A Research Study of Hand Gesture Recognition Technologies and Applications for Human Vehicle Interaction

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Abstract

This paper describes the primary and secondary driving task together with Human Machine Interface (HMI) trends and issues which are driving automotive user interface designers to consider hand gesture recognition as a realistic alternative for user controls. A number of hand gesture recognition technologies and applications for Human Vehicle Interaction (HVI) are also discussed including a summary of current automotive hand gesture recognition research.

1 Introduction

In recent years, the issue of driver distraction has received increasing attention from the media, public, government, industry and safety organisations. Initially, much of the concern focussed on the use of mobile phones. Legislators were urged to take action, without having much evidence-based research to support decision-making. It is now increasingly recognised that there are many more sources of distraction inside and outside the vehicle and their impact on the safe operation of the vehicle is potentially unsafe. The means for controlling these distractions extend well beyond legislation [8].

A common form of driver distraction is caused by the driver using his single visual resource to find a specific vehicle control, for example to operate the radio or climate function. The primary motivation of research into the use of hand gestures for in-vehicle secondary controls is broadly based on the premise that taking the eyes off the road to operate conventional secondary controls can be reduced by using hand gestures.

Developing a safer Human Machine Interface (HMI) for secondary controls without compromising the primary function of driving has become a major challenge for automobile manufacturers. This paper suggests that hand gesture recognition may offer potential safety benefits for some types of secondary controls. Face, head and body gesture recognition technologies may also offer some safety benefits but discussion relating to these technologies is outside the scope of this paper.

2 Human Vehicle Interaction:The Driving Task

During the primary task the hands are used for steering (lateral-directional) control, and the feet provide outputs for longitudinal control (acceleration / deceleration). Other in-car tasks that require vision, such as operating the radio must be considered as secondary [43].

The process of time-sharing can be modeled simply [43]. Consider that a driver is to perform a specific in-car task that requires vision; the driver samples the task with a glance, returns to the forward view, samples the task again, and returns to the forward view, etc., until the visual aspect is completed. In some cases a single glance is sufficient, but other in-car tasks often require several glances.

Glance times typically range from 0.6 to 1.6 seconds with a mean glance time of approximately 1.2 seconds and a number of models have been developed to provide a computational foundation for simulating the actions that drivers perform on hand controls in vehicles [14].

2.1 Task Classification

Wierville [43] suggests that in-car secondary tasks can be separated into five categories, based largely on the level of visual and manual resources needed, and can be classified as follows: *Manual Only* tasks can be performed by one of the driver's hands, without visual reference after sufficient practice. Good examples are sounding the horn and operating the directional signal indicator levers; *Manual Primarily* tasks are a closely related category in which the driver uses vision to find a control and possibly to determine its present setting prior to adjustment; *Visual Only* tasks are completely or largely visual, they are always information gathering and require no manual input; *Visual Primarily* tasks rely heavily on vision, but require a degree of manual input; The final classification of in-car tasks is *Visual-Manual*. These are distinguished by their interactive visual and manual demands. The driver gathers information and uses it for making additional manual inputs, or the driver makes manual inputs sequentially to access desired information.

From a drivers ease of use and safety perspectives, it is clear that manual only and manual primarily tasks are the most desirable since these can be achieved with minimum visual demands which allows the driver to concentrate on the primary task of driving. Visual primarily and visual-manual tasks are clearly the least desirable. Therefore a major objective for automotive manufactures is to develop a user interface, such as speech or gesture recognition, that can improve the task classification for specific tasks from visual primarily and visual-manual to manual only and manual-primarily, to achieve major safety benefits.

3 Prevalence of Distractors

Distractions while driving are common; telephone surveys by Beirness [3] show that 81% say they talk with passengers, 49% admit they eat or drink while driving and 12% admit they read maps while driving. Operating driver controls for radio, CD and mobile phone also appear to be high distracters with high frequencies.

The National Crash Data [33] also shows a high prevalence of distraction; again driver controls for music appear in the top six distracters.

One of the most comprehensive sources of information to date on the causes of crashes comes from the recently completed 100-car study conducted by the Virginia Technology Transportation Institute. This study monitored 100 cars for 13 months using in-vehicle video cameras and extensive vehicle instrumentation. The study recorded over 42,000 hours driving, 761 near-crashes, and 72 crashes. Nearly 80% of all crashes involved driver distraction in the three seconds prior to the incident [11]. Mobile phones, Navigation systems, and other in-vehicle driver controls were associated with the highest frequency of distraction-related crashes and near-crashes. It is interesting to note that these figures, the first that have been taken from live data collection during the actual crash, are substantially higher than those from other sources that rely on second-hand information.

In summary, there is evidence that a considerable amount of driving time involves potentially distracting activities, and driver controls feature as a distraction in most research surveys, particularly controls associated with radio, CD, climate, navigation and mobile phones.

4 HMI Trends and Issues

Not too long ago, when the instrument panel on a popular car consisted of five or six instruments, and five or six auxiliary (secondary) controls to operate the radio and heating system, making a hand gesture in a designated space to operate one of these controls would rightly have been seen as an unnecessary extravagance at best, and lunacy at worst. A typical Human Machine Interface (HMI) of an early production vehicle would have a total of approximately 20 controls including foot pedals, steering wheel and hand brake. The majority of controls would relate to the primary driving task with very few secondary controls.

In contrast, although today's modern luxury vehicles are fitted with essentially the same number of primary controls, there has been a proliferation of complex information, navigation, entertainment, driver assistance, telematics, and seat comfort driver controls together with a corresponding increase in potential distraction.

In response to this huge increase in secondary controls, most automotive manufactures have taken a pragmatic approach. Frequently used, or high importance, secondary controls have been given a dedicated hard switch, typically restricted to around 20, usually situated in the centre stack area. The remainder of the secondary controls, often in excess of 100 (in some cases as high as 700), are often accessed by a menu based secondary control interface to reduce the number of individual control switches. Two main technologies have been developed to input commands into these menu based interfaces: a central rotary controller used by BMW, Audi, Mercedes Benz, Nissan, Opel, PSA, Renault and Volkswagen or a Touch screen as used by Jaguar, Land Rover, Lexus, Honda, Saab, Toyota and Ford. A smaller subset of the functions can often be controlled by Speech recognition or by steering wheel controls.

Since each of these secondary control interfaces has inherent design limitations [28] and both involve Visual Primarily and Visual Manual task classification, there is increasing interest in alternative user interfaces that do not suffer from the same limitations and one of these alternatives is gesture recognition. To date, although there is no known gesture recognition driver control system designed into a commercially available production vehicle, some automotive manufacturers are developing new gesture recognition systems in collaboration with a number of universities and suppliers.

In addition to the proliferation of in-car secondary controls, driving is becoming an increasingly demanding task as more vehicles on our roads every year make longer journeys as people adapt to a more mobile lifestyle. This can clearly be seen from the National Statistics Census [25] that shows a huge increase in the number of cars on the road and a corresponding increase in the number of vehicle kilometers over the last fifty years. This trend is set to continue and the National Statistics office has projected further traffic increases.

5 Introduction to Hand Gesture Secondary Controls and review

Although hand gestures vary greatly among contexts and cultures, they are intimately related to normal communication. Because gestures contain information and can be made without taking eyes-off-the-road, they are ideal for developing specific in car interaction tasks that can minimise driver distraction.

There are numerous possible automotive applications for hand gestures but little research has been conducted to guide the selection and development of successful techniques for vehicle secondary controls. Some limited research has been done outside the automotive field which aims to develop basic guidelines for the use of gesture recognition in virtual environments and which examines cognitive, perceptual and human factors motivation [10].

A literature review of current research investigating the use of hand gestures for vehicle secondary controls has been carried out and is briefly summarised in the following section. This summary presents the different technologies and techniques used by different researchers. Previous research does not focus on understanding driver behaviour or the limitations of hand gestures.

An examination of the visual-demand, cognitive human factors and perceptual motivations for the use of hand gestures in automotive environments is also missing from the literature. Recent research has also neglected to examine the role of hand gestures for specific interaction tasks common to most automotive environments such as interior lighting, interior closures, outside vehicle applications, context sensitive applications and many more. Instead, research has most frequently focussed on the variety of hardware solutions available for implementing gesture-based interaction. As a result, the automotive human machine interface design community lacks a framework for hand gesture interaction that could be used to help the identification of appropriate and effective hand gestures and task-based applications.

The literature review and the resulting analysis led to the proposed classification of the research. Figure 1. presents an overview of the categories used to organise and classify previous research. Each of these categories will now be discussed.

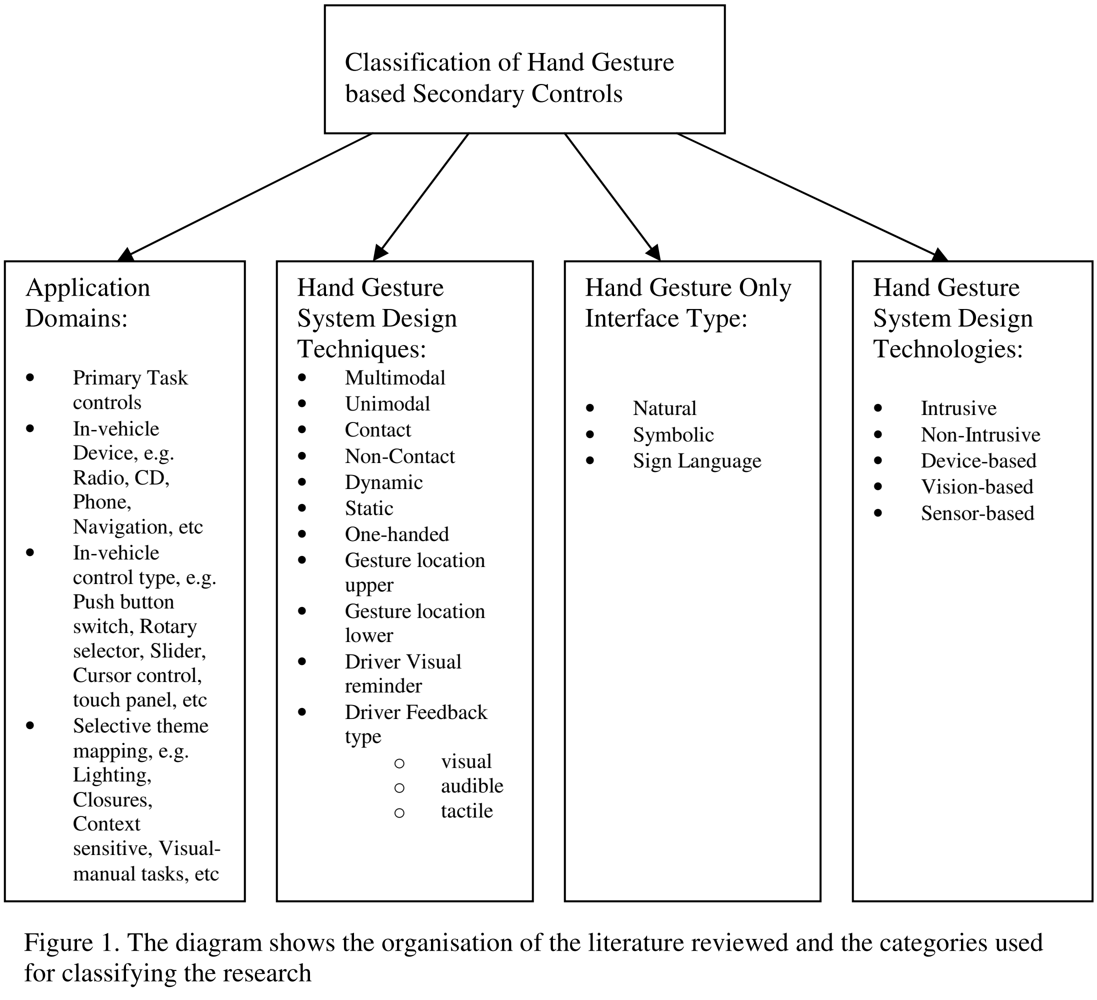

Figure 1. The diagram shows the organisation of the literature reviewed and the categories used for classifying the research

5.1 Hand Gesture Only Interfaces

Gesture interfaces can range from those that recognize a few symbolic gestures to those that implement fully fledged sign language interpretation. Gesture interfaces may also recognise static hand poses, or dynamic hand motion, or a combination of both. In all cases each gesture should have an unambiguous semantic meaning associated with it that can be used in the interface.

However, this Paper will address only one specific use of the term "gesture" – that is, hand gestures that are considered natural or co-occur with spoken language. This narrow focus is because the author fully agrees with the views expressed by Cassel [9], who states that she does not believe that everyday humans have a natural affinity for a learned "gestural language". Natural hand gestures are primarily found in association with spoken language, (90% of gestures are found in the context of speech according to McNeil [24]. Thus, if the goal is to get away from learned, pre-defined interaction techniques and create *natural* and safe interfaces free of visual demand for normal human drivers, then the focus should be on the type of gestures that come naturally to normal humans.

Therefore, this Paper is focussed on discussing the use of natural, dynamic non-contact hand gestures only and, although safety is the primary motivation for this research, other automotive applications will also be mentioned.

5.2 Natural Hand Gesture Interfaces

At the simplest level, gesture interfaces can be developed which respond to natural dynamic hand motion. An early example is the Theremin, an electronic musical instrument from the 1920's. The Theremin responds to hand position using two proximity sensors, one vertical, and one horizontal. Proximity to the vertical sensor controls the music pitch, proximity to the horizontal one controls volume. The Theremin is successful because there is a direct mapping of hand motion to continuous audible feedback, enabling the user to quickly build a mental model of how to use the device.

Myron Krueger's Videoplace [17] is another system that responds to natural user gesture. Developed in the late 1970's and early 80's, Videoplace uses real time image processing of live video of the user. Background subtraction and edge detection are used to create a silhouette of the user and identify relevant features. The feature recognition is sufficiently fine to distinguish between hand and fingers, whether fingers are extended or closed, and even which fingers. With this capability, the system has been programmed to perform a number of interactions, many of which closely echo our use of gesture in the everyday world. The key to its success is the recognition of dynamic natural hand gestures, so users require no training. These types of natural gesture that can be easily remembered, causing minimum cognitive driver workload, make them an attractive proposition for use with in-vehicle secondary controls.

5.3 Symbolic Hand Gesture Interfaces

Unlike Videoplace and the Theremin which both respond to natural free form gestures, interfaces with a wider range of commands may require a symbolic gesture to differentiate between commands. In these cases individual commands are associated with pre-learned gesture shapes. Symbolic gesture interfaces are often used in immersive virtual environments where the user cannot see any traditional input devices in the real world. In this setting there are typically a set of pre learned gestures used for navigation through the virtual environment and interaction with virtual objects.

Within the context of virtual environments that are able to use two-handed hand gestures, there are a number of advantages in using symbolic gestures for interaction, including: (i) Natural symbolic interaction because gestures are a natural form of interaction and easy to use. (ii) Terse and Powerful because a single gesture can be used to specify both a command and its parameters, and (iii) Direct interaction because the hand as an input device eliminates the need for intermediate transducers [4].

However, there are problems with using symbolic gestures for in-vehicle secondary controls. Gesture interfaces are not self-revealing, so the user has to know beforehand the specific set of gestures that the system understands. Naturally, it becomes more difficult to remember the gestural command set as the number of gestures increase. There is also a segmentation problem because tracking systems typically capture all of the user's hand motions, so the start of any gestural command must be segmented from this continuous stream before being recognised. Also, It is estimated that the number of symbolic gestures required for the complete set of secondary controls would range from 300 to 700 so the use of symbolic gesture recognition interface to replace the conventional menu based secondary controls does not appear realistic, however, it is quite possible that a small specific set of natural symbolic hand gestures could be used to supplement existing menu based secondary controls. The scope of this research will only include symbolic hand gestures that are considered natural or occur in human-to-human conversation.

5.4 Sign Language Hand Gesture Interfaces

An obvious application for gesture interfaces is the interpretation of formal sign language. In contrast with other gestures, sign language does not rely on other input modalities for interpretation and can be used to express syntactic and semantic information. Sign language interfaces can be used for low level continuous speech production for example Fels and Hinton [12] produced sign language gesture systems that translate hand gestures into word, vowel, and consonant sounds. Starner and Pentland [34] have also devised a sign language interface that converts sign language to speech, but significant training is needed to learn the gestures required by the system [5]. This is too restrictive for in vehicle controls and is perhaps even more difficult than learning voice commands. Therefore the use of sign language gestures for the controlling in-vehicle secondary controls is rejected and is outside the scope of this research.

There are two other types of hand gesture interfaces, which should be mentioned for theoretical completeness, Speech with Hand Gesture, and Conversational Systems, and although they are outside the scope of this research, they will be briefly mentioned in section 5.5.1.

With the theoretical background of hand gestures discussed and the different types of hand gesture interfaces described, Hand Gesture Recognition Techniques will now be discussed to provide an understanding of the options and limitations facing automotive hand gesture interface designers when considering hand gesture only interfaces.

5.5 Hand Gesture Techniques

Dynamic, non-contact Hand Gestures are used, and are being researched, for a wide range of applications. From a selective literature review the following applications have been found: remote crane control; aircraft traffic control; human computer Interaction; virtual environments; remote robot manipulation; wearable human computer interfaces [23]; home appliance control [44]; TV control [22]; music; room lighting [27]; hearing aids [16]; weather forecasting [20]; presentations [4]; mobile phone [36]; translation [12]; jukebox [13] and 3D Kiosk [15]. The two common factors in all of the above applications are the use of dynamic and non-contact hand gestures.

5.5.1 Multimodal and Unimodal Gesture Interfaces

People communicate with other people and their environment by means of different modalities as appropriate, e.g. speech, gestures, touch and mime. This would suggest that the use of gesture might be most powerful when combined with other input modalities, especially voice. There is very little multimodal automotive research available to validate this suggestion, however, research of multimodal human *computer* interaction is more prevalent, and indeed confirms the above suggestion. Allowing combined voice and gestural input provides much improved ease of expression. Typical computer interaction modalities are characterized by ease versus *expressiveness* trade-off. Ease corresponds to the efficiency with which commands can be remembered, and expressiveness corresponds to the size of the command vocabulary. Common interaction devices range from the mouse that maximizes ease, to the keyboard that maximizes expressiveness. Multimodal input overcomes this trade-off, combined speech and gestural commands are easy to execute whilst retaining a large command vocabulary. Voice and gesture complement each other and when used together, create an interface more powerful than either modality alone [5].

Although it may be true that multimodal speech and gesture may be more powerful than hand gesture only interfaces for human computer interaction and possibly even automotive interfaces, as previously outlined, there is no current framework that guides the selection and development of successful hand gestures for vehicle secondary controls. This may have led to some inappropriate secondary control gesture application developments and some that appear to have been completely overlooked. Therefore, this Paper intends to provide a glimpse into a range of possible automotive gesture applications.

5.5.2 Contact and Non-Contact Hand Gestures

It is recognised that contact-based hand gestures using a touch pad and expansion of existing handwriting recognition techniques is a possible gesture-based interface for in-vehicle secondary controls that is capable of offering safety benefits [18]. The decision to exclude contact based interfaces allows a more in-depth analysis of non-contact gesture recognition technologies and possible automotive applications. Non-contact gesture recognition also appears to offer three unique factors, firstly, no working in-vehicle non-contact dynamic hand gesture based system could be found despite numerous research efforts, secondly, non-contact gestures meant there was no physical interface at all, and thirdly, dynamic non-contact gestures could possibly be used outside the vehicle, although this does not offer any safety benefits, it does offer the opportunity for further experimentation with new ideas and concepts.

5.5.3 Dynamic and Static Hand Gestures

From the outset of this research, it was understood that if static gestures were used to replace existing secondary controls, the driver would have to recall potentially hundreds of individual hand gestures each of which would map to a particular in-vehicle secondary control. Common sense suggests that this would create too many problems because drivers are unlikely to learn all these gestures and even if they did the additional mental workload may offset any safety benefit obtained by reducing drivers eyes-off-road time. Finally, when observing human-to-human communications, the use of dynamic hand gestures appears to be much clearer than static gestures with less ambiguity. For these fairly basic common sense reasons, it was initially decided to concentrate on researching dynamic hand gestures only.

5.5.4 Gesture Driver Interaction

When reviewing previous research it is interesting and instructive to note the differences in approach with regards to driver interaction when using gestures, in particular visual reminders, gesture location and system feedback, these are now briefly described.

5.5.4.1 Visual Reminders

Gestures themselves are not self-revealing, lacking the discoverability afforded by menu and button-based paradigms [4]. For this reason, their use in virtual environments must be prefaced with an explanation of the interaction technique's capabilities. Visual reminders should also be available to provide guidance to the user and enable learning of more complex or less intuitive techniques. Prefacing the use of an in-vehicle control with an explanation of the gestures to be used is obviously not a realistic option and providing visual reminders is also questionable since this would cause the driver to take his eyes off the road and neutralise any safety benefit against a conventional control that required a single glance. This suggests that if visual cues must be used, they should be used for more complex visual manual tasks, which require multiple glances. It also suggests that similar to the way voice is used as a supplementary control for some tasks, gestures should also be used sometimes as a supplementary control.

5.5.4.2 Gesture Location

Although it is possible to perform a hand gesture virtually anywhere within the drivers reach zone, there are effectively three main zones in which dynamic, non-contact hand gestures can be performed for in-vehicle controls. The first is directly in front of the driver in the windscreen area as used by Alpern and Minardo [2], this would allow either hand to be used. The second is in the middle of the car in the central windscreen area, this would only be available for use by one of the hands, and the third zone is in the centre stack area below the height of the windscreen as used by Althoff [1]. If a specific gesture zone is not to be used and gestures are to be used as a supplementary input method, then it could be argued there is a fourth potential location, namely at or adjacent to the relevant tactile control, this may help users with mental modelling of the gesture and aid recall. No research has been identified on the best location of hand gestures for in-vehicle applications that would provide optimum safety, ease of use and user acceptability. This lack of research probably explains why there appears to be no agreed standard location. Based on ease of use and the ability to use either hand the first zone immediately in front of the driver is probably the best, however, this may momentarily compromise forward visibility and attract unwanted attention from other motorists or pedestrians. Both these disadvantages could adversely affect user acceptability, zone 3 may improve user acceptability since the gesture is hidden from view and there is no obstruction of forward visibility, however, the use of one hand only may be restrictive to some users, perhaps reinforcing the need for the gesture to be a supplementary input modality. The optimum zone to carry out hand gestures is clearly an area of further research.

5.5.4.3 System Feedback

In the field of human computer interaction (HCI) and virtual environments there is universal agreement that feedback when using hand gestures is both recommended and beneficial. In HCI Turk [40] states "Do give user feedback. Feedback is essential to let the user know when a gesture has been recognised". Feedback could be inferred from the action taken by the system, when that action is obvious, or by more subtle visual or audible confirmation methods [40]. For virtual environments, Cerney and Vance [10] state "Provide continuous feedback to the user. Continuous feedback reinforces user confidence in the system and assures the user that a command has been recognised. When coupled with proprioceptive stimuli via gesture, feedback may encourage cross-modal transfers and enhance presence [6].

Since providing rapid system response is a well documented design guideline for general automotive HMI design, it is reasonable to accept and apply the above conclusions for automotive hand gesture applications.

5.6 Hand Gesture Technologies

There is a body of research detailing gesture technologies [5,19]. Billinghurst [5] describes an example of an impractical technology for HVI: "Hand Gesture only interfaces with a syntax of many gestures typically require precise hand pose tracking. A common technique is to instrument the hand with a glove which is equipped with a number of sensors which provide information about hand position, orientation, and flex of fingers" such as the Dataglove [45]. Wearing a glove is clearly not a practical proposition for automotive applications and wearable suits as used in virtual environment applications would be impractical also. In HCI, pen or stylus input is commonly used with shortcut gesture strokes, again this is not practical for automotive applications, but a variant of this approach using the finger to draw gestures is a viable contact-based approach. For the above reasons, the range of hand gesture technologies available for automotive hand gesture research is much smaller than the range used in human computer interaction or virtual environments. The main reasons are that the automotive environment is safety critical, spatially limited and has substantially more practical user restrictions. As discussed below automotive hand gesture technologies favour a non-device based approach and a non-wearable or non-intrusive approach. .

5.6.1 Intrusive and Non-intrusive Hand Gesture Technologies

There are many examples of research into hand gestures using intrusive technologies for a range of applications from virtual reality, human computer interaction, wearable computers, home automation, gaming and many more. The "Tinmith-Hand" [29] is a glove based gesture interface system for augmented and virtual reality. Several virtual reality data gloves are evaluated in [7] and criticised for being too expensive and bulky for widespread mobile use. A lightweight input device is described using only one bend sensor on the index finger, an acceleration sensor on the hand and a micro switch for activation. User tests indicate that several test subjects complained about the necessary cables and other physical properties of the input device. Several attempts to reduce the physical restrictions imposed by cables have been made. A wireless finger tracker is presented in [41], an ultrasonic emitter is worn on the index finger and the receiver, capable of tracking the position of the emitter in 3D, is mounted on a head mounted device (HMD). To avoid placing sensors on the hand and fingers the "GestureWrist" uses capacitive sensors on a wristband to determine the configuration of the fingers [30] although this has only been used to differentiate between two gestures (fist and point). Active infrared imaging can be used to simplify the task of separating hands and handheld objects from the background, and is therefore used in several wearable gesture interface systems [37,41]. The "Gesture Pendant" demonstrated in [37] is an active infrared camera in a necklace. It is a gesture interface primarily designed for home automation and as an aid for disabled and elderly people. Gesture recognition in the pendant is performed by Hidden Markov Models (HMM) based on the work done in mobile interpretation of sign language [23].

For in-vehicle use it was very clear that the likelihood of drivers realistically wearing a glove or bodysuit simply to facilitate the operation of in-vehicle secondary controls was highly unrealistic and the comprehensive literature search into automotive hand gesture recognition could not find a single use of intrusive technology. From this, the preferred technology has to be non-intrusive since this is the only one that is likely to gain widespread user acceptance.

5.6.2 Vision-based or sensor-based Technologies

There are two approaches to vision based gesture recognition; model based techniques which try to create a three-dimensional model of the users hand and use this for recognition, and image based techniques which calculate recognition features directly from the hand image. Rehg and Kanade [31] describe a vision based approach that uses a stereo camera to create a cylindrical model of the hand. They use fingertips and joint links as features to align the cylindrical components of the model. Image based methods typically segment flesh tones from the background images to find hands and then try and extract features such as fingertips, hand edges, or gross hand geometry for use in gesture recognition. Using only a coarse description of hand shape and a Hidden Markov Model (HMM), Starner and Pentland [34] are able to recognise 42 American Sign Language gestures with 99% accuracy. In contrast, Martin and Crowley [21] calculate the principle components of gestural images and use these to search the gesture space to match the target gestures. All automotive Static and most Dynamic, non-contact hand gesture research found, uses vision-based technologies, however, it is well documented that some technical challenges remain to be resolved, namely coping with dynamic backgrounds, variable lighting conditions and response times. In the long term, it is expected that the vision based approach to automotive hand gesture recognition will be adopted by many automotive OEMs since it is likely the above mentioned technical difficulties will be overcome. Computer processing power costs are anticipated to continue to reduce, response times will continue to increase and when cameras are used for other automotive interior applications the system costs could be shared.

5.6.3 Sensor-based Technologies

In order to find a solution that can be used today and one that overcomes some of the limitations of vision-based systems, limited research has been carried out using a sensor-based approach. Lasers have been used for gesture musical applications [26], however no automotive use of lasers for hand gesture applications has been found. Capacitive and infra-red techniques have been referred to in some literature [42,32], but no evidence or publications of working hand gesture systems has been identified.

Electric Field Sensing (EFS) was initially pioneered by Massachusetts Institute of Technology (MIT), and can detect the presence of a human hand on or near to a conductive object. EFS is not affected by dynamic backgrounds or variable lighting conditions and has very fast response times. However, the system limitations of EFS for in-vehicle applications have been investigated by this research via experimentation and EFS was found to be sensitive to the user being earthed, thickness of clothing worn, water, contact with other person(s) within the vehicle and there was computational difficulty in locating a hand in 3D. After further research, all the above technical difficulties were eventually resolved and EFS was initially used as the gesture technology for the early stages of this research. As research progressed a range of simpler and less capable sensor-based technologies were also investigated for specific applications.

5.7 Application Domain Secondary Control Tasks

In this section different application domains for mapping automotive hand gestures are discussed. Three main options have been identified: (i) mapping to in-vehicle device, (ii) mapping to in-vehicle control type, and (iii) selective mapping to theme or function.

Mapping to in-vehicle device: A set of gestures could be created and mapped to a complete device such as Radio, CD, Navigation System or mobile phone. Although potentially helpful in terms of providing a consistent interface with a specific device, it is very likely that a complete set of gestures would be in excess of 20 for each device, even with visual reminders this number of gestures would create significant cognitive workload. Many of the gestures would not be natural so some type of mini-device gesture language would also need to be created, it is unlikely therefore that mapping a complete set of gestures to a device will achieve good results in the overall evaluation criteria of visual demand, cognitive workload, ease of use and user acceptability.

Mapping to in-vehicle control type: A set of gestures could be created to mimic each individual in-vehicle control type, these comprise of: (i) momentary push button switch; (ii) latching push button switch; (iii) push and hold push button switch; (iv) momentary rocker switch; (v) latching rocker switch; (vi) rotary position selector switch with end stops; (vii) rotary position selector switch with end stops and pull and double pull action; (viii) rotary switch with continuous rotation; (ix) rotary switch with/without end stops with turn and push for cursor control; (x) slider with end stops; (xi) thumbwheel with end stops; (xii) thumbwheel with continuous rotation; (xiii) thumbwheel with/without end stops with turn and push for cursor control and (xiv) touch panel switch.

With almost 15 different in-vehicle control types, further investigation confirmed that creating natural mimic gestures for each control type had substantial limitations and therefore is not recommended.

Selective Mapping to theme or function: Selective mapping to theme or function reveals a number of interesting possibilities, themes that could be analysed include but are not restricted to the following: (i) interior lighting, switching or adjustment could be controlled by hand gesture; (ii) Interior closures such as glove box, ash tray or windows could all be opened by hand gesture; (iii) exterior closures such as doors, boot, fuel filler cap could be another theme; (iv) external driver identification from outside the vehicle by hand gesture could be used to improve vehicle security; (v) internal driver identification could be used for a personalisation theme; on recognition of a valid driver identification gesture the seat position, steering wheel position, radio, climate, navigation and phone settings could all be pre-configured to suite the individual preferences of that driver; (vi) context sensitive responses could be used to accept/reject incoming phone calls, SMS text messages and emails by using yes/no hand gestures, and several other similar context sensitive applications could also be developed; (vii) gesture could possibly be used selectively for one or more specific control types e.g. on/off, or analogue, or perhaps even cursor control; (viii) visual manual tasks are clearly the most distracting for the driver, therefore selective mapping for a logical group of visual manual tasks such as navigation or phone may offer significant safety benefits.

Because one-handed gestures used in human-human conversation are limited in number, the author does not believe that neither mapping different hand gestures to a complete in-vehicle device such as a radio, nor mimicking each different type of in-vehicle control type is feasible. The use of selective mapping to theme and function appears to offer more realistic practical possibilities and potentially greater user benefits.

From the literature review the key categories of hand gesture classification have now been identified as: Application domain; Gesture Technique; Gesture Technology; Gesture type. Further analysis has identified key factors for each category, which need to be considered when mapping, and evaluating hand gestures to secondary driving controls, the following section summarises previous research in terms of these categories and key factors.

5.8 Summary of Previous Research

The scope of key criteria for evaluating the mapping of hand gestures against secondary controls has been defined by making a number of trade-offs and exclusions. The criteria have been cross-checked with previous research to establish how useful it may have been to previous researchers and this serves to indicate its potential usefulness for future researchers. The key findings from this cross-check exercise are given below. There are a number of common themes that are noticeable from this analysis; Table 1. illustrates these common themes more clearly.

First, all automotive research is based on one-handed gestures using a non-intrusive approach, this is to be expected due to reasons of practicality and convenience as discussed earlier.

Secondly, all but one (13 out of 14) are researching in-vehicle secondary controls, more specifically, infotainment, since operating infotainment controls is believed to be one of the main causes of in-car driver distraction. Gesture recognition is a potential way to make operating these controls easier and safer by improving the task classification and maximising eyes-on-the-road and hands-on-the-wheel times. This research seeks to expand this polarised application area and evaluate hand gestures for interior lighting, interior closures and other selective themes.

Thirdly, and perhaps most surprising is that the majority (11 out of 14) are researching non-contact gesture as opposed to contact. Contact based gestures using touch pads or touch panels are commercially available and the technology is proven, touch pads are in widespread use with laptop computers and therefore user acceptability should be less of an issue. The real power of these touch-based gestures is their ability to quickly enter alphanumeric characters with very high recognition rates [18], for example a postcode such as "CV8 2HU". Due to these significant benefits, it is expected that touch-based gestures will be introduced in the near future and already the after-sales market has seen the introduction of a touch-based gesture Navigation system from Sony [35]. It should be noted that touch-based gestures require a physical user interface and there are issues of interface placement with left and right-handed drivers together with the additional cognitive loading of recalling the appropriate characters. Limited experiments carried out by the author also suggest that touch pads are difficult to use for cursor control in a moving vehicle due to intermittent contact of finger on touch pad.

Classification of Hand Gesture based Secondary Controls	Research Status			Application Domain					System Design Technique											Gesture Type			Gesture Technology				
	Concept	Simulation\Wizard-Of-Oz	Functional Prototype	Primary Task Controls	General Secondary Controls	In-Vehicle Device	Control Type	Selective Theme	Multimodal	Unimodal	Non-Contact	Contact	Dynamic	Static	One-handed	Gesture Location Upper	Gesture Location Lower	Visual Reminder	System Feedback	Natural	Symbolic	Sign Language	Non-Intrusive	Intrusive	Device-based	Vision-based	Sensor-based
Scope of Research Framework	*	*	*		*	*	*	*		*	*		*		*	*	*	*	*	*			*			*	*
General Motors (CMU)		*			*					*	*		*		*		*	*	*		*		*			*	
BMW AG (TUM)		*			*					*	*			*	*		*		*		*		*			*	
BMW Research Group		*			*				*		*		*		*	*				*			*				
Daimler Chrysler (GIT)			*		*					*	*			*	*		*		*		*		*				*
Daimler Chrysler (Fermus)		*			*				*		*		*		*					*			*				
Daewoo Motor Co. (UoD)			*		*					*	*			*	*					*			*			*	
Mitsubishi Corp. (KU)		*			*					*	*		*		*								*			*	
Lexus	*				*					*	*		*		*												
Reanualt (LIMSI)		*			*				*		*		*		*								*				
Toyota	*				*					*	*		*		*	*				*			*				
Nissan			*					*		*	*		*		*					*			*				
UMEA	*							*		*	*		*		*	*					*		*				*
Sony			*					*		*		*	*		*		*			*			*				
ART			*		*				*			*	*		*					*			*				
Alpine Electronics			*		*					*	*			*	*					*			*			*	
Canesta	*				*					*	*			*	*					*			*			*	

Table 1. Summary Analysis of previous automotive research

Apart from the non-intrusive approach for non-contact hand gestures used for in-vehicle secondary controls, there are very few other similarities. There appears to be no consensus on whether static or dynamic hand gestures are most appropriate for automotive use, this is surprising since this choice is a fairly high level decision fundamental to any interface design. Furthermore, there is no common theme on which type of gestures are most appropriate for example, natural or symbolic. No automotive research using sign language could be found. There is also no agreement on whether the vision-based approach or sensor based approach is best, and some automotive manufacturers are involved in developing both types.

A more detailed analysis reveals even more differences in aspects of the hand gesture interface including, the location where the hand gestures should be performed, whether a display is to be used for visual reminders or whether the interface should be completely eyes-free, whether the gestures are to replace or simply supplement existing secondary controls, which secondary controls are applicable for hand gestures, what type of feedback should be used and finally, are the hand gestures using a unimodal or multimodal approach by combing with speech or some other interface technology. There also appears to be conflicting data on user acceptability of hand gestures, this is clearly a critical issue if the potential safety benefits offered by hand gestures are to be realised. This analysis clearly indicates a wide range of different approaches that are taken in the research of automotive hand gesture recognition, there is virtually no design framework or rule-set to be followed and it is hoped that this research will seek to contribute to such a design framework that could be used by future researchers. The research carried out to this point has allowed the main gesture classifications to be identified together with the key design factors within each classification, these will now form the basis for creating and developing a series of prototype hand gesture interfaces and applications.

6 Introduction to Electric Field Sensing

It is possible to use multiple electrodes to create electric fields, and then measure the induced potentials and displacement currents caused by the proximity of a human body or body part. The term Electric Field Sensing (EFS) will be used to refer to a family of non-contact measurements of the human body that may be made with slowly varying electric fields [38]. These measurements can be used to measure the distance of a human hand or other body part from an object; this facilitates a vast range of applications for a wide range of industries.

Figure 2. shows the basic operation of Electric Field Sensing, the top diagram is a model that describes all sensing modes for a single transmit-receive pair with a single target object. [39]. There are 3 modes of Electric Field Sensing, Human Shunt Mode, Transmitter Loading Mode and Human Transmit Mode.

This simple hand sensor consists of two electrodes: a transmitter driven by a low frequency, low voltage signal, and a receiver that detects the transmitted signal through the capacitive paths given in Figure 2. In order to reduce interference from ambient electromagnetic background, the receiver usually has a narrowband response centred at the transmit frequency, generally provided by a synchronous detection scheme [26].

The transmit and receive electrodes can be used in a variety of ways, each of which modifies these capacitances differently. These changing capacitances are seen as a changing current arriving at the receiver.

6.1 Shunt Mode

Before a hand comes into the region between transmitter and receiver, a signal is received through the intrinsic capacitive coupling C_o determined by the electrode size and proximity. When the hand enters, the amount of signal detected at the receiver is altered by the capacitive coupling from transmitter into the hand (C_t), hand into receiver (C_r), and body into ground (C_g). The body is essentially perfectly conductive at these frequencies, especially when compared with the picofarad-level capacitances detailed above. If the body is not extremely close to either electrode, C_g dominates, and the body is effectively a grounded shield (electric field lines from the transmitter couple into the hand and are directed through the body to the room, away from the receiver), thus the received signal decreases as the hand approaches. This is termed 'shunt mode' depicted at bottom right of Figure 2. [39].

6.2 Transmitter Loading Mode

Transmitter loading mode uses a single electrode, in 'loading mode', current is pulled from the transmitter plate into the body via C_g and measured. This is how the classic Theremin and most other embodiments of capacitive sensing work. Transmitter Loading Mode is the only mode that does not have an external receive electrode.

6.3 Transmit Mode

In transmit mode, the transmit electrode is put in contact with the users body, which then becomes the transmitter, either because of direct electrical connection, or capacitive coupling through the clothes, which is shown as path C_t which dominates.

When the hand moves, the spacing to the receiver changes, which changes the value of C_r. When the spacing from the hand to the receiver, r, is large, the received signal is approximately $1/r^2$, because the hand acts like a point object and the field falls off as $1/r^2$. By Gauss's Law, the induced charge on the receiver also goes as $1/r^2$. Since the potentials on the electrodes are defined by the Fish circuit, we know the capacitance to be $C=Q/V$, and the received current $I_R=2\pi CV$. When the hand is very close to the receiver, C_r (typically) has the geometry of a parallel plate capacitor, and the signal goes to $1/r$ [38]. The Transmit mode sensing technique works very well for tracking the motion of a user in contact with a transmitter, as the received signals are only a simple function of the distance between the body and receive electrode, limb position can be easily estimated [26]. The Transmit Mode sensing technique is one that has been overlooked until recently.

6.4 System Hardware

The capacitance and displacement currents for electric field sensing are of the order of Pico farads (10^{-12} Farads) and nanoamps (10^{-9} Amps), requiring more sophisticated detection strategies [46]. A synchronous detection circuit is used to detect the transmitted frequency and reject all others, acting as a very narrow band-pass filter. The displacement current can be measured with approximately 10 or 12-bit accuracy. Small displacement currents require good shielding, however the capacitance of shielded coaxial cable is orders of magnitude greater than the capacitance between the electrodes. Cable capacitance low-pass filters the received signal, typically limiting the operating frequency and introducing a phase shift that is compensated for in the synchronous detector. Placing a current amplifier at the

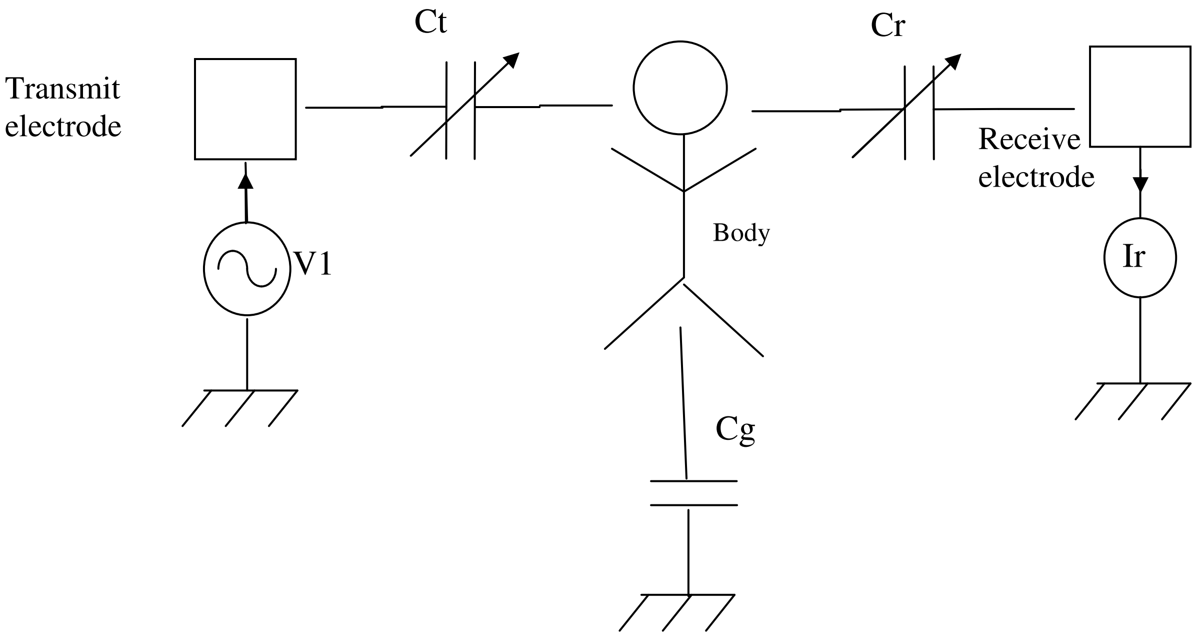

Figure 2. Equivalent Circuit for all modes of EFS [39]

receive electrode allows higher frequencies to be used. The typical frequency range for electric field sensing human computer interface applications is 50KHz to 150KHz.

The only power consumed by the transmitter is the energy required to charge the capacitance of the transmitter electrode to the oscillating voltage. In practice the transmitter power is less than a milliwatt. This allows the design of very low power systems with no radio interference.

7 Applications of Hand Gesture Recognition

The primary goal of the author's research into hand gesture recognition for automotive human vehicle interaction is to identify and evaluate possible applications and driver safety benefits. Most research is focusing on developing gesture interfaces for menu based secondary control systems since these potentially offer the most safety benefits. It is likely that these menu based gesture recognition systems will be used as a supplementary method of user control for the driver, just as voice and steering wheel controls have been developed. Research by the author has identified that the approach to map hand gestures to a selective theme or function appears to offer the best way forward since mapping to a device or mimicking each individual control type has serious limitations.

Selective mapping to theme or function reveals a number of interesting possibilities as described in 5.7.

Because one-handed gestures used in human-human conversation are limited in number, the author does not believe that either mapping different hand gestures to a complete in-vehicle device such as a radio, or mapping each different type of in-vehicle control type is feasible. The use of selective mapping to theme and function appears to offer more realistic practical possibilities and potentially greater safety benefits.

After considerable analysis of all the possible selective themes and functions, it was found that each set of gestures could fit into the following application domain classifications:-

- Pre-emptive Gestures
- Function Associated Gestures
- Context Sensitive Gestures
- Global Shortcut Gestures
- Natural Dialogue Gestures

Each classification is now discussed and a number of examples of each classification are given.

7.1 Pre-emptive Gestures

A pre-emptive natural hand gesture occurs when the hand is moving towards a specific control type or device and the detection of the hand approaching is used to pre-empt the drivers intent to operate a particular control. Examples of such functions could include operation of the interior courtesy light, as the hand is detected approaching the light in the roof console the light could switch on. If the hand is detected approaching the light again it would switch off, thus the hand movement to and from the device being controlled could be used as a pre-emptive gesture.

If such a basic technique of simply detecting hand proximity is used then clearly there are few potential applications because many controls are located together to provide logical grouping for the driver, to differentiate which control the driver requires even at a distance of several centimetres will be very prone to error. Therefore, the target applications are those devices and controls that are well separated from other controls. In addition to the interior light, other possible examples might include lighting the door pocket when a hand approaches to help the driver find the object he/she is looking for, operation of motorised sun visors to automatically fold down or away when a hand approaching is detected, increasing the brightness of switch graphic illumination at night when a hand approaching is detected.

7.2 Function Associated Gestures

Function Associated gestures are those gestures that use the natural action of the arm/hand to associate or provide a cognitive link to the function being controlled. For example, moving the arm in an angular sweep pivoted about the elbow in front of the windscreen could be used to signify that the driver wishes to switch on the windscreen wipers. Similarly, moving the driver's hand/arm downwards along the side of the door window pillar is associated with opening the door window. These gestures have an action that can be associated with a particular function.

7.3 Context Sensitive Gestures

Context Sensitive gestures are natural hand gestures that are used to respond to driver prompts or automatic events. Possible context sensitive gestures to indicate yes/no or accept/reject could be a thumbs-up and a thumbs-down. These could be used to answer or reject an incoming phone call, an incoming voice message or an incoming SMS text message. The same yes/no gestures could also be used to accept or reject prompts for automatic navigation re-routing, for example, if the advanced navigation system has been informed of an accident ahead it could ask the driver if he/she wishes to be automatically re-routed to avoid possible delays, similarly, if low fuel is detected, the system could ask the driver if he/she would like to be automatically routed to the nearest fuel station. It may also be possible to simply use one of the yes/no gestures for other functions, for example, if the Traffic Announcements (TA) come on as you are listening to a music CD and you have just heard a TA a few minutes previous, you could use the same No gesture to stop the TA and revert back to the music CD.

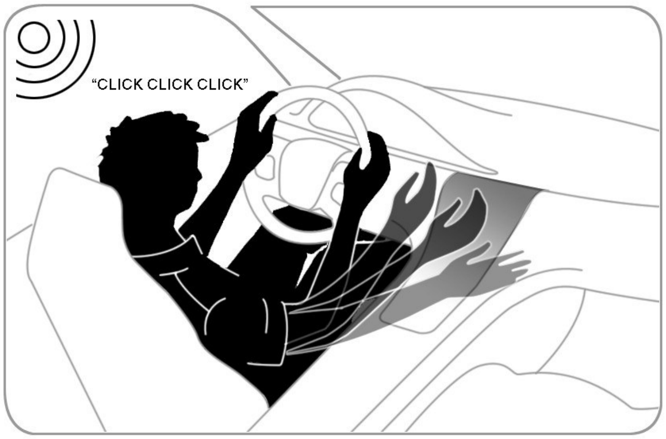

Figure 3. Context Sensitive Accept gesture in response to incoming phone call

7.4 Global Shortcut Gestures

Global shortcut gestures are in fact natural symbolic gestures that can be used at any time, the term natural refers to the use of natural hand gestures that are typically used in human to human communications. It is expected that hand gestures will be selected whereby the user can easily link the gesture to the function being controlled. Possible applications could include fairly frequently used controls that present unwanted high visual workload, such as phone dial home, phone dial work or set navigation destination data entry to home.

7.5 Natural Dialogue Gestures

Natural dialogue hand gestures utilise natural gestures as used in human to human communication to initiate a gesture dialogue with the vehicle, typically this would involve two gestures being used although only one gesture at any given time. For example if the driver fanned his hand in front of his face, the gesture system could detect this and interpret that the driver is too hot and would like to cool down. An audible and/or visual prompt could be offered to the driver to ask if he/she would like all climate controls to maximum cold. If the driver then uses one of the context sensitive yes gestures such as thumbs-up, this could cause all the climate controls to be automatically set to low, including; switching on the air conditioning, setting the temperature to lowest setting, directing air vents at the drivers face and switching the heated/cooled seat to lowest temperature. Other dialogues could be initiated in a similar manner by using appropriate gestures. Other examples include using a natural gesture for I'm cold to initiate a dialogue of "do you want hottest settings?", or a natural gesture for I'm hungry or thirsty could be used to initiate a dialogue of "do you want to be directed to the nearest services or restaurant?". The applications are only limited by our ability to find a natural gesture to initiate the required meaningful dialogue.

7.6 Application Domain Summary

Analysing previous research confirms that no attempts have been made to suggest that hand gestures are appropriate for primary driving task applications such as vehicle lateral or longitudinal control to replace steering wheel or foot pedals respectively. This is fully understandable due to the fact that physical tactile feedback is an essential user expectation and a requirement for such safety related activities, also, physical interfaces such as the steering wheel give much more accurate manual dextrous control which is not possible with hand gestures in free space.

In fact there are a range of other primary driving task related controls that are not appropriate for hand gestures because they are safety critical and have very strong stereotype physical driver controls associated with them, they include exterior lights, automatic transmission gear selection, direction signal indicators, and horn.

Other tasks that are not appropriate for this research are those that are operated from outside the vehicle when the vehicle is stationary, for example opening the doors, boot or fuel filler cap, because they offer no safety benefits. These external controls may offer other benefits such as increased ease of use, convenience or emotional appeal, but this research is only concerned with hand gesture applications that offer potential safety benefits so the application domain of interest is limited to in-vehicle secondary controls that are carried out when the vehicle is moving.

8 User Acceptability

The rate of introduction of any automotive gesture recognition system is more likely to be dictated by the rate of user acceptability and not the timing of technical issue resolution. The rate of user acceptability will be driven by how fast and widespread gesture recognition becomes established and accepted in our everyday lives including other environments in which human interaction with machines takes place. These include interactions in the office, home, banking, gaming and other leisure activities.

Within the automotive environment there are two parallel paths likely to be implemented within the next 5 years that will introduce the public to automotive gesture applications. The first is as mentioned above, switching by hand proximity for interior lighting applications, the second method is likely to involve the introduction of touch based gestures using a touch pad or a touch screen. Touch pad or touch screen based gesture recognition is achieved by using a number of shortcut keystrokes on a conventional touch pad or touch screen. Touch pads are typically used for cursor control on laptop computers or for alphanumeric character data entry and will probably lead the way in gaining user acceptability with computers, industrial control panels and of course automotive applications. Touch screens are already being used for automotive applications, point of sale terminals and PDAs. The introduction of touch-based gestures to touch screens will further increase ease of use and for this reason it is likely that new devices such as mobile phones and MP3 players will be seen using touch screen based gestures. User acceptance of touch-based gesture automotive systems technologies will be an easier first step for the public to accept because they retain a physical user interface.

The transition from touch based gesture systems to non-contact hand gesture systems for automotive menu based secondary controls is difficult to predict, however, it is probable that these systems will be offered as a supplementary method of user control within a 10 year time frame. Standalone applications such as interior lighting are likely to be introduced much earlier. The detailed implementation of dynamic non-contact hand gestures is critical to the success of the deployment of this method of control, in particular, to ensure there are no unwanted false triggers by inadvertent operation. Non-contact hand gestures provide no tactile feedback and this issue requires further investigation to establish whether other forms of visual or audible feedback are required for user acceptability. Another human factors issue to be considered when developing non-contact gesture applications is the implications for user acceptability of contravening widely established and accepted stereotypes for operating specific controls.

9 Further Research

Further detailed research is now focussed on investigating those applications where safety has been identified as the primary potential benefit, more specifically, a comparison of using hand gestures versus conventional user controls will be carried out for this small number of specific applications to establish if improvements in task classification, eyes-off-the-road times and overall task times can be achieved. This research will be the subject of future Papers.

10 Conclusion

Most research into automotive non-contact hand gesture recognition has been focused on secondary controls, in particular, infotainment, since operating infotainment controls is believed to be one of the main causes of in-car driver distraction. Gesture recognition is a potential way to make operating these controls easier and safer by improving the task classification and maximising eyes-on-the-road and hands-on-the-wheel times. Safety is expected to remain the main governmental and business driver to encourage further research by automotive OEMs, Universities and Suppliers into the use of hand gesture recognition for automotive HMI applications. However, the author believes that the concept of selective themes of pre-emptive gestures, function associated gestures, context sensitive gestures, global shortcut gestures and natural dialogue gestures may offer the best route forward and this concept is being further developed.

The author is also actively engaged in developing a distinctive gesture based HVI for other categories of gesture recognition as described earlier. This research includes activation of interior lighting by hand proximity, interior closures such as window control, exterior closures such as boot opening and driver identification by gesture for security and convenience features.

Numerous techniques for non-contact hand gesture recognition are being developed and although most have technical issues, it is expected these challenges will be overcome within the next decade.

The rate of introduction of any automotive gesture recognition system is more likely to be dictated by the rate of user acceptability and not the timing of technical issue resolution. Touch based gesture recognition will probably lead the way in gaining user acceptability with PC computer tablets, PDAs and point of sale terminals.

This paper confirms that there are a wide number of possible applications and potential benefits for non-contact hand gesture based HVI. Gesture recognition will not be appropriate for all secondary controls, the challenge is to identify those controls which offer the most safety benefits by improving task classification from visual-manual to primarily manual, this will increase eyes-on-the-road and hands-on-the-wheel times and is likely to involve specific infotainment and climate control functionality. For some applications hand gesture recognition offers the possibility of substantial safety benefits, for other applications gesture recognition potentially offers increased ease of use, and perhaps even increased emotional pleasure when carrying out certain tasks such as opening or closing the drivers window. However, conflicting data on user acceptability for using hand gestures remains a challenge. Future research by the author will involve detailed studies to investigate potential increased safety and ease of use benefits together with user acceptability for a wide range of non-contact hand gesture human vehicle interaction applications.

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