BIONIC – ‘eyes-free’ design of secondary driving controls

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The BIONIC project (Blind Operation of In-car Controls) was set-up to develop an ‘eyes-free’ prototype interface, enabling drivers to access secondary and ancillary controls whilst minimising the visual demands within the car. This research was initiated out of concern for the increasing use of multi-function screen based interfaces that place an additional visual workload on the driver. BIONIC has created new guidelines for the design of highly tactile control interfaces, based upon a series of experimental studies and the development of prototype designs that are described in this paper. The first iteration prototype controls were assessed in a driving simulator trial. Second iteration working prototypes were then installed within a Honda Civic demonstrator vehicle and these novel controls were compared to the current interface in on-road trials. A strong emphasis was placed on measures that directly relate to safety, such as the number and duration of glances made to the control and/or display. A reduction in total glance duration of 10% was stated as our target in the grant proposal; the BIONIC interface achieved an overall reduction of 20% and 32% for the HVAC and SAT NAV tasks, respectively. The BIONIC ICE tasks required a 7% increase in total glance duration, but this was a consequence of its poor location in the vehicle due to the constraints of fitting the prototype interface into a production vehicle.

Keywords: vehicle ergonomics, driving, control design, tactile interfaces, visual impairments.

1. AIMS OF THE BIONIC PROJECT

BIONIC stands for ‘Blind operationION of In-car Controls’. We did not plan to enable people with severe visual impairments to drive cars - rather we hoped to demonstrate that accessing complex technology whilst driving could be made safer by being less demanding upon the driver, both visually and mentally. This was to be accomplished by developing an ‘eyes-free’ prototype control interface that provided high levels of tactile and kinaesthetic information. We introduce the term ‘eyes-free’, in the same vein as the term ‘hands-free’ for mobile phones, to refer to minimising the visual demands within the car interior allowing the driver to attend primarily to the visual environment outside the car. To achieve this goal, the needs, abilities and preferences of drivers (in particular older drivers who experience increasing visual and cognitive impairments) were placed at the centre of the research. In addition, BIONIC learnt from the experience and strategies adopted by people who are visually impaired when operating control interfaces on consumer products.

The BIONIC consortium was operational from 2001 to the end of 2004 and comprised HONDA Research & Development, Loughborough University, Visteon, ARRK Formation Ltd., SAMMIE CAD Ltd., RNIB and Nottingham University. The research was funded by the EPSRC, via the Loughborough Innovative Manufacturing and Construction Research Centre.

2. RESEARCH CONTEXT

The basic need for this research emerged from four core issues:

1. With the predicted explosion in the application of Information Technology within future vehicles, many more functions will be available to drivers with their associated controls and displays. The clear concern is that drivers’ interaction with multiple systems will cause an increase in visual distraction and mental workload, with negative implications for safety [1]. The hands and fingers are capable of sensing a wide variety of tactile features, such as edges, textures and contours. As a result, traditional manual controls can provide considerable information concerning their function, mode of operation and current status that 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 location, size, shape, texture, orientation, and tactile and auditory feedback characteristics [2].

As a means of coping with the increasing levels of functionality on offer, there is a particularly worrying trend for car manufacturers to use multi-function screen-based interfaces (e.g. touch screens). In many cases, such interfaces are being employed to enable the driver to interact with many established functions of the vehicle, as well as the recently introduced telematics functions such as satellite navigation. As a result, previously simple control operations (e.g. using a rotary dial for fan speed selection) have become considerably more complicated and, in some cases, now involve a number of discrete steps all requiring vision to a screen interface (e.g. mode selection, option choice, adjustment setting). Research studies have shown that interfaces of this kind require large “eyes off road” time, and increase the likelihood of drivers wandering out of lane [3,4].

2. Although there is a wide range of manual controls in current vehicles, the tactile sense is commonly under-used and under-valued. This is despite evidence that tactile-based controls can require minimal use of vision and information processing resources, and offer significant usability benefits in relation to screen-based interfaces. Whilst guidelines exist for the coding of controls [5,6,7,8,9], they all suffer from being out of date (particularly in terms of materials), and they were not specifically developed for use within a driving context. Older people potentially have most to gain from an increased availability of tactile 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 [10]. Given that older people are a rapidly increasing segment of the driving population, this is evidently an important advantage. In addition, a well designed tactile control has clear potential to provide a pleasure feature within the car [11].
3. Speech recognition has potential for the ‘eyes-free’ operation of a restricted range of non-safety related functions, but given recognition rates of less than 100%, individual driver preferences, and the unpredictable noisy environment, it is considered that supplemental manual controls will always be necessary.
4. There is limited specific and up-to-date guidance available to vehicle designers on how to design physical controls to minimise the need for vision. Useful, but rarely used, knowledge exists on the design of controls for non-visual use, based on research conducted for people with visual impairments [12,13]. The Trace R&D Center in the US (see <http://www.tracecenter.org>) provides a number of examples of basic controls that have been optimised for use by people with visual and other disabilities. Visually impaired people have considerable experience and insight regarding the use of tactile cues and residual vision. As such, they are well placed to verbalise what specific characteristics of a control facilitate non-visual use. In contrast, for the wider population there is much evidence that the visual sense is the dominant sense for everyday life, with hearing also of significance [14]. Subsequently, sighted people do not have the same focus to their use of the skin senses. Consequently, we decided to involve visually impaired people in our preliminary research. This approach was novel, in that it advocated the use of ‘non-users’ in the design process [15].

The thrust of the research was to support the design of novel control interfaces for future vehicles so that visual and mental demands are kept to a minimum. BIONIC has created new guidelines for the design of manual controls for secondary and ancillary functions in future cars. These guidelines are based upon a series of experimental studies and the development of prototype designs that are described in this paper. The initial work of the project involved baseline knowledge gathering on the design of tactile controls, both within the vehicle area and elsewhere. Drawing from current data, a ‘pool’ of control concepts for operating a sub-set of established and future functions of vehicles was generated. Specific experimental studies subsequently identified the characteristics of in-vehicle controls that reduced or removed the requirement for vision. The results of this research enabled a range of first iteration prototype controls to be built that were assessed using a driving simulator trial. Second iteration working prototypes were then built for evaluation within a Honda Civic demonstrator vehicle. In the final stage of the project, the usability of the novel controls in relation to current designs was evaluated in on-road trials. A strong emphasis was placed on measures that directly relate to safety, such as the number and duration of glances made to the control and/or display [16]. A reduction in total glance duration of 10% was stated as our target in the grant proposal.

3. PROJECT STAGES

Brief details of the various project stages are given below:

3.1 Knowledge gathering

This stage involved a literature review and a review of current control interface design was conducted by visiting showrooms for all major car manufacturers.

3.2 Study 1: To determine the tactile cues that visually impaired participants find most useful in determining control location and function

Twelve participants were selected (7 females, 5 males, age range 17-42 years). 3 had no sight whilst the remainder had sight described as ‘cannot see well enough to recognise a friend who is an arm’s length away’. Individual interviews were held during which a portable CD/tape/radio unit was presented for exploration and comment (see Figure 1). Videos were taken for detailed analysis of the strategies that were used to locate controls and to identify their function.

The results showed that location, shape and protrusion were the key features of importance. Many participants commented that a reference 'landmark' was very useful for searching the device and for finding functions when requested. We termed this a 'hand control reference point' and the final BIONIC design exploits this feature. Another important finding was the issue of avoiding what we have termed 'tactile noise'. For example, some participants confused the built-in microphone cover with the release button for the CD flap. This made us realise that the construction features of the device should avoid creating tactile sensations that could be interpreted as a functional control. Lastly, we found out that indented symbols were extremely difficult to differentiate. For example, the arrangement of the tape controls for pause, stop/eject, fast forward, rewind, play and record was learnt by use rather than simply perceived by touch.

3.3 Study 2: To identify which secondary control designs can be used by drivers without looking

Twenty drivers (15 male, 5 female, age range 18-61 years) were interviewed in their own car. As part of the selection criteria, they had to have owned the car for at least 12 months so that it could be assumed that they were familiar with the various secondary controls. The participants were asked to keep looking at a point through the windscreen some distance away whilst attempting to operate a selection of secondary controls when so requested. This allowed participants to use their peripheral vision, as is the case when driving, without specifically taking their eyes off the road to look inside the car.

This baseline study provided clear evidence that using existing in-car secondary controls non-visually can be particularly difficult for some cars/designs/tasks. Indeed, for some tasks (e.g. switching the fog lights on), failure rates and mean 'achieving' times were high (40%; 10secs) for what is essentially a single step operation. Furthermore, it was apparent that a wide range of factors (relating to the individual, the tasks and control design) impacted on failure rates/task times. This high-level understanding of relevant factors assisted greatly during the generation and development of the BIONIC design.

3.4 Development of functionality specification and scenarios for critical use

A complete list of functionality for current cars was compiled with reference to high specification cars such as the Mercedes S Class and the BMW 7 series. A series of focus groups with experienced drivers reduced this list of functionality down to that which would need to be easily accessed before, during and after normal driving and in the event of an emergency. Scenarios of different types of use were developed to help identify the important functionality and their frequency and sequence of use. The main scenario was arriving at a foreign airport on a cold, wet night, hiring an unfamiliar car and preparing to drive off. An associated scenario was promptly getting lost on departing the airport.

3.5 SAMMIE evaluation to identify optimum control and display location in a Honda Civic

At this stage it became important to fine tune the selected BIONIC concept to the intended demonstrator car – the Honda Civic. This car has a dashboard mounted gear selector which is in a very good position for both reach and vision. This location would have been a prime site for the BIONIC interface but, clearly, this was not possible. The SAMMIE CAD system [17,18] was used to model the interior of the Honda Civic and identify alternative areas which were suitable for positioning the pods and the screen for easy reach and vision by drivers of all shapes and sizes (see Figure 2).

FIGURE 1: Exploration of a portable audio unit by visually impaired participants

FIGURE 2: SAMMIE CAD model of the Honda Civic interior showing 3D reach volumes for both hands

3.6 Generation of concept designs for an 'eyes-free' interface

Brainstorming sessions were held which resulted in a large number of concepts being generated. Several of these were visualised using the Lightwave software (see Figure 3). These concepts ranged from providing a 'chord'

interface, whereby the driver would push one or more buttons in combination to select different functions, to presenting individual controls directly on the display. One interesting concept aimed to ensure that the driver could operate it 'eyes-free' by recessing the controls so that they could not be seen and had to be learnt. Slowly, the initial BIONIC design began to emerge. We opted for a strong modal design, completely avoiding any multi-function controls, by providing 3 separate 'pods', one each for SAT NAV (satellite navigation), HVAC (heating, ventilation and air conditioning) and ICE (in-car entertainment). Each pod has an integrated hand control reference point where the palm of the hand can rest, with the fingers naturally resting on the pre-set buttons at the top. Consistency between the pods was important – for example, the large rotary dial on each pod was assigned to adjust volume in the SAT NAV and ICE pods and to adjust fan speed in the HVAC pod.

3.7 Study 3: To identify the relative strengths of coding using shape, size and location

Ten participants (5 male, 5 female, aged 22-34 years) were blindfolded and asked to find specific cardboard cut-out numbers (1-9) on 6 different boards. Separate boards were prepared for different coding methods, singularly and in combination: size (9 increments in size arranged out of order), location (9 different sized numbers arranged in order), location and size (9 different sized numbers arranged in order). Shape was held constant with 9 different shapes – the numbers themselves. The boards were presented randomly using a repeated measures design.

The results showed conclusively that the most important coding was by location. Other coding methods could be used in combination, but with care. Certain features, such as 'holes' and horizontal or vertical lines, were found to be important in identifying numbers and these could be used to advantage when developing a tactile design. See [18] for further information.

3.8 Development of the BIONIC pods

The SAMMIE evaluation identified several possible locations of the pods. It was finally decided to locate the pods between the 2 front seats as this enabled use by both the driver and the front seat passenger. The Lightwave visualisation (see Figure 4) was transferred into a full engineering CAD package (Pro-Engineer) and non-operational rapid prototypes were made, including an integrated supporting structure. These were evaluated for ease of access and quality of interaction in the demonstrator car.

3.9 Study 4: Evaluation of BIONIC pods using a driving simulator

Twelve participants (6 male, 6 female, aged 19-52 years) evaluated the non-operational pods using a driving simulator to provide a fairly realistic primary task where they were asked to follow a white van and to keep a safe distance behind. No BIONIC training was provided and participants initially completed a 'guessability' exercise whereby they were asked to operate selected functions using the pods without driving. This was followed by a period of driving during which time they were again asked to operate selected functions but they had to drive safely and could only take glances to the pods. Lastly, a 'poncho' exercise was set-up whereby looking at the pods was not possible.

The results showed that high success rates, in the range 80-100% across the participants and conditions, were achieved with the prototype BIONIC design. Only 2 participants did not achieve 100% in one of the 3 conditions, but their best efforts were both 94%. Improvements to the design were identified from the errors observed. The coding of the 6 pre-sets for SAT NAV and ICE pods was improved by using 3 large dividers to separate them into 3 groups of 2 (before it was 2 groups of 3 pre-sets). The area accessed by the thumb was lowered to provide better differentiation between the pre-sets and the on/off button.

3.10 Study 5: Simulated use of a touchpad for destination entry using the left or right hand

Sixteen participants (8 male, 8 female, all right-handed) 'drove' in the driving simulator for 10 minutes. During this time, they were asked to draw letters and numbers on a simulated touchpad. This 'touchpad' used a till receipt roll of paper that was fed through to a window area where the participant used their first finger, with a small pencil mounted on a rubber thimble, to mark the paper as requested. Participants were asked to use their left and right hand, in a balanced order. The rolls of paper were inspected blind and assessed for their quality in order to predict what percentage could be recognised by suitable software.

There was some evidence that using the non-preferred (left) hand for data entry was more demanding (increased glances, perceived workload) and the quality of handwriting was poorer, as compared with the right hand. In terms of the impact of these differences on driving performance, speed variability was found to be higher when drivers were using their left versus right hand, however, there were no differences in lateral variability. It was concluded that a final BIONIC system should ideally allow a touchpad to be placed in a range of positions within the vehicle to suit the handedness and comfort requirements of the driver.

3.11 Construction of a working prototype for BIONIC pods and screen interface

The design was finalised in Pro-Engineer with allowances made for accommodating the electronics. The electronics were developed and hand-built and fitted to the next generation of rapid prototypes. The labels and graphics were produced and applied to the pods. The structure and graphics of the screen interface were designed and passed to a Visteon partner for software development.

FIGURE 3: Generation of concept designs for an 'eyes-free' interface, including an early version of the BIONIC pods mounted on the dashboard.

Aim:

To reduce the visual load on the driver

Method:

Fixed hand rest

Tactile and location coding of controls

Stereotypes followed

Allows for non-visual use of controls

FIGURE 4: Final BIONIC pod design for the SAT NAV, HVAC and ICE functions

3.12 Preparation of an instrumented demonstrator Honda Civic

The Honda Civic was fitted with the working prototype BIONIC interface (pods and screen) as well as 'lipstick' cameras for monitoring the drivers' visual behaviour, physical actions and the road and traffic environment (see Figures 5 and 6). The BIONIC interface was designed to be inter-changeable with the car's standard interface to enable comparisons to be performed.

3.13 Road trial evaluation of the BIONIC interface

Sixteen drivers (8 male, 8 female, with a 50:50 split between a 'younger' group aged 21-33, and an 'older' group aged 55-70) were selected for the road trials. Each participant drove the instrumented car, fitted with either the BIONIC or the standard interface, in a balanced presentation order. Before commencing driving, the experimenter spent 3-4 minutes quickly demonstrating the interfaces. They were then asked to perform 13 tasks with the SAT NAV, HVAC and ICE interfaces whilst driving down an 'A' road: turn on the radio and select classic FM; make the sound come out of the front speakers; turn on the CD; select track 7; increase the bass and the treble; turn on navigation; select the shortest route to Thistle Street Edinburgh; select map view; zoom map to 1/2 mile view; turn off navigation; increase fan speed and direct the airflow to the face; turn off the air-conditioning; direct the airflow to windscreen. In order to allow for some limited familiarity with the experimental situation and the interfaces, 2 seats of tasks were completed; the second of which was used for analysis.

The mean total glance duration for all tasks was 51.7 seconds for the BIONIC interface compared to 62.3 seconds for the standard interface. This represents a 17% reduction in the 'eyes off road' time, and exceeds the target that was set of 10%. Looking more closely at the data, the BIONIC interface achieved an overall reduction in total glance duration of 20% and 32% for the HVAC and SAT NAV tasks, respectively. However, the BIONIC ICE tasks required a 7% increase in total glance duration. This was due to the relatively poor location of the ICE pod (the rearmost of the 3 pods) which made it difficult to make quick glances to it whilst being operated by inexperienced users. This constraint was imposed because we had to work around the production Civic interior as it stood. If the BIONIC concept is used in future models, then it would be conceived as an integrated part of the interior and would not be so vulnerable to such constraints.

FIGURE 5: Interior of the Honda Civic showing the prototype BIONIC interface

FIGURE 6: Video images from the 'lipstick' cameras used for analysis of glance location and duration

3.14 Development of guidelines for 'eyes-free' interfaces

This series of studies and evaluations has led to the compilation of generic guidelines for designing 'eyes-free' interfaces. Examples include: provide hand control reference points (e.g. hand and/or finger rests that allow the user to consistently locate the hand in relation to the controls); avoid tactile noise (i.e. tactile information on the surfaces surrounding controls that could be mistaken for active control areas, such as split lines or screw heads); avoid indented symbols - embossed symbols that can be traced with the finger around the entire shape enable much superior recognition; avoid multi-function controls; provide clear information on modality (e.g. a clear separation was provided between the SAT NAV, HVAC and ICE modes by designing 3 pods); arrange controls to suit their function, sequence of use and importance; arrange individual controls into iconic shapes that are easily recognisable by the hand and eye to enable speedy location of a desired control; identify 'sweet spots' where displays and/or controls can be located that are easily reached or viewed by a wide range of driver sizes; provide consistency between modes; identify stereotypes and design accordingly; viewing static pages of addresses is easier than scrolling down continuous lists; avoid menu hierarchies; provide redundancy – tactile and visual;

design the task so that it can be performed with either the preferred or non-preferred hand; location, or spatial, coding is very important; shape, texture and protrusion coding are also very useful; tactile feedback of control operation is critical.

4 THE FUTURE

The BIONIC project has shown tangible safety benefits for 'eyes-free' interface design. The generic guidelines arising from this research could be used to design more effective and efficient interfaces for people who do not have the freedom to stop whatever they are doing every time they need to interact with technology, whether on-the-job or on-the-move. Examples include driving, examining screen displays from remote camera systems, operating machinery, sail-boarding, cycling and commuting. Any additional visual distraction during these activities could have a serious safety issue. Other potential benefits of 'eyes-free' interfaces would include improved productivity and pleasure of use. We are also keen to be involved in developing innovative interfaces for elderly users and people who are visually impaired.

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