Proceedings of the
IEEE Intelligent Vehicles Symposium 2000
Dearborn (MI), USA • October 3-5, 2000

Using finger-pointing to operate secondary controls in automobiles

Niall Cairnie, Ian W. Ricketts, Stephen J. McKenna, Gordon McAllister

Department of Applied Computing, University of Dundee,
Dundee, DD1 4HN, U.K.
Tel: (44) 01 382 344 146 or Fax: (44) 01 382 345 509
{ncairnie, ricketts, stephen, gmcallis}@computing.dundee.ac.uk

Abstract

Driver inattention is the cause of many automobile accidents. The operation of secondary vehicle controls has been found to be a cause of driver inattention. In this paper, we describe a prototype finger-pointing interface for the operation of these controls. A 6 DOF sensor is used to compute the point targeted on the display, located in front of the driver. The prototype Graphical User Interface (GUI) is described. Specifically, we provide experimental results concerning the sizes of buttons that can be used in the finger-pointing interface. We also discuss the types of GUI controls that we have found feasible to operate using our system.

1 Introduction

We define *driver inattention* to be the temporary state in which the driver is not processing the appropriate visual information that the primary task of driving demands. This paper describes work undertaken as part of the UK Foresight Vehicle ACTIVE project (Advanced Camera Technology in Visual Ergonomics) which aims to make driving safer by decreasing the amount of attention that a driver must devote to the operation of secondary controls. A novel, non-contact interface has been developed for operating such controls which include the radio and the climate controls (HVAC). Primary driving controls such as the steering wheel, gear stick, accelerator and indicators are not operated using the new system. The traditional, physical, secondary controls have been replaced by a computer interface, operated by the driver using finger-pointing. The major potential safety benefit of this new interface is decreased driver inattention. More specifically, this may be achieved in the following ways. (A) Faster interaction with secondary controls, resulting in a reduction in the amount of time in which the driver's eye-gaze is not on the forward scene. (B) The ability to situate the computer display in a position much closer the driver's normal line of sight, increasing the ability of the driver to use peripheral vision whilst operating the secondary controls. (C) The layout on the computer display could be transferred from vehicle to vehicle, obviating the need for the driver to adapt to a new layout of secondary controls in an unfamiliar vehicle. (D) The interface can be operated with both hands still on the wheel. Note that, with traditional, physical, secondary controls, involuntary steering is sometimes initiated when reaching for controls.

As well as the potential safety benefits associated with replacing the physical controls with a computer display, other possible benefits exist. There are likely to be reduced wiring costs. A reduction in attempted theft of the radio may result, since this object would no longer be visible. Lastly, the removal of the traditional array of physical secondary controls offers the chance for fresh design solutions.

In Section 2, the safety implications of current in-vehicle secondary control interfaces are discussed with reference to published studies. In Section 3, we present an overview of the prototype system, and explain how the user interacts with the system to operate the secondary controls. In Section 4, the development of the prototype Graphical User Interface (GUI) is discussed. We provide empirical results concerning the sizes of buttons for use on the finger-pointing interface. We also discuss the types of GUI controls that we have found feasible to operate using our system whilst driving. The prototype GUI that has been developed is then described. Finally, we conclude in Section 5 by briefly summarising the main results of the paper and suggesting future areas for research.

2 Safety Implications of Secondary Controls

In 1995, the National Highway Traffic Safety Administration (NHTSA) created the Crashworthiness Data System (CDS) to gather data on the various causes of crashes. Tow-away accidents in the U.S. are selected at random for inclusion in this database, and drivers involved in these accidents are interviewed if possible. Wang et al. [5] analysed whether or not CDS crashes in 1995 involved driver

0-7803-6363-9/00/$10.00 © 2000 IEEE

inattention. Crashes were classified as *inattentive* if at least one of the drivers involved was inattentive. The remaining accidents were classified as *attentive* if all drivers involved in the accident were known to be attentive; otherwise they were classified as *unknown*. They found that the CDS crashes in 1995 contained these categories in the following proportions: *inattentive* (25.6%), *attentive* (28.4%) and *unknown* (46.0%). They also gave a number of sub-classifications for the *inattentive* crashes. In particular, they found that 2.5% of all CDS crashes in 1995 were caused by distraction due to secondary controls (this percentage is likely to be conservative, since 46.0% of all crashes were classified as *unknown*). Specifically, this 2.5% was composed of distractions due to: *adjusting radio/cassette/CD* (2.1%); *adjusting climate controls* (0.3%); and *using a cellular phone* (0.2%). Note that the latter two of these are likely to have relatively high random sampling variation. The 1995 CDS contained 4536 crash files, and each crash file was weighted so that the database was nationally representative. The percentages stated above reflect these weightings.

Wierwille and Tijerina [6] analysed a database of 189,464 detailed police narratives collected in 1989 in the State of North Carolina. They performed keyword searches of these narratives and then manual reviews to determine the proportion of accidents caused by visual distraction of the driver. Some accidents were found to be caused by distraction due to secondary controls, and collectively these accidents implicated particular secondary devices in the following ratios: *'standard' radio/cassette* (69 %); *climate controls* (10 %); *cellular phone* (8 %); *wiper/washer* (8 %); and *citizens' band (CB) radio* (5 %). These relative weightings reveal which particular secondary controls may be causing the most accidents. The ratios broadly agree with those found by Wang et al. [5].

Wierwille and Tijerina [6] also analysed the 61,707 narratives collected in the first 4 months of 1992 for the same database, to allow comparison with the data from 1989. They observed the following trends: an increased number of accidents caused by CD players and cellular phones, and a slightly decreased in the number caused by CB radios. They conclude that the adoption of new in-vehicles devices requiring the driver's visual attention is likely to cause accidents. This conclusion is instructive: it implies that the number of accidents caused by distraction due to secondary controls will increase with the proliferation of cellular phones and in-vehicle route-guidance systems.

3 The Prototype System

Let us now describe the prototype system that has been developed. It has been designed so that the driver is less likely to lose track of the forward driving scene whilst interacting. The traditional physical controls have been replaced by a computer interface. Such an interface could be designed to operate using a touch-screen display. However, such a display would still require a driver to reach for the controls. Instead, a prototype system has been developed which uses finger pointing gestures. A driver need not even remove his/her hands from the steering wheel in order to operate such an interface. The position of the cursor on the Graphical User Interface (GUI) is repeatedly moved to the point on the screen at which the driver is pointing. The cursor's position is updated at approximately $20Hz$, which is fast enough for any cursor movement to be perceived as smooth by humans. A GUI control that is being pointed at is 'clicked' by pressing a physical button on the steering wheel.

A computer vision system is currently being developed to detect and track pointing gestures and to thus estimate the point targeted on the display. This work is reported in another paper [2]. In the meantime, the prototype system uses an electromagnetic sensing device to measure the 3D position and orientation of the driver's finger relative to the display. This approach permits development and evaluation of the interface to be performed in parallel with development of the vision system. The prototype system is shown in Figure 1. Details of the computation performed on the readings from the electromagnetic sensor in order to estimate the point on the display at which the driver is pointing are given in the Appendix. To simulate secondary devices, audio/visual feedback from the prototype interface was given when the driver activated the appropriate control. For example, music was played to simulate the radio.

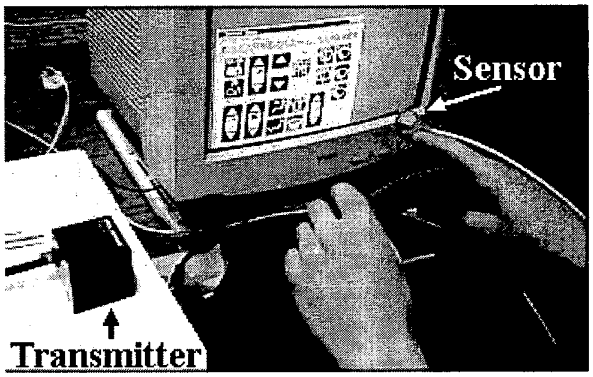

Figure 1: A laboratory-based prototype using an electromagnetic sensor

An interesting question that must be resolved is: 'What is the best position for the display screen in a car when a finger-pointing interface is being used for secondary controls?'. A number of positions suggest themselves: (1)

above the steering wheel on the top of the dashboard, (2) behind the steering wheel, visible through the wide gap in the middle of the steering wheel (currently a common position for the speedometer), (3) in the 'middle console', to the right (left in U.K.) of the steering wheel, just below the dashboard, (currently a common position for the radio/tape), and (4) above and to right (left in U.K.) of the steering wheel, on the top of the dashboard. Of these, having the display in position (1) is appealing for the following reasons. Firstly, both hands can be kept on the steering wheel whilst using the finger-pointing interface. Secondly, the display is in a position much closer to the driver's normal line of sight when driving. This offers the driver the chance to gather some knowledge of the forward scene using peripheral vision whilst operating the secondary controls. Evidence for this is suggested by Summala et al. [3]. They investigated the task of maintaining a car in a lane, using only peripheral vision, whilst performing certain in-vehicle tasks. They found that, for experienced drivers, inferior lane maintenance using (only) peripheral vision was apparent when the display was in position (3), rather than position (1) or (2). For novice drivers, better lane maintenance using (only) peripheral vision was discernible when the display was in position (1), rather than position (2) or (3). Overall, these results indicate that position (1) is attractive, since it permits drivers of any experience to use peripheral vision for lane maintenance.

We performed informal trials of our finger-pointing interface with the display in each of the four positions described earlier. We found that the pointing actions required were most natural when the display was in position (1). Moreover, both hands could be kept on the wheel for position (1), but not in positions (2) and (3). The system therefore uses position (1).

We note here that the GUI could be presented in a head-up display, rather than an LCD computer screen. This will not be attempted until possible safety problems associated with head-up displays in automobiles have been resolved (see Tufano [4]).

4 GUI Design

In this section, we provide empirical results concerning the sizes of buttons for use on the finger-pointing interface, and discuss experimentation to determine which GUI controls it was feasible to operate using our system whilst driving. The prototype GUI is then described.

4.1 Control Buttons

The size of buttons on the interface is of importance. If they are small, they will be difficult to activate correctly, leading to increased driver inattention. Conversely, only a few large buttons can be displayed simultaneously resulting in the need for hierarchical control structures such as menus. An experiment was performed to investigate this trade-off using the prototype finger-pointing system shown in Figure 1. The prototype GUI has a 15 × 10 cm display area. This can be fitted on the dashboard behind the steering wheel in many existing cars. The plane of the display was approximately vertical. The steering wheel used had a diameter of 24 cm and was tilted at an angle of approximately 15° from the vertical. The closest point on the screen to the index finger's knuckle was approximately 4 cm down and 1 cm rightward from the top-right corner of the 15 × 10 cm display. The distance from this point to the finger's knuckle was approximately 15 cm.

In this experiment, a series of target buttons were placed on the screen in pseudo-random positions. The time taken by the subject to activate each target button after it appeared on the screen was recorded. Each target button was activated by moving the cursor over it using finger-pointing and clicking an auxiliary, physical button on the steering wheel with the other hand. Once a target button was activated, a short delay of pseudo-random length was introduced before the next target button was shown in a new position. This was repeated until 40 target buttons of fixed size had been activated. During the time delay between each new button appearing, the subject's pointing finger returned to the normal position whilst driving (i.e. somewhat curled around the wheel). This resulted in the cursor appearing at the bottom of the screen when the subject later subsequently attempted to activate the next button. This experiment was repeated using buttons of various sizes. The results are summarised in Table 1.

Angle Subtended by Button (Degrees)	Mean Activation Time (seconds)	Standard Deviation (seconds)
2.0	1.78	0.41
4.0	1.38	0.17
6.0	1.28	0.18
8.0	1.33	0.24
10.0	1.19	0.13

Table 1: *Mean activation times for differently sized buttons.*

The mean activation times shown in Table 1 are likely to differ from the actual mean activation times that will be observed whilst driving an actual vehicle. Two main reasons for this are that in this laboratory experiment no far-to-near accommodation of the eyes occurs and the subjects did not know in advance the positions of the buttons. However, the relative magnitudes of the mean activation times that were recorded provide an indication of the sizes of buttons that are appropriate for finger-pointing interfaces.

The results shown in Table 1, indicate that buttons which subtend an angle of at least 4° provided near-optimal mean activation times. The button that subtended an angle of 2° gave a substantially inferior mean activation time. Its standard deviation was also higher. If the finger's knuckle is 15 cm from the display, a button that subtends 4° at the knuckle corresponds to a button of size approximately 1 × 1 cm. This 'minimum size' of button differs from the smallest buttons used in GUIs for normal PCs.

4.2 GUI Control Types

Experimentation was used to develop a set of Graphical User Interface (GUI) controls that could replace the rich variety of physical controls for secondary devices. These GUI controls had to replicate the function of the physical buttons and be easy to activate using finger-pointing whilst driving, i.e. they should not themselves cause driver inattention. Physical buttons for secondary devices are replaced by GUI buttons of an appropriate size. When possible, these GUI buttons contain icons that intuitively convey the functionality, as opposed to text, which is rather visually demanding. A physical spin button is a pair of related buttons, one of which usually performs an 'up' function, e.g. increase the fan speed, the other of which usually performs a 'down' function. The two buttons comprising a physical spin button are usually aligned either side-by-side or one-above-the-other. Such physical spin buttons are replaced by GUI spin buttons. Physical slider controls appear to be difficult to replicate because of the precision of pointing, especially if the the slider can be in many different positions. Physical rotational dials are replaced by GUI spin buttons. Physical readout dials are replaced by GUI 'progress bars' as commonly used to indicate how near a computing task is to completion. Alphanumerical readouts on current vehicles, e.g. the frequency of the current radio station, can be replaced by text on our GUI of a sufficient size. A significant advantage of a pointing interface is that textual or graphical feedback can appear on the buttons themselves since this text or graphics will not be occluded during activation as with traditional interfaces that rely on touch. This integrates user feedback directly with the GUI control. Whenever possible, we have attempted to depict on a GUI control its function and the current state of the device it controls. This decreases clutter and hence visual attention required to scan the GUI.

4.3 The prototype GUI

A GUI was designed based on the insights regarding the type and sizes of GUI controls just described. In view of the size of the display and the results concerning the sizes of GUI buttons, it was impossible to simultaneously display the controls for all of the secondary devices. In fact, this is beneficial since the GUI would be far too visually demanding if it contained a large array of small buttons and icons. A compromise was struck in which controls for some commonly used secondary devices are shown on the main screen, together with a GUI button that leads to a sub-screen containing less frequently used controls. The main screen of the prototype GUI is shown in Figure 2. Buttons on the GUI have been grouped together if they are related to the same device, or same type of device. This makes it easier to scan the GUI to find a button.

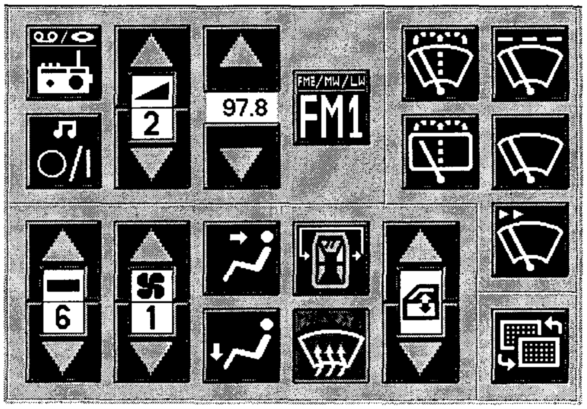

Figure 2: The main screen in the prototype GUI

Wang et al. [5] and Wierwille and Tijerina [6] found that a large proportion of those crashes attributed to the operation of secondary controls are caused by distraction due to audio In Car Entertainment (ICE) devices, i.e. radio, CD and tape. In view of this, it seemed sensible to include on the main GUI screen an audio group. This group consists of the buttons in the top-left of Figure 2. Included in the audio group is a GUI button that allows the driver to 'toggle' between the ICE devices, namely radio, CD and tape. Also included on this audio group were the major controls for the ICE device currently in use. For example, when the radio is in use, a button that can toggle between the bands (FM1, FM2, MW and LW) a button that performs the 'tune upwards' function (station search) and a spin control for volume.

Other commonly used controls on the main screen were: (i) certain wiper controls (the group of five buttons in the top-right of Figure 2), (ii) the temperature control for the air released through the vents (a spin control), (iii) fan speed (a spin control), (iv) the fan's vent release area (three buttons), (v) window up/down controls, and (vi) a button leading to other sub-screen containing containing less frequently used controls (bottom-left button in Figure 2).

The traditional physical interface for secondary controls makes use of tactile feedback. In our system, some tactile feedback is given by the physical button on the steering wheel. However, audio-visual feedback is given in order to compensate for the loss in the variety of tactile feedback. For example, each time a button is activated, audio feedback either in the form of speech output or beep is given, unless unnecessary, e.g. increasing the volume of the radio. To allow the user to easily select buttons on the GUI, a button changes colour (drastically) when the cursor is moved over it. The size of the cursor has also been increased to speed interaction with the GUI.

5 Conclusions

It is probable that driver inattention is the cause of most automobile accidents and the operation of secondary vehicle controls has been found to be a cause of driver inattention [5, 6]. In this paper, we have described a prototype finger-pointing interface for the operation of secondary vehicle controls. Results concerning the amount of attention that a driver must devote to the operation of such controls using this interface are favourable. Consequently, the methods may lead to safer driving and further development and evaluation of this interface is therefore appropriate. We note that the experimental results concerning the type and sizes of controls for the GUI pertain to in-vehicle use, and not to finger-pointing interfaces in general.

Summala et al. [3] have investigated the task of maintaining a car in a lane, using only peripheral vision, whilst performing certain in-vehicle tasks. However, tasks involving the detection of static and moving hazards in the forward scene (e.g. other vehicles and pedestrians) using only peripheral vision, whilst performing in-vehicle tasks, appear not to have been investigated. Such research would be beneficial.

In the prototype system we have used a physical button on the steering wheel. We are currently investigating an alternative method for activating controls based on dwell-time. We are also developing algorithms that learn to predict the control that the driver wishes to use next. Such algorithms can be used to adapt the interface to a particular driver, making it quicker and safer to operate. We plan to investigate the use of intuitive gestures other than pointing to operate certain secondary controls. More details of some of these other aspects of the project are reported elsewhere [1].

6 Acknowledgements

This research was funded by UK EPSRC Grant GR/M26633 through the LINK Foresight Vehicle Initiative. The ACTIVE project is being conducted in collaboration with the Institute of Behavioural Sciences at the University of Derby, Vision Dynamics Ltd. and Daewoo Motor Company Ltd. The authors wish to thank the project partners for many helpful discussions.

Appendix: Estimating the Target

Here we provide some details of the calculations performed to estimate the point on the display at which the driver is pointing. The electromagnetic sensing equipment (a Polhemus 3-Space Fastrak) consists of transmitter box (approx. $6 \times 6 \times 6cm$) and a smaller sensor which is attached rigidly near the end of the driver's index finger. The Fastrak is connected to a laptop PC via an RS232 connection. It samples the 3D position and orientation of the sensor with respect to the transmitter co-ordinate system (an orthonormal system with its origin inside the transmitter). Let $\mathbf{p}_T = [x_T, y_T, z_T]$ denote the 3D position of the sensor where subscript T denotes that the transmitter co-ordinate system is used.

The position and orientation of the display are first determined in the transmitter's co-ordinate system. This calibration step is performed during system set-up and involves the user obtaining three position vectors by positioning the sensor at (i) the top left corner, (ii) the top right corner and (iii) the bottom left corner of the display screen. These three points have transmitter co-ordinates $\mathbf{p}_T$, $\mathbf{q}_T$ and $\mathbf{r}_T$ respectively. Now define a normalised co-ordinate system relative to the display screen. In this system (denoted by subscript D), the three points ideally have co-ordinates $\mathbf{p}_D = (0,0,0)$, $\mathbf{q}_D = (1,0,0)$ and $\mathbf{r}_D = (0,1,0)$. In practice, the points do not define an orthogonal basis due to measurement errors. Let $\mathbf{x}_T$, $\mathbf{y}_T$ and $\mathbf{z}_T$ denote direction vectors for the display co-ordinate system's x-, y- and z-axes, given in the transmitter co-ordinate system. Then, we take $\mathbf{x_T} = \mathbf{q_T} - \mathbf{p_T}$ and $\mathbf{y}_T^* = \mathbf{r}_T - \mathbf{p}_T$. Note that $\mathbf{x}_T$ and $\mathbf{y}_T^*$ are not necessarily perpendicular due to measurement errors. Therefore, we take $\mathbf{z}_T$ to be the normalised version of $\mathbf{y}_T^* \times \mathbf{x}_T$ (i.e. the z-axis is normal to the display). Finally, we compute $\mathbf{y_t}$ from $\mathbf{z}_T \times \mathbf{x}_T$. This results in an orthogonal co-ordinate system that is an approximation to the true screen co-ordinate system. The accuracy of this approximation sufficed for our needs.

It is convenient to compute a transformation matrix $\mathbf{M}$ that transforms any point $\mathbf{p}_T$ in the transmitter co-ordinate system to a point $\mathbf{p}_D = \mathbf{M}\mathbf{p}_T$ in the display co-ordinate system. Let us write $\mathbf{x}'_T = [x_1, x_2, x_3]$, $\mathbf{y}'_T = [y_1, y_2, y_3]$, and $\mathbf{z}'_T = [z_1, z_2, z_3]$ for the normalised versions of $\mathbf{x}_T$, $\mathbf{y}_T$ and

$\mathbf{z}_T$. A 'rotation matrix' $\mathbf{R}$ is defined as:

$$\mathbf{R} = \begin{bmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \\ z_1 & z_2 & z_3 \end{bmatrix}$$

Consider the orthonormal co-ordinate system whose axes are oriented the same way as the screen co-ordinate system, but whose origin is the origin of the transmitter co-ordinate system. Let us refer to this co-ordinate system as the 'intermediate' co-ordinate system and denote it using subscript I. Next, compute $\mathbf{p}_I = \mathbf{R}\mathbf{p}_T$. Since the display co-ordinate system and the transmitter co-ordinate system are both orthonormal systems, $\mathbf{p}_I = [d_x, d_y, d_z]$ is the position of the origin of the display co-ordinate system with respect to the intermediate co-ordinate system. To transform from the intermediate system to the display system requires a translation. The transformation matrix, $\mathbf{M}$, that we require is:

$$\mathbf{M} = \begin{bmatrix} x_1 & x_2 & x_3 & -d_x \\ y_1 & y_2 & y_3 & -d_y \\ z_1 & z_2 & z_3 & -d_z \\ 0.0 & 0.0 & 0.0 & 1.0 \end{bmatrix}$$

The procedure for computing the point on the display to which the finger is pointing can now be completed as follows. Given a point $\mathbf{p}_T$ and the orientation of the finger, we can compute another point $\mathbf{s}_T$ on the line along which the finger is pointing. Using $\mathbf{M}$, we transform these two points to the corresponding points $\mathbf{p}_D$ and $\mathbf{s}_D$ in the display co-ordinate system. The direction of pointing is $\mathbf{v}_D = \mathbf{s}_D - \mathbf{p}_D$. The parametric equation for the line along which the finger is pointing is $\mathbf{l} = \mathbf{p}_D + \mu\mathbf{v}_D$, where $\mathbf{l}$ is the locus of points on the line as μ varies. A point is on the display plane if and only if its z component is zero. Denote, by z_v and z_p, the z components of $\mathbf{v}_D$ and $\mathbf{p}_D$, respectively. The line $\mathbf{l}$ intersects the display plane when $z_p + \mu z_v = 0$. Hence, the intersection occurs when $\mu = -z_p/z_v$, and so the the (3D) point of intersection, in the display co-ordinate system, is $\mathbf{p}_D - (z_p/z_v)\mathbf{v}_D$.

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