic cues (e.g. shape, size, textures) used by visually impaired people to discriminate different generic controls (e.g. rotaries, buttons, sliders), for operating certain generic functions (e.g. continuous control, 2-way selection, alphanumeric data entry).

Evaluation-based research would clearly need to incorporate greater task context, and the input from non-users would not be required. In this stage, a range of different methods are relevant to the investigation of non-visual use of controls (on-road performance testing, user feedback, etc.). For example, certain car manufacturers use a "poncho test" in which the driver wears a cloak which prevents him/her from viewing the interior

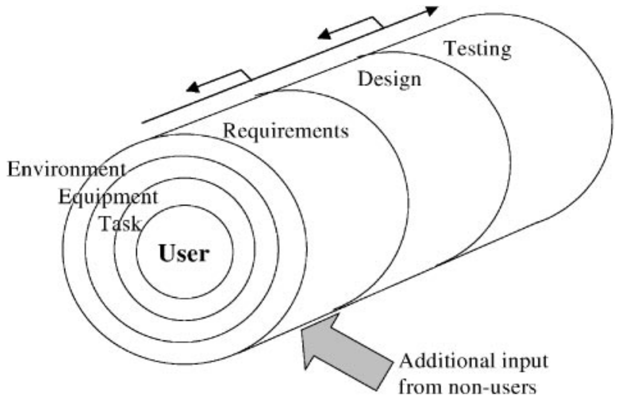


FIGURE 3. Overview of user-centred design and the expected input from non-users.

of the car. With this method researchers/designers can examine the extent to which drivers are able to use alternative control designs without vision, although the ecological validity of such a "forced" method could be questioned.

## 6. Issues with involving non-users in design

It is a common misperception that those with severe visual impairments possess heightened sensitivity of their other senses. In reality, there is no evidence that tactile sensitivity (or hearing ability) is enhanced as a result of the loss of sight (Hollins, 1989). Indeed, if blindness is due to diabetic retinopathy (a common cause of impairment for older people), then both visual and touch abilities are found to reduce markedly (Hollins, 1989). Nevertheless, some basic differences do exist between the sighted and those with limited vision, of relevance to the design of novel control interfaces for use in cars.

A particular difference concerns the ways in which visually impaired people tactually explore objects compared with sighted people. Lederman and Klatzky (1987) have noted that the way in which we use our hands and fingers to explore an object is largely the same for sighted and non-sighted individuals (e.g. rubbing to assess material texture, pressing to assess hardness of material). However, certain distinctions exist. For instance, studies have shown that those with visual impairments have learnt to use some additional strategies which enhance their performance on particular tasks in comparison with blindfolded sighted people. An example is the use of the two-handed gripping action which blind people use when estimating the curvature of long objects (Davidson, 1972). Whether any significant differences exist in relation to the use of basic controls is an empirical question that has not been addressed.

Issues concerning mental models and expectancies potentially have the greatest implications for the validity of the non-user approach. The context-based expectancies of visually impaired people regarding some specific aspects of in-car control interfaces (layouts, operation methods, etc.), will inevitably differ from that of sighted drivers in two particular ways. Firstly, expectancies may not exist in any shape or form or may be limited. Such an eventuality may arise for people who have never driven a car and built up specific mental models regarding in-car controls. Secondly, the expectancies of visually impaired people regarding in-car controls may contradict driver stereotypes. An example may be the possession of a different stereotype regarding the lower/higher movement of particular controls. This would occur because the visually impaired individual has had some experience of car controls from many years ago, or has transferred learning from other consumer products (e.g. videorecorders, microwaves).

In many respects the seriousness of these cognitive issues depend on the degree of abstraction from the driving task context that one chooses to investigate control interfaces. It is believed that visually impaired people have much to offer in the design of generic control types to facilitate non-visual use (rotaries, buttons, sliders, etc.). Limitations in their input would be expected when considering the design of specific in-car controls for use within particular driving contexts (e.g. where to locate adaptive cruise control buttons). This point relates back to the need to include the additional data from non-users at the very beginning of the design process, prior to detailed investigations with full context (users, tasks and environments).

A further point concerns the ultimate need for a visually appealing solution in car design. The vehicle interior is the primary perspective of the driver and passengers, and has a considerable influence on whether a car is purchased or not. This is a more general issue pertaining to the complex trade-off decisions that must be made when designing a consumer product such as an automobile.

The above points are not necessarily limitations in the approach, but are research questions that must be borne in mind when considering the relevance and/or the importance of data that arises from "non-users". To understand their significance, one must conduct research that exposes visually impaired people to in-car control interfaces (evidently, without the driving task elements).

## 7. Conclusions

There are two main arguments to this paper. Firstly, that there is a need for an increased use of haptic cues with respect to the control interfaces for future cars. This basic requirement has emerged from three core issues. Future research and development must aim to understand the specific benefits of haptic control interfaces in relation to existing designs.

(1) Although there is a wide range of manual controls in current vehicles, the sense of touch is commonly under-used and under-valued (Prynne, 1995). This is despite the evidence that (a) haptic cues have the potential to enhance the usability of in-car controls, and (b) alternative screen-based control interfaces have negative implications for driving safety.
(2) With the explosion in the application of ubiquitous computing within future vehicles, many more functions will be available to drivers with their associated controls and displays. There is an urgent need for usable, integrated designs to ensure that drivers' interactions with multiple systems do not cause an increase in visual distraction and mental workload, with potential negative implications for safety.
(3) There is limited specific and up-to-date guidance available to vehicle designers on how to design physical controls to minimize the need for vision.

The second primary argument in this paper concerns the opportunity to learn from non-users in the design process. In this context, it is believed that much can be learnt from people who are blind or who have low vision to facilitate an understanding of the features of in-car controls that enable non-visual use, and conceivably to aid in the development of novel designs. Research must address the extent to which such benefits can be realized in practice.

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