VIRTUAL ROAD SIGNS

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ABSTRACT

Conventional road signs are subject to a number of problems and limitations. They are unable to disseminate dynamic information to road users, their visibility is heavily dependent on environmental conditions, they are expensive to maintain and frequently the target of vandals and thieves. Virtual road signs (VRS) differ from conventional signs in that they exist only in an information database – no physical signs exist on the roadside. By projecting virtual signs into a driver's field of view at the correct time, virtual road signs attempt to mimic conventional road signs. In addition, their visibility is independent of weather and traffic conditions, they can be tailored to specific driver and vehicle needs (such as truck drivers), and they cannot be vandalised like physical signs.

This thesis examines many of the major technical design decisions that must be made in implementing a virtual road sign system. A software prototype was designed and written to implement an experimental VRS system. The prototype served as a testbed to assess the technical feasibility of a VRS system and investigate alternative VRS designs. One limitation of the project was the lack of suitable display device that could display virtual signs inside a vehicle in real-time. Therefore, this project examined only the proof-of-concept. A test world was created around a university campus in which virtual signs were 'erected' to target a visitor to the campus. The prototype used a handheld GPS receiver to track a vehicle as it was driven around the campus. A Kalman filter was implemented to filter the GPS data and predict the motion of the vehicle when GPS data was unavailable. A laptop PC provided onboard processing capability inside the test vehicle. The prototype shows that technical implementation of virtual road signs is potentially feasible, subject to limitations in current display devices such as heads-up displays. Potential applications include signs custom-designed for tourists to indicate places of interest, bilingual signage, and aiding co-drivers in rally car driving. Before large-scale implementation can be considered, however, much research is needed, particularly with respect to systems acceptability to the public and road authorities.

This thesis is dedicated to my family,
who offered support, inspiration and
assistance as it progressed.

DECLARATION

I declare that this is my own, unaided work. It is being submitted for the degree of Masterate of Technology at Massey University. It has not been submitted before for any degree or examination in any other University.

Rhys Nicholls
28th day of February, 2001

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PREFACE

I first thought of the idea of virtual road signs while reading a newspaper some time ago. A current topic in the news at that time was the proposition of adding the Maori translation of road sign messages and placenames to the existing sign infrastructure. Advocates claimed that it is a Maori right to have bilingual signs, and that current signs are discriminatory. While bilingual signage seemed like a good idea to many, critics claimed that the sheer size of the task would make it prohibitively expensive and impractical. Only 15% of the population of New Zealand are of Maori ethnicity, and it is likely that a similar percentage can read the Maori language. Therefore, any campaign to duplicate sign messages would arguably apply to a small proportion of the total population.

Indeed, many countries in the world speak more than one major language, and it is desirable to display road signs in all of these languages. The use of internationally standard symbols overcomes the language barrier to some extent, but there are inevitably many signs that still use text to convey their message. Even if it is practical from a physical and economic point of view to express a sign's message in multiple languages, there will always be tourists who cannot read road signs adequately. A better solution is to somehow display a sign's message to suit the needs of individual drivers and their vehicles.

While reading the newspaper, I happened to think back to an overseas holiday to England with my family in 1993. One of the things that struck us about travelling on the roads in England, apart from the congestion, was the brilliant road sign infrastructure. Being unfamiliar with the road network, we were continually reliant on road signs for navigation. The signage was impeccable, with the layout of every major intersection displayed on huge signs well before the intersection was reached. The fact that I can only remember getting lost once is testimony to the excellent signage. I then thought of the situation in New Zealand, where there is only one major state highway, and signs are relatively sparse in comparison. The situation is gradually improving, but many will argue that there simply isn't the money nor the traffic volume in many areas of the country to justify the sign density seen in England. How can technology be applied to suit individual drivers in specific conditions, as well as create new signs at a practical cost? In the future, virtual road signs might just be one solution.

The motivation for this thesis is a vision in which virtual road signs are reality, a vision where virtual road signs contribute to improved road safety. Certainly, the idea of virtual road signs is not currently practical, even on a small scale. But one day, the required technology may develop to an extent that makes virtual road signs a feasible idea, rather than a figment of one's imagination. As we worked on the project described in this thesis, the comments we received from people who inquired about the project were very encouraging. At first, it was expected that people would find the virtual road sign idea too futuristic and approach the idea with some scepticism. But for most people, this was not the response received at all. They could actually see benefits of virtual signs, and wanted to know more about how they might work. A truck driver pointed out how roadworks signage often does not give the drivers of heavy vehicles enough time to slow down safely. He could see how virtual signs could help him. Other people were simply glad to hear of the prospect of extra signage.

In New Zealand, the penetration of automotive navigation systems is very low in private cars. In many overseas countries such as Japan, the United Sates, and many European countries, navigation systems are commonplace. New systems are being continually developed and released to cater for every information need of drivers, not just their need for navigation aids. Latest systems allow passengers to check their email, review the latest stock prices and surf the Internet. It seems only a matter of time before vehicles will be able to walk the dog and do the banking. It seems ridiculous to think that the vehicle manufacturers haven't already considered the idea of virtual road signs. Perhaps they have, and there are real reasons why they may not be practical. Or, perhaps they are simply waiting for the right technology. Perhaps drivers are not ready for the idea of virtual road signs yet. Time will tell.

The structure of this thesis is described as follows. Chapter 1 sets the scene by describing some of the problems and limitations of conventional road signs. The idea of virtual road signs (VRS) is introduced as one possible way of overcoming many of the problems associated with conventional road signs. The broad topic of augmented reality is introduced, which describes the way in which virtual signs are presented to drivers. The types of display commonly used for augmented reality are described, with particular reference to *heads-up displays*. A heads-up display is considered to be the most suitable device currently available for the display of virtual signs. As such, it is referred to frequently throughout this thesis. Some pros and cons expected of virtual road signs are listed, and the prototype software developed for this project is then introduced. Current traveller information systems are reviewed, followed by a review of some popular visual displays used by current systems to provide drivers with navigation and en-route trip information. The chapter concludes with a closer examination of some of the factors affecting perception of heads-up displays, in order to assess the suitability of such a display for virtual signs. Chapter 2 begins with an overview of the three functional components of a general VRS system. It then summarises the design and operation of the VRS prototype developed for this project. The coordinate systems of the prototype are briefly described, followed by a brief discussion of how these coordinate systems may be adapted for general VRS systems that cover a very large area.

Chapters 3-6 describe the three main subsystems of a general VRS system. With the exception of Chapter 6, each chapter begins by outlining some of the design issues that must be investigated when designing a general VRS system. The second part of each chapter is devoted to a discussion of the specific design decisions that were made for the VRS prototype. Chapter 3 addresses the positioning and tracking subsystem, which is responsible for measuring the location of a vehicle in the real world. It begins by examining some of the properties of positioning systems likely to be needed by a VRS system. Two different positioning techniques are presented. An experiment is conducted to verify the real-world accuracy of one satellite-based positioning technique. The remainder of Chapter 3 describes issues of positioning and tracking for the VRS prototype.

Chapters 4-5 address the second major VRS subsystem, the data subsystem. Chapter 4 investigates issues relating to the design of virtual worlds in which virtual road signs are contained. It begins by describing the role and design of sign regions, which are areas in the world where virtual signs shall be displayed. A discussion of various methods of representation of a virtual world is then presented. The important task of determining which sign regions are currently associated with a vehicle's position is described. This includes a discussion of one possible memory caching strategy, which improves the real-time performance of a VRS system. The remainder of the chapter is concerned with the specific design decisions made for the VRS prototype. The first part of Chapter 5 investigates issues relating to the design and processing of the most important objects in a VRS system, virtual signs. The chapter begins by discussing some important design aspects of virtual signs, such as their presentation style and the design of the sign face. Next, a description of how virtual signs may be processed in software is given. Like the virtual world in Chapter 4, one possible memory caching strategy is described to improve performance. The specific design decisions for virtual signs are described for the VRS prototype. The chapter concludes by presenting the database structure of the prototype, which encompasses the material in both Chapters 4 and 5.

Chapter 6 addresses the third and final major VRS subsystem, the display subsystem. This is primarily concerned with the display of virtual road signs. The chapter launches straight into the specific implementation of the VRS prototype. The user interface of the prototype is described, followed by an explanation of how the display subsystem is initialised and how the rendering of signs is optimised to best accommodate the limited screen space. The algorithms responsible for allocating signs to screen locations are then described, with examples.

Chapter 7 explains how the VRS prototype was tested using real-world data. A test world was constructed and a target user selected for the purpose of testing. A set of features were identified that may be of potential interest to the target user, and the coordinates of each feature were measured. A set of virtual signs was then designed to indicate the presence of the chosen features as the target user drove around the test world. The chapter goes on to explain how a set of sign regions were computer-generated in order to avoid the tedium of manual calculation. The testing methodology is described, followed by presentation of major prototype results. The results are primarily concerned with the performance and accuracy of the positioning and tracking subsystem. The chapter concludes with a thorough discussion of the results of prototype testing.

Chapter 8 appraises all major design decisions of the VRS prototype. It begins with an assessment of the positioning and tracking subsystem. Issues of accuracy are highlighted, and an improved subsystem is recommended for a real VRS system, based on the prototype. A discussion of the data subsystem and display subsystem follows. One of the key issues discussed in this section is the excellent scalability of the prototype – that is, it is noted that the prototype can be extended to handle very large virtual worlds with minimal degradation of performance. The storage requirements of virtual sign data are estimated for much larger worlds than the world tested in Chapter 7. Several other high-level data management issues are considered, such as how virtual sign information may be kept up-to-date. The hardware costs of the prototype are estimated, and these are compared with the estimated costs of a real VRS system using current technology, and the estimated costs that consumers might be willing to pay for a VRS system. Several potential applications of virtual road signs are proposed, and several issues of systems acceptability of a VRS system to the public and authorities are highlighted. The chapter finishes with a brief description of opportunities for future research. Chapter 9 presents the major conclusions of this project and concludes the body of the report.

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CHAPTER 1
Introduction

Imagine for a moment the following scenario. It is 5:30pm at the end of a busy weekday and the city traffic is heavy. The sky is darkening as night descends. Outside, torrential rain is falling and the wind batters your vehicle as you hurtle down the highway. A short time later, you round a bend and see that two vehicles have collided at an on-ramp. Normally, you would brake hard and struggle to control the vehicle in such conditions. But this time your mind is at ease. You have already slowed to a safe crawl and moved into another lane opened just minutes ago to divert traffic. As you pass the crash scene, you adjust your speed to the slippery conditions, as do surrounding vehicles. You have never travelled this route before, yet you know exactly where you are, and before long you are back on the beaten track. Then a sign emerges out of the gloom, and you cannot help but smile: dinner will be served in ten minutes, just in time for your arrival home.

How plausible is this scenario? In the year 2001, the opening scene will be familiar to all seasoned road users. Of these, a fair proportion of drivers in Europe, America and Japan will be accustomed to navigating their vehicle with the help of some automated navigation system. But the driver in this scenario was not focussing their attention on a conventional display panel inside their vehicle. As they drove along the highway, they were seeing computer-generated signs in their field of view that did not actually exist on the roadside. This is the idea of virtual road signs (VRS).

1.1) Conventional Road Signs

Road signs are a major source of short-term road and traffic information to road users. The variety of signs is enormous: some signs are permanent, such as state highway signs that give directions and distance to settlements; others are temporary, such as roadworks and accident signs. Traffic signs control the flow of traffic; automatic signs can switch on to warn road users of icy conditions; and illuminated variable signs can adapt to variable traffic conditions. Whether a sign is intended to alert the road user to convenience, danger, or the law, its purpose is the same: to provide road users with useful information to improve the safety and enjoyment of their journey.

Let us define a conventional road sign as one which is not automated in any way, such as a wooden or metal sign on the side of a road. Conventional road signs are subject to a number of problems and limitations:

1) Signs are capable of providing static, unchanging information only.

Permanent sign data must be approximated to cater for all categories of road user. For example, speed signs erected at the beginning of curved roads suggest the recommended speed at which to traverse the curve. Often this speed is calculated to account for the worst road conditions that can reasonably be expected on a regular basis; for example, driving at night in a light vehicle such as a family sedan, in wet weather. In dry conditions, it may be safe to navigate the curve at a speed 15 kilometres per hour faster; in a heavy vehicle such as a truck, a speed 20 kilometres per hour slower might be the maximum safe speed. To an overseas tourist or a learner driver, it may be unclear which category of road user these signs target. Recently, the idea of variable speed limits on highways in New Zealand has been proposed (NZPA, 2000 [a-b]). Some people argue that using static signs to enforce variable speed limits would confuse drivers more than they are worth.

2) Dynamic information cannot easily be disseminated.

The minimum age of messages conveyed by conventional signs is typically in the order of hours. For information that needs to be conveyed more urgently, conventional signs are not a practical option. Even if they could be erected in time, the problem of selecting a standard sign still exists, as construction of a custom sign would take far too long. Temporary signs are difficult and cumbersome to continually update.

3) The environment has a significant influence on sign visibility.

Bad weather can have a detrimental effect on the ability of a driver to observe road signs. Large vehicles can conceal a sign completely. This is a common problem with road markings at major urban intersections. For example, in queued traffic, a driver unfamiliar with the lane configuration of an intersection fails to see the road-painted lane arrows and is forced to assume the most likely configuration. Unfortunately, lane configurations are often inconsistent between intersections, as urban drivers will attest.

4) Signs are expensive, intrusive and bulky.

The construction costs of signs are high and increasing. Permanent road signs clutter the landscape. Temporary road signs are bulky and hazardous to carry, and their placement on the road is potentially hazardous to road users.

5) Sign maintenance is an ongoing problem.

Road signs are often the target of graffiti and theft, endangering road users and incurring an even higher cost. Recently, this point has been highlighted by a number of newspaper articles. In one instance, thieves removed protective barriers warning road users of a large hole in the road (Nash, 2000). Only the quick action of a passing police patrol avoided the occurrence of a serious accident. In another instance, the occupants of a vehicle were killed when they failed to stop at an intersection because the Stop sign had been stolen. The labour cost of repairing damaged and vandalised signs is a significant proportion of total sign cost.

1.2) What are Virtual Road Signs?

In the last decade, an explosion in the telecommunications industry and the continuing convergence of telecommunications, computers and consumer electronics has been the driving force behind society's thirst for up-to-the-minute information. *In-vehicle navigation systems* have evolved to help fill the niche of dynamic information dissemination to road users that is beyond the domain of conventional signs. In-vehicle systems retrieve information about the current traffic and road situation and present it to drivers on a small display device inside their vehicles. This device is one component of the *human-machine interface (HMI)*. Research shows that current HMIs are far from perfect from a safe driving point-of-view, and a number of improvements can yet be made. This report describes a project that investigates one such improvement: to implement a HMI that realistically renders computer-generated road signs directly into a driver's field of view. The signs mimic real road signs in their appearance, but because the signs do not actually exist on the roadside, the signs are described as virtual. A driver views their surrounding environment as per usual, with signs superimposed onto the image they perceive. This technique is one example of *augmented reality*.

By their nature, virtual road signs convey visual information to a driver. Drivers can usually obtain more than 90% of the information needed for the driving task through the faculty of vision (Kuroki and Asou, cited by Okabayashi and Sakata, 1991). The advantage of visual information over auditory information is that it can be 'self-paced'; that is, the driver can glean the information when the traffic situation allows. In this thesis, the proposed purpose of virtual road signs is to disseminate two specific categories of information to drivers:

1) Navigation information, which instructs a driver how to navigate their vehicle for the purpose of route guidance. This may be static (historic) or dynamic (for example, responsive to other traffic to avoid congested areas).

2) En-route trip information that may be of interest to a driver. This second category consolidates a very wide range of information, some of which is currently disseminated to road users by conventional signs, some by other means (for example, traditional dashboard indicators such as excessive speed, seat belt reminder, low fuel) and some which is not conveyed at all. There are two main information types:

a) Notification of service facilities, such as nearby hotels, restaurants, workshops or parking spaces (OECD Scientific Experts Group, 1988).

b) Hazard warnings, which concern transient problems or specific topics relating to road conditions, the current traffic situation, rule compliance or vehicle manoeuvres (OECD Scientific Experts Group, 1988). Examples are roadworks, accidents, ice.

1.3) Augmented Reality: The Next HMI Frontier

1.3.1) Overview

Section (1.7) reviews the presentation styles of current in-vehicle HMIs that provide navigation and en-route trip information to drivers. Most current in-vehicle HMIs use colour displays mounted on or near the dashboard, known as instrument-panel (IP) displays. Regardless of the actual display type utilised, two key issues of in-vehicle IP displays affect the safety of drivers and their vehicles:

1) Distraction. The presence of an animated display close to the driver often attracts the attention of the driver even when he/she has no intention of interpreting the display.

2) The continual need to divert attention back and forth between the in-vehicle IP and outside world. Systems that require long glance durations to assimilate the desired information from a display are dangerous. Treat *et al.* (cited by Ashby and Parkes, 1993) highlight improper lookout, excessive speed and inattention as the leading causes of accidents. Smiley and Brookhuis (cited by Ashby and Parkes, 1993) argue that attention and perception errors predominate over simple response errors in accident causation. For all the benefits that they bring, current in-vehicle instrument panel HMIs inevitably aggravate this problem.

The challenge is thus to investigate how navigation and en-route information can be presented in a more seamless manner that makes the combined tasks of driving and assimilating information safer. The primary objective of virtual road signs is to address this challenge.

Augmented reality (AR) is one research topic that is proposed as an ideal medium to realise virtual road signs in practice. AR is described by Groves (1999) as "virtual reality overlayed on reality: a system allowing you to see virtual world objects overlayed on your physical surroundings." It overlays a computer-generated image onto the real-world scene observed by the user to assist the user in their environment (see Figure 1.1). In short, AR is what makes virtual road signs 'virtual'. In this context, the driver is already scanning their environment through the vehicle windscreen, a natural driving activity. AR would superimpose virtual road signs into the driver's field of view. Careful sign design and positioning would ensure that the driver's view of the forward road scene was not impaired for the purpose of safe driving (see Figure 1.2 for an example).

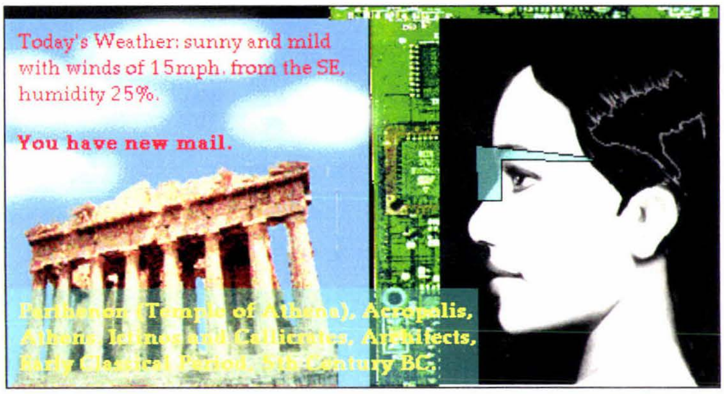

Figure 1.1: Example of augmented reality: text is overlayed on a real world scene, as observed by a viewer (DeVaul, Rhodes and Schwartz, 2001)

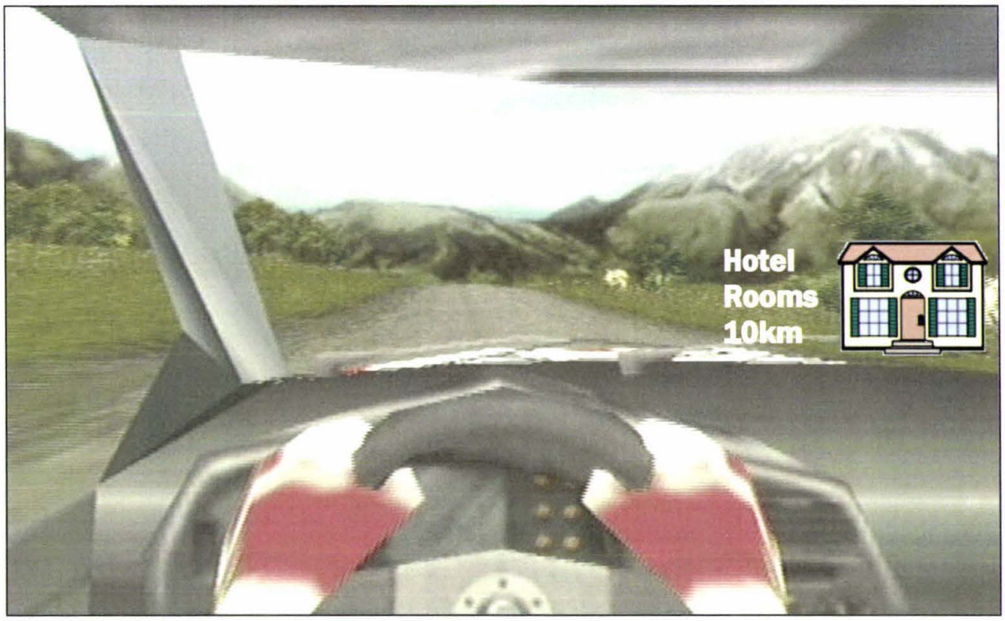

Figure 1.2: Example of how a virtual road sign might appear to a driver

By seamlessly augmenting a driver's forward view with computer-generated images, a driver no longer needs to divert their attention to a separate display of an instrument panel HMI. This reduced demand on the driver's focussed attention should translate into more time available for the driving task. The driver simply focuses on the task of scanning their outside environment as usual, periodically looking at the virtual road signs as they appear.

AR is perhaps the only way of implementing virtual road signs with sufficient realism. In theory, signs can be made virtually undiscernible from reality; that is, conventional road signs. If implemented correctly, virtual signs should present no more of a distraction to a driver than conventional signs. Another advantage is that, unlike current instrument panel HMIs, AR is semi-immersive: it does not completely surround the driver in an artificial world, yet it gives the impression that artificial images fit into the real world. AR can superimpose signs into the driver's field of view with an effective focal length of five metres or more, generating an illusion that the signs really do exist at some distance in front of the vehicle.

1.3.2) AR Display Devices

Current AR efforts use three categories of display device:

1) Video screens, in which live video input of a real scene is merged with live computer-generated imagery and the augmented result is viewed by the user on a computer monitor (Groves, 1999).
2) *Head-mounted displays* (HMDs), based on LCD, CRT or fibre optic technology (Pimentel and Teixeira, 1995). AR researchers have been working with two types of HMD: (a) *video see-through*, and (b) *optical see-through* (Vallino, 2000). The 'see-through' designation arises from the need for the user to be able to see the real world view that is immediately in front of them when wearing the HMD. A video see-through HMD uses video cameras that are aligned with the display to obtain the view of the real world. In this sense, a video see-through HMD is very similar to video screens described in (1), except that the user has a heightened sense of immersion. The optical see-through HMD eliminates the video channel that is looking at the real scene (Manhart, Malcolm *et al.*, cited by Vallino, 2000). Instead, the merging of real world and superimposed images is done by optics located in front of the user's eyes.
3) *Head-up displays* (HUDs). Automotive HUDs reflect a projected image off the inside windscreen surface of a vehicle into a driver's field of view.

Clearly, video screens described in (1) are much too bulky to display virtual signs inside a vehicle. The use of video see-through HMDs in vehicles is not practical because drivers want to see the real-world view with their own eyes. A HUD is considered a more practical option for displaying virtual signs because it does not require drivers to wear any headgear.

1.3.3) The Use of HUDs for Augmented Reality

HUDs were considered for widespread automotive use as early as 1985 (Enderby and Wood, 1992). HUDs have been used successfully in military jet fighters for many years to reduce the need of pilots to take their eyes off the airspace ahead; for example, during high-speed manoeuvring when timing is critical. Some advantages of automotive HUDs as a method of communicating information, such as that traditionally handled by the dashboard of a vehicle or navigation directions, are:

1) Reduced time to recognise the information content, compared to *heads-down displays* (HDDs) such as in-vehicle instrument panels. In one simulated experiment involving twelve drivers, the average response time to navigation information presented on a full-windshield HUD was 341 milliseconds faster than for an in-vehicle instrument panel (a 23% difference) (Steinfeld and Green, 1998).
2) Possible reduction of navigation error rates, compared to in-vehicle instrument panels (Green, Williams, Hoekstra, George and Wen, 1993, cited by Steinfeld and Green, 1998).
3) Reduced eyestrain, due to a shorter distance between the HUD image and the forward view of the outside world, compared to in-vehicle instrument panels (Todoriki, Fukano, Okabayashi, Sakata and Tsuda, 1994). The driver is not required to continually adjust their focal point from long-range (when scanning the outside environment) to short-range (this focal adjustment is known as *eye re-accommodation*).
4) Increased eyes-on-the-road time (Gish, Staplin, Stewart and Perel, 1999). In one experiment, Todoriki *et al.* (1994) found that the number of glances towards a HUD was significantly less, per minute, than for an in-vehicle HDD. They concluded that the application of a HUD to navigation systems could be expected to contribute to improved driver safety.

Given their advantages, integration of HUDs into automobiles has been slow over the last 15 years and driver acceptance remains low. There are several problems concerned with the readability of automotive HUDs which may help explain why this has been so. These include:

1) Contrast interference: difficulty seeing HUD symbology during the day due to lack of contrast between symbology and the background scene.
2) Increased driver workload required to interpret the HUD symbology while driving.
3) Propensity for capturing and holding driver's attention, away from the forward road view (Gish *et al.*, 1999).
4) A possible increase in navigation error rates, compared to in-vehicle instrument panels. In one simulated experiment involving twelve drivers, a full-windshield HUD produced almost twice as many errors as an in-vehicle instrument panel (Steinfeld and Green, 1998).

In addition, Gish *et al.* (1999) found no significant difference between the recognition rates of information presented on a simulated HUD, compared to a simulated HDD. In this experiment, the ability of 36 participants to detect targets external to a vehicle (such as pedestrians and other vehicles) and perform in-vehicle tasks (such as respond to navigation information) was tested. The HUD was mounted five degrees below the line of sight, whereas the HDD was mounted twenty degrees below the line of sight. Surprisingly, the recognition rates for the HUD and HDD were both very similar, although the response time of participants was slightly better for the HUD overall. This was true both when drivers performed one task at a time and when drivers were required to attend to dual tasks simultaneously.

Sviden (1993) describes one scenario that was predicted for the year 2000 in the early 1990s, as presented in Box 1.1. Although real HMIs like that described now exist, the level of ubiquity suggested by Box 1.1 has clearly not eventuated.

> "Cars have now received an intelligent RSI (Road Service Informatics) visor, in front and above the driver. The RSI unit has display optics at its edge and can be adjusted in position and brightness to fit the individual drivers. The driver can see one row of symbols and a line of text above the traffic scene in front of him. He normally 'experiences' the symbols with his peripheral, rather than his direct, vision. The principal and standardized information on the RSI unit is combined with more detailed head-down information on the integrated dashboard displays."

Box 1.1: Implementation of in-vehicle HMIs, predicted by Sviden (1993) for the year 2000 (p30)

Even though there is no consensus as to the benefits of HUDs, a HUD would appear to be the most effective present-day device for displaying virtual road signs. The idea of using a projection device such as a HUD as an in-vehicle AR display device, specifically for the purpose of displaying virtual road signs that convey navigation and en-route trip information.

is not new (Chislenko, 1997; Spohrer, 1999). However, while plenty of ideas have recently been bandied about, few concrete implementations or prototypes appear to have been developed yet. The research project described in this thesis addresses this research opportunity.

1.4) Expected Benefits and Drawbacks of Virtual Road Signs

The true novel factor of virtual road signs is the style of information presentation. By combining this style of presentation with the functionality of current navigation systems, the expected benefits of virtual road signs are numerous. Box 1.2 describes some of these benefits with respect to the aforementioned problems associated with conventional signs, followed by some drawbacks of virtual road signs.

Benefits of virtual road signs:

1) Dynamic information can be communicated to road users very effectively:
    a) In real-time or near real-time. Sign messages can be easily updated in one or more databases as information comes to hand.
    b) On a per-user basis; for example:
    - Nearby landmarks or facilities e.g. supermarkets.
    - Reminder to take a break from driving on long trips.

    c) On a per-road basis:
    - Temporary road conditions e.g. roadworks, detours.
    - Adverse road conditions e.g. slippery surface (ice, oil), metal surface.
    - Adverse weather conditions e.g. snow, high winds, flooding, hot road shimmering.
    - Adverse traffic conditions e.g. vehicle collision, vehicle breakdown.

2) Dynamic and static information can be tailored to meet the needs of specific road user categories; for example:
    - Speed recommendations on curves and corners can be set separately for motorcycles, light vehicles (cars) and heavy vehicles (trucks) to suit traffic and weather conditions.
    - Learner drivers can receive additional driver assistance e.g. "Apply Brakes Now".
    - Vision-impaired drivers e.g. elderly drivers: virtual signs can be made as large as necessary.
    - Hearing-impaired drivers: aural information such as engine revs and ambulance sirens can be represented in visual form.
    - Emergency service drivers e.g. police, ambulance, fire: additional information can be provided for safer high-speed driving e.g. status of nearby intersections.
    - Tourists: a separate set of signs can indicate local attractions.

3) The visibility of virtual signs is excellent in all environmental and traffic conditions (subject to ambient light conditions), such as in heavy traffic and at night.

4) Construction costs are minimised as real materials are not needed. Signs are not manufactured in a physical sense.
5) Sign placement incurs a very low labour overhead as no physical erection is required. Signs can be easily "erected" in remote locations.
6) Virtual signs do not wear with time due to atmospheric exposure, nor is repair necessary.
7) Graffiti and theft is impossible, meaning a further cost saving in maintenance.
8) Signs have no impact on the surrounding environment. There is no chance of drivers colliding with virtual signs in an out-of-control situation. Environmental damage is non-existent.

Drawbacks of virtual road signs:

1) The possibility that virtual signs may cause excessive visual distraction while driving.
2) Issues of liability in case of system failure (for example, if the wrong signs are displayed).
3) Vehicles must be fitted with expensive system hardware to display virtual signs to drivers.

Box 1.2: Expected benefits and drawbacks of virtual road signs

Virtual road signs are presented here as an idea to supplement existing road signs, rather than replace them completely. Replacement of conventional road signs would only be feasible if all road users were provided with a means of viewing virtual road signs. Even if this becomes practical at some time in the distant future, issues of liability in the case of system failure reinforce the need for conventional road signs as a backup.

One of the attractions of virtual road signs is that even though the style of information presentation is quite different, many of the advantages of current in-vehicle HMIs apply, and thus many of the lessons learnt can also be applied. The information is there if and when the driver wants it, continually changing as a vehicle travels down the highway, and perhaps able to be edited and customised to a planned trip. Therefore, while the idea of virtual road signs is a potentially revolutionary idea with respect to in-vehicle HMIs, it can be considered an evolutionary phase in the development of in-vehicle HMIs overall.

1.5) Project Objectives

The objectives of the virtual road sign (VRS) project were:

1) To determine the technical feasibility of a VRS system, within the limits of current technology.
2) To investigate the major design decisions for a general VRS system.
3) To implement one particular VRS system, using real-world test data, for the purposes of demonstration.
4) To consider potential future applications and implications of the technology.

In order to fulfil these objectives, a working software prototype was developed. The prototype served as an ideal experimental project to brainstorm ideas, analyse and implement them quickly, and assess the result without commercial bias or burden. This report describes most aspects of the prototype, ranging from its high-level architecture down to lower-level details of implementation. The architecture and fundamental design decisions presented are intended to be sufficiently general such that they may be applicable to the development of other VRS systems. The final working prototype demonstrates an example of one possible VRS system implementation using a small set of real-world data. Although small scale and purely research-oriented, the prototype intends to spark the imagination with what might be possible on a larger scale; for example, a commercial end-user application.

The main limitation of this project was the unavailability of a suitable display device, such as a HUD, that could be incorporated inside a vehicle to present virtual signs to the driver. This meant that a full demonstration of a working VRS system was not viable. Therefore, the objective of the prototype was redefined: to assess the technical feasibility of virtual road signs by way of a restricted *proof-of-concept simulation*. The challenge was to decide on a practical design compromise that worked with available display devices, such as a computer monitor or a laptop LCD screen. One feasible option was to record the non-augmented view that would be observed by a driver using a video camera mounted inside the vehicle. On arrival back into the lab, virtual road signs could be superimposed onto the captured video and replayed to simulate the augmented driver's view. For example, Kim, Kim, Jang, Kim and Kim (1998) used this technique in an outdoors AR system that mounted a CCD camera on a radio-controlled helicopter. A tracking system measured the position and precise orientation of the camera, and virtual images were superimposed on the captured image in real-time using video overlay hardware. Another simpler option was to forego the video entirely and record only the vehicle tracking data during a journey. As we shall see, the lack of a suitable display device was successfully overcome.

1.6) Review of Intelligent Transportation Systems and Advanced Traveller Information Systems (ATIS)

1.6.1) Introduction

The phrase *intelligent transportation systems* (ITS) describes an incredibly diverse field combining advances in communication, tracking, information engineering, electronics and automobiles. The coupling of information technology and communications is increasingly known as *telematics*; therefore, ITS can be considered as the application of telematics to road transport. The goal of ITS is to apply technology to make transportation safer and more efficient, with less congestion, pollution and environmental impact (Zhao, 1997). The original phrase coined for ITS was *road transport informatics* (RTI), which later became known as *intelligent vehicle-highway systems* (IVHS) in the USA to embody the notion of an integrated system (Catling, 1994), and *advanced transport telematics* (ATT) in Europe. All of these acronyms remain valid and roughly synonymous with ITS. ITS has evolved from its most basic means back in 1910, when the Jones Live Map was advertised as a means of replacing paper maps, to a wide variety of modern-day systems that cater to every information need of drivers. A brief history is presented in Catling (1994) and Zhao (1997).

To organise ITS into manageable units, ITS activities are broken down into a set of user services (Drane and Rizos, 1998), such as:

1) Advanced traffic management systems (ATMS), which manage traffic on transport networks to reduce congestion and improve travel times.
2) Advanced traveller information systems (ATIS), which provide information directly to drivers, such as the best route to travel to reach a particular destination.
3) Commercial vehicle operations (CVO), which use automatic vehicle location systems linked with computer-aided dispatch systems to manage commercial vehicle fleets.
4) Advanced public transport systems (APTS), which are concerned with improving the efficiency of public transport information and control systems.
5) Automated highway systems (AHS), which use automated vehicle control systems to drive vehicles with minimal or no human intervention required (Whelan, 1995).

Virtual road signs provide *en-route driver information* (in contrast to pre-trip planning information) and belong in the ATIS category. ATIS is defined as systems that "acquire, analyze, communicate, and present information to assist surface transportation travellers in moving from a starting location (origin) to their desired location" (Whelan, 1995, p63). ATIS provides a variety of information that assists travellers in private vehicles or public transportation, such as location of traffic incidents, weather and road conditions, parking sites, optimal routes, recommended speeds and lane restrictions. One ATIS service is concerned with the task of *route guidance*. Route guidance is the process of guiding a driver along a predetermined route chosen because it is quicker, shorter or more convenient; *dynamic route guidance* uses real-time information such as traffic congestion to choose the route (Catling, 1994). The most basic envisaged use of virtual road signs is to apply virtual road signs to an existing route guidance system. As a driver travels along their chosen route, virtual road signs would display navigation instructions to keep the driver on track and up-to-date. A more general VRS system would not limit itself to the display of navigation information; rather, it would use virtual signs to convey almost any type of visual information to the driver.

Figure 1.3 shows the main components of a vehicle-based ATIS. There are two potential sources of information:

1) Relatively static information, including internal data, such as a description of the vehicle, and external environmental data, such as local road and intersection layout. Because this data changes infrequently, it can be stored on one or more onboard databases inside a vehicle. Typically, road layout for a defined area, such as a city, is stored in its own digital map database.
2) Relatively dynamic information, such as current lane status (open/closed) on a highway. Because this data changes frequently, it makes sense to transmit it from one or more offboard (remote) data stores, maintained by a variety of information providers, when it is needed in real-time. An ATIS-enabled vehicle receives the data via a wireless communication system such as radio.

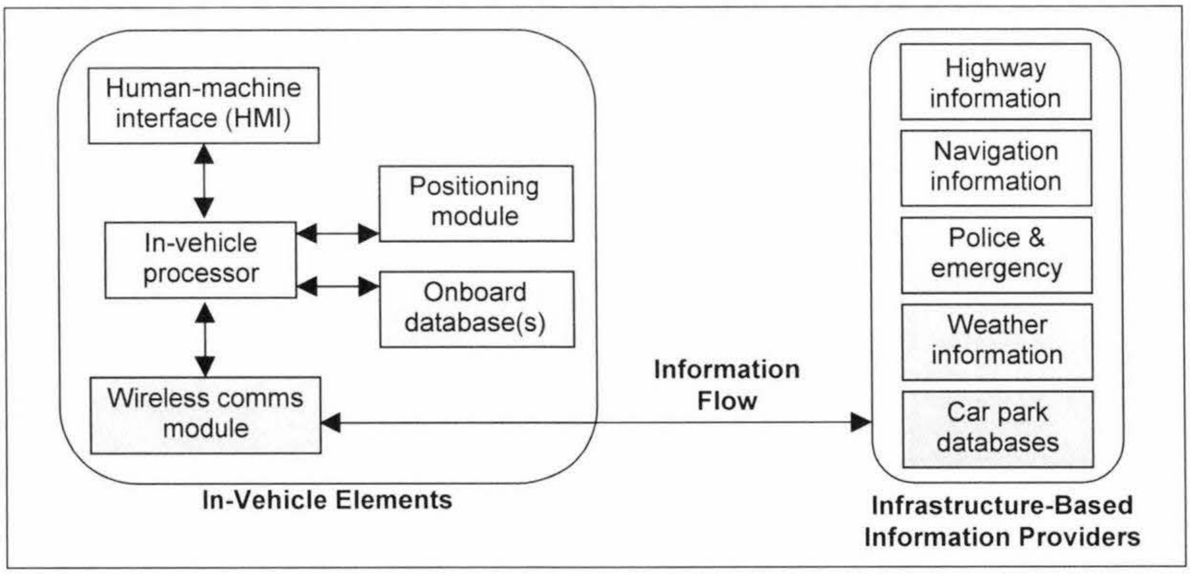

Figure 1.3: Components of an advanced traveller information system (ATIS) with onboard and offboard information sources.

A positioning module combines one or more sensor measurements to calculate the position of the vehicle relative to the Earth. An in-vehicle processor accepts the vehicle's current position as an input and performs various map-related functions, such as determining the messages that should be presented at the vehicle's given location. At the same time, real-time information may be received via an in-vehicle communication system and passed on to the processor. A *human-machine interface* (HMI) completes the system by presenting the data output by the processor in a human-readable form so that the driver can interpret it. In addition, the HMI provides one or more input devices such as a keyboard which allows the driver to communicate with the system; for example, to indicate their intention to select a new route to the nearest petrol station. The HMI is responsible for all interaction between the driver and the rest of the system.

1.6.2) Data Management

In this context, data management describes where the source of driver information is located and how the information will be communicated between the source and a vehicle. The two main data management philosophies of current ATIS systems are now described. Where appropriate, real-world systems are reviewed to exemplify current developments in ITS technology.

1) Onboard databases

The simplest category of ATIS encompasses *autonomous navigation aids*, which are essentially self-contained route guidance systems (OECD Scientific Experts Group, 1988). These *standalone* systems do not utilise any communication link with the environment external to a vehicle. Map data is stored in its entirety in each vehicle in an onboard, static (unchanging) format. Early projects such as DRIVEGUIDE and NAVICOM were based on this idea. Modern route guidance systems store all navigation information in a CD-ROM- or DVD-based database. For example, Alpine's DVD-based navigation system store uses map databases provided by NavTech to provide coverage of entire countries, such as Japan and the United States (Alpine, 2001). Drivers select the street that they seek, and the system directs the driver to that destination according to the driver's preference (for example, the quickest route, route that maximises travel on freeways, or route that minimises travel on toll roads). The system can also remember custom destinations specified by the driver.

While onboard map databases provide the luxury of almost instantaneous updates as a driver's travel plans change or side trips are added, they require a dedicated (and relatively costly) on-board processor (Arnholt, 2000). Data cannot be updated on-the-fly; rather, users must pay for periodic upgrades to the map database. In addition, such systems cannot disseminate real-time information.

2) Offboard databases

A more convenient and flexible data management option is to retrieve travel information from an offboard data source and relay it to vehicles via wireless communication as they need it. These mobile ATIS systems relay information between vehicles, sensors and land databases via powerful remote server computers. Offboard ATIS systems are steadily increasing in popularity due to their ability to provide up-to-date information to drivers (GPNN, 2000 [a]). Vehicle hardware is easier to update, more flexible in the range of options available to drivers and potentially less expensive to buy (GPNN, 2000 [b]). Numerous companies are currently exploring the offboard navigation model, including Motorola, Alpine and Visteon. In Japan, Denso already provides systems for Mercedes with dynamic route guidance via real-time traffic information input.

1.6.3) Wireless Communication

Wireless communication is an incredibly active research topic, encompassing radio, analog and digital cellular telephony, radio pagers, private land mobile radio, infrared and radio *wireless local area networks* (WLANs), microwave relays, and geostationary and low-Earth-orbit satellites (Elliott and Dailey, 1995). An excellent synopsis and comparison of wireless communication is presented by Elliott and Dailey (1995). Three major wireless communication methods dominate current ATIS systems: (1) beacons, (2) radio, and (3) cellular. An example of each method applied in the real world is described below.

1) Beacons

At the UK's first ever ITS national test project, detailed information on local traffic and weather conditions is transmitted to in-vehicle terminals provided by Alpine and programmed by Lucas Varity (M2 Presswire, 1999). Data is first sent from each vehicle via dedicated short wave communications (DSRC), to 80 roadside beacons. These high-speed DSRC beacons are positioned on gantries at key locations along the motorway. The information from beacons is then transmitted via a digital wireless data network, known as the RAM Network, to a central database managed by the national automobile association, RAC. The RAM Network provides two-way, real-time wireless data communication over dedicated radio frequencies. The RAM Network uses Mobitex, the international packet-switched standard for wireless data communications, originally developed by Ericsson. The central database interfaces with RAC's commercial travel and traffic information system (CATTiS). At RAC, travel and traffic data is retrieved and updated according to the central database. The results are transmitted back via the RAM Network to the beacons and via DSRC, to alert approaching vehicles to possible delays and adverse weather conditions ahead.

2) RDS-TMC

In Europe, the standard means of communicating real-time traffic information is via the Radio Data System Traffic Message Channel (RDS-TMC) (Kujawa, 1999). RDS-TMC is a protocol developed by the European Broadcast Union to employ subcarrier frequencies that are part of every publicly broadcast FM radio signal. Specific channels are reserved for traffic data. This data is normally gathered from roadside sensors strategically located around and within metropolitan areas. Data gathered by sensors is automatically tabulated into statistics that can be expressed by voice in simple terms for broadcast purposes. Traffic data can be retrieved within vehicles equipped with a properly configured audio system. Alternatively, the broadcast centre may elect to provide preprogrammed direction and caution information to drivers. The traffic sensor network is densest in Western Europe, particularly in Germany and France, and includes nearly every bridge in England. Nearly 65 per cent of audio systems sold with new cars in Europe have RDS-TMC circuitry installed. In the year 2000, Visteon and Clarion announced plans to launch systems that integrate real-time traffic data and dynamic rerouting information overlaid on in-vehicle navigation displays (GPNN, 2000 [c]). Both companies planned to use the RDS/TMC FM subcarrier networks and traffic codes.

3) Cellular

One limitation of RDS-TMC is that, being one-way, it does not support transmission of vehicle data back to the ATIS infrastructure. For example, this capability would be useful to provide more personalised information to a driver. Roadside beacons are also not well-suited to providing tailored information to specific vehicles. Cellular telephone networks address this niche. These are radio-based mobile communication systems that employ a set of base stations to transmit and receive signals (Drane and Rizos, 1998). The most commonly cited standard for cellular communication is the Global System for Mobile Communications (GSM). GSM is an open non-proprietary standard that supports a variety of digital services, most notably the digital cellular mobile telephone system in Europe, operating in the 900 MHz frequency band (Whelan, 1995). The market of personalised driver information was pioneered by GM's OnStar system, which offers pushbutton cellular connection to the OnStar service for emergencies, navigation and location services to personal vehicle users (Kujawa, 1999). It is now in its fourth year of service; in February 1999, over 40,000 subscribers had signed on in the US. Soon, OnStar and ATX Technologies will also provide "concierge" services to assist in the location of restaurants, gas stations, parking areas, hotels and motels

(Frenzel, 2001). The systems are equipped with GPS chipsets whose signals are transmitted to a service centre. In 1999, GM began shipping its OnStar 2 system that features three-button controls and a dedicated OnStar cellular network.

1.6.4) Internet-based ATIS

In the year 2000, manufacturers of ATIS systems embraced the Internet as an integrated means of providing real-time information to drivers. For example, InfoMove, a two-year-old company from Seattle, is looking at delivering customised Internet content and traffic data via handheld devices connected in cars (GPNN, 2000 [d]). A client-side browser provides the user interface, while a back-end server processes the data. Once the appropriate hardware is in place, InfoMove will enable automobiles of different manufacturers – using different computers or handheld devices, Web portals, and wireless carriers – to communicate with each other via the InfoMove database. UK companies CarCom Ltd. and Netcom Internet are combining to add Internet connectivity to CarCom's new in-car communication, navigation and computing platform. The CarCom system will use real-time traffic information provided by the UK's Metro service, which is sourced via the Internet. In March 2000, PSA Peugeot Citroaen and French communications giant, Vivendi, announced a joint venture to develop Wappi, a multi-access Internet portal (Electronic Times, 2000). Wappi aims to give motorists access to a wide range of up-to-date travel information via an in-vehicle screen and a GSM mobile telephone. Wappi includes assistance and emergency service links, user guides and maintenance tips, and will also have the ability to carry out a remote diagnosis on vehicle breakdowns. In the US, Utah's Department of Transportation provides traveller information and traffic updates to the public via email, which drivers receive automatically via their mobile phone or even their *personal digital assistant* (PDA) (Communications News, 2000).

The European Commission has launched a project known as the 'Multimedia Car Platform', which combines broadband Internet access with mobile telephony to present driver information on the dashboard (M2 Presswire, 2000). The project uses the latest mobile phone standards, such as GSM and third-generation cellular technology, 3G, to provide localised information (for example, describing traffic, parking and route guidance), regional information (such as news, weather and special events) and national information (such as news) to drivers and passengers. The system will support voice recognition control for the driver and hands/eyes control for passengers. This means that drivers can safely use the system on the move while passengers can enjoy a more direct interaction. The broadband information flow will use the IP protocol, which is a standard communications protocol used by the Internet. In the future the system could also be incorporated into trains, trucks, and buses, giving travellers all the facilities of the Internet and broadband broadcast-quality media while on the move. Another location-based service idea being considered is the opportunity to display advertising or special promotions to drivers as they drive within range of one or more businesses (Arnholt, 2000).

One of the problems with offboard databases is that collectively, offboard ATIS systems will require more bandwidth than is available in most current cellular networks. For this reason, it is predicted that true offboard navigation will not become mainstream for several years (GPNN, 2000 [a]). In the US, onboard-offboard hybrid systems are being developed which contain a smaller onboard database, reduced processing capability and onboard communications. In these systems, there is a degree of flexibility as to where information will be stored at any time. For example, most road layout and route guidance information may be stored remotely where there is sufficient storage capacity. Only when a vehicle enters a new region may it be necessary to download local road layout and route guidance information into onboard databases, to relieve the load on the communication system.

1.7) Review of Human-Machine Interfaces in Advanced Traveller Information Systems (ATIS)

1.7.1) Introduction

Zhao (1997, p143) defines the human-machine interface (HMI) provided for automotive navigation as a "module that provides the user (driver of a vehicle) with a means to interact with the location and navigation equipment computer and devices". The objectives of HMI design are to increase productivity and safety, maximise performance and ensure comfortable, ergonomic and effective human use. Inside a vehicle, the HMI permits a driver to indicate how they wish to proceed (for example, select a new route) and provides the driver with the stimulus they seek for navigation. In this context, the focus is on design and style of information presentation to the driver, specifically with respect to visual display-based interfaces, as it is this interface type that is capable of presenting virtual road signs. Ergonomics and non-visual interfaces, such as voice recognition, are not considered.

For any visual HMI to be effective, it must be timely, relevant to the current driver task, easily discerned without error and easily understood (Ashby and Parkes, 1993). Ideally it should match the expectations and experience of the user but not distract them so much that it jeopardises the safety of driver or vehicle. Thus it should not compete directly for the limited attention resources of the driver. In addition, the interface design should be consistent and minimise the memory load of the driver (Zhao, 1997).

An in-vehicle HMI concerns the two-way in-vehicle interaction between driver and equipment. An in-vehicle HMI consists of one or more display devices that are fully self-contained within a vehicle, such that the information displayed to each driver is personal and possibly unique. Examples include liquid crystal displays (LCDs), cathode-ray tube displays (CRTs), electroluminescent displays, plasma display panels and vacuum fluorescent displays (Zhao, 1997). The following elements are important in the design of an in-vehicle HMI (Catling, 1994):

1) The scope and type of information.
2) The range over which the system will display information.
3) The information content necessary to assist drivers, and information content sought by drivers.
4) The presentation style of information.
5) The timing of information provision linked with the motion of a vehicle.
6) The sequence in which information is displayed.

The nearest equivalent of virtual road signs using current technology is a hypothetical hybrid system that combines the dynamism and communication benefits of current in-vehicle HMIs with the presentation style of *variable-message signs*. Therefore, a review of both these types of HMI is now presented.

1.7.2) Variable-Message Signs

Variable-message signs (VMS) are physical signs positioned at strategic locations whose information content can be changed remotely. Variable direction signs indicate alternative routes as a function of the traffic situation on a network as a whole (Camus and Fortin, 1995). Alphanumeric signboards display short phrases relevant to current road or traffic conditions, allowing a wide variety of messages to be sent in an instantly-readable format, such as roadworks and road closures. The disadvantage is that foreign motorists may be unable to understand the messages displayed, as it is impractical to display the messages in more than one or two languages. A third category of VMS is pictograms which typically display schematic representations of the road network (such as in Japan) or traffic symbols. While the information conveyed is less explicit and may take longer to interpret than alphanumeric signs, this type of sign overcomes the language barrier (Camus and Fortin, 1995). The main advantage of VMSs is unquestionably their universal reception by all road users. This makes them more suitable for conveying safety-critical information. Once they are constructed at high financial cost, their effectiveness as a communication medium for collective dynamic control improves linearly as the number of road users increases. However, many drivers are tempted to think that such signs "only apply to others", particularly when dealing with dynamic route guidance information (Catling, 1994). Furthermore, the opportunity to convey information and the content of VMSs is very limited due to the short viewing time involved; ECMT (1995) suggests that most drivers cannot interpret more than seven words when travelling at speed. The high cost and large amount of space required by a VMS limits their potential implementation to specific stretches of road, such as busy highways or roads prone to seasonal weather. On highways, there may be no opportunity to turn around if the driver fails to observe the sign.

In Germany, variable-message signs aim to control traffic by showing ordinary traffic signs, such as signs that display admissible maximum speeds (Behrendt, 2000). The collection of traffic data is done conventionally through induction loops or radar sensors. Special sensor systems are able to determine the specific weather conditions (fog, heavy rain, black ice, etc). Unlike other European countries, Germany does not use alphanumerical verbal displays: instead, standard international traffic symbols are used. In the US, the Washington DOT has installed nine variable message signs that issue variable speed limits as well as information on road conditions, tyre chain requirements and highway closures (American City & County, 1998). The signs are part of Travel Aid, an intelligent transportation system designed to improve safety and minimise accidents. Wide aperture radar tracks current vehicle speeds, while six weather stations monitor temperature, humidity, precipitation, wind and road surface conditions. The information from all sources is gathered and transmitted by packet radio and microwave transmission to a control centre. Travel Aid then calculates safe speeds that are confirmed by DOT staff members and transmitted to the variable message signs.

1.7.3) In-Vehicle HMIs

In-vehicle HMIs offer several advantages over variable-message signs. Drivers can acquire their own personal information when necessary: for example, when he/she is lost and requires guidance back to the nearest highway. There is no chance of information transfer being impeded by other vehicles or bad weather conditions. Drivers can reconfirm information at their leisure, reducing the criticality of interpreting information at a specific time. The range of available information is much greater, but more importantly, drivers can obtain only that information they request. However, the flexibility of in-vehicle information systems always presents the possibility of information overload, which can be a particular concern for elderly drivers (Catling, 1994; Verwey, 1993). Schraagen (1993) makes the observation that dynamic graphical map displayed by the ETAK in-vehicle HMI did not reduce the number of navigation errors committed by a driver when compared with a conventional paper map. Also, most in-vehicle HMIs demand a fair amount of prior learning to be useful, which instantly reduces their potential market.

The need for drivers to divert their visual attention away from the external environment can be particularly problematic when they are learning how to use an in-vehicle HMI. The size of the display often aggravates this problem, forcing the driver to divert their focus back and forth between a small screen and the outside world. Popp and Farber (1991) investigated four different experimental display layouts of a simulated in-vehicle HMI, two of which displayed images very similar to roadside signs, and the other two displaying a sign and map simultaneously. All four displays forced drivers to observe them intensively for similar time durations and thus divert their attention away from traffic. In-vehicle instrument panel displays with limited contrast (such as LCDs) can delay information perception (Haller, 1991). Drivers' eyes are normally adapted to luminance levels of the outer forward view, which are typically much higher than the luminance of in-vehicle displays. Even after re-accommodation when the driver diverts their attention back to the in-vehicle display, their eyes may not be fully adapted to the reduced background light level of the display. Wierwille, Hulse, Fischer and Dingus (1991) found that drivers increase their proportion of time spent looking at the roadway centre (outside the vehicle) in heavy traffic conditions; similarly, they reduce the amount of time devoted to in-vehicle navigation displays in response to unanticipated scenarios (such as external vehicle accidents) when immediate control of the vehicle is more important. This suggests that an in-vehicle display is only effective for initial incident warning; once the driver knows of an impending incident, they prefer to rely more on what can be seen and heard outside the vehicle. Wierwille *et al.* (1991) state that during this time, navigation demands can in fact be postponed until the incident is brought under control.

Current in-vehicle visual HMIs present navigation and en-route trip information to drivers in a variety of styles. Wynalek favours the development of in-vehicle systems which use tiny displays that fit within the opening used by conventional car radios (Murray, 2001). Such displays accommodate only a few words of text. In a traffic-hazard warning system developed by Georgia Tech, known as the Safety Warning System, drivers are alerted to real-time hazards, dangerous weather and other traffic conditions by one of 64 pre-programmed text messages shown on an LED display (Wilson, 1999). These text-based displays can be read quickly and easily by drivers, but they are not optimal for displaying navigation information. For this information, arrows and symbols are preferred. A popular presentation style is known as *turn-by-turn*, in which arrow icons direct drivers at the correct time whenever a turn off the current track is required. Two navigation systems that use the turn-by-turn presentation style are shown in Figures 1.4.a and 1.4.b. Both systems indicate the direction of the turn to take, the name of the new street to turn onto, the distance to the turn-off and the distance to the driver's selected destination. In addition, NeverLost's display (Figure 1.4.b) presents an illustration of the road layout to further clarify each turn to a driver.

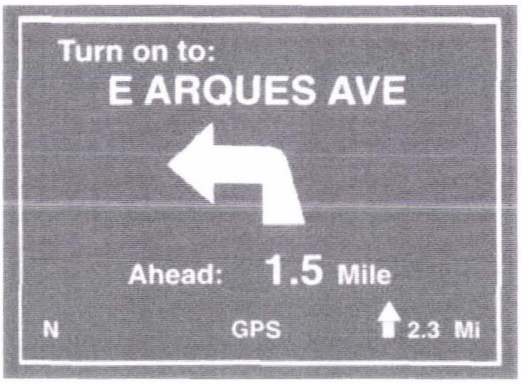

Figure 1.4.a: In-vehicle display of the TetraStar navigation system (Eby, 1999, p300)

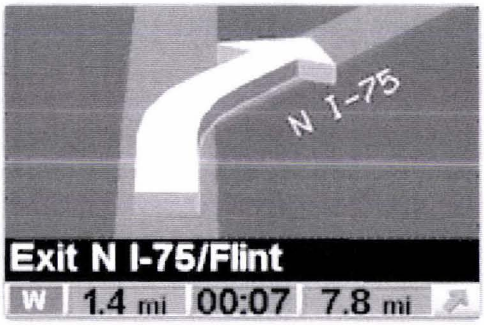

Figure 1.4.b: In-vehicle display of the NeverLost navigation system, recently fitted in Hertz rental cars (Bursa, 2000; image source: Hertz, 2001)

Other in-vehicle displays combine turn-by-turn instructions with an aerial planar view of the surrounding roads on a dynamic map. The advantage of these displays over turn-by-turn displays is that they resemble paper maps, allowing drivers to see exactly where they are, where they are going, and where nearby settlements, major roads and other facilities are located. Two examples of plan-view displays used by current navigation systems are shown in Figures 1.5.a and 1.5.b.

Recently, Nissan has announced details of its BirdView navigation system, which takes the viewpoint of an observer high above and slightly behind a vehicle (Nissan, 2001). The driver

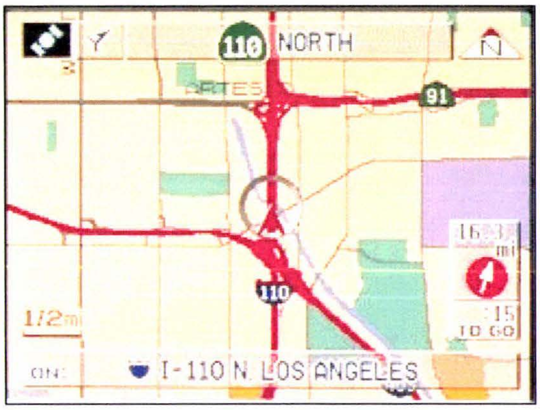

Figure 1.5.a: In-vehicle display of Alpine's DVD-based navigation system (Alpine, 2001)

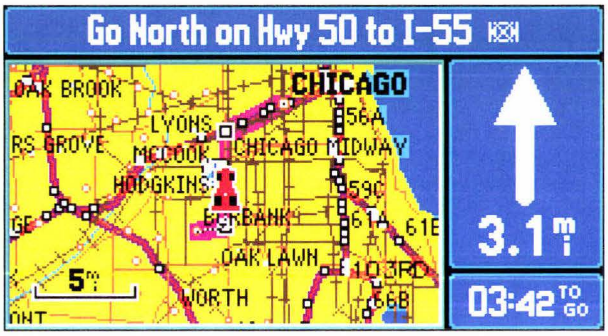

Figure 1.5.b: In-vehicle display of Garmin's StreetPilot ColorMap (Garmin Corporation, 2001)

can simultaneously see a detailed view of each intersection in the lower part of the screen for guidance on what turn to make, while the upper portion of the screen displays a zoomed-out view so the driver can anticipate the distance to the next intersection (Lewis, DeMeis, Mehri and Russelburg, 2000). The resulting upper display is a broad, panoramic three-dimensional map, shown on a HUD, which continues to the distant horizon ahead of the vehicle, as shown in Figure 1.6. The lower display (not shown) may closely remember a turn-by-turn display such as that shown in Figure 1.4.b. The idea is that by reducing the amount of zooming in and out required, the level of driver distraction is reduced. The system also displays real-time traffic information and warns of natural events such as floods or typhoons.

Figure 1.6: In-vehicle display of Nissan's BirdView navigation system (Nissan, 2001).

1.8) Suitability of a HUD as an In-Vehicle Display Device

1.8.1) Overview

As mentioned in (1.2), the aim of virtual road signs, as it is discussed in this thesis, is to mimic real road signs while overcoming many of the problems associated with conventional signs. By this definition, it is clear from (1.7) that virtual road signs do not match the style of information presentation used by current in-vehicle ATIS systems. Virtual road signs are opaque by their nature: their aim is to attract the driver's attention for a specific purpose at a specific time. Unlike turn-by-turn directions and aerial map views, virtual signs are only suitable for display on an AR display device, such as a HUD. One can argue that if AR allows drivers to interpret information in a more natural form, then virtual road signs are a more natural style of presentation than turn-by-turn directions and aerial map views.

The ways in which HUDs can be used to enhance the presentation of information to drivers have been re-addressed by vehicle manufacturers and researchers in recent years. Todoriki *et al.* (1994) proposed a route guidance system which overlaid a large guiding arrow onto the road ahead to direct drivers at intersections. They found that in a study of three participants, the average response time and number of glances were less for this "on-the-scene HUD" than for a conventional HUD that showed a plan view of the intersection. Steinfeld and Green (1998) tested a simulated HUD in which the outlines of roads at an intersection were superimposed to correspond exactly with the view of the intersection as observed by a driver. By labelling the superimposed outlines and displaying further route guidance information, the driver could determine which route to take. This idea is currently being tested as a means of aiding navigation in snowploughs (Trimble, 2000). When a snowplough driver cannot see the road ahead due to excessive snow or white-out conditions, a visual representation of the road is displayed on a HUD. As well as navigation applications, HUDs have also been used to enhance the night vision of drivers. The 2000 model of the Cadillac deVille used thermal imaging and a HUD to enhance the driver's view of the central part of the road scene. The system allowed drivers to spot pedestrians and animals on the road at night more easily (Pierce, 1999).

As mentioned in (1.3.3), of all the current display devices that may be suitable for displaying virtual road signs, an automotive HUD would appear to be the prime candidate at the present time. Thus, the perception of information presented on an automotive HUD is of particular interest. In order to gain a better insight into the suitability of this device for displaying virtual road signs, a literature review was undertaken of some of the factors affecting perception of information when displayed on an automotive HUD.

1.8.2) Field of View

The field of view of a display is the angle over which symbology may be displayed. A HUD with a narrow field of view can only display symbology in a narrow space, whereas a HUD with a wide field of view can spread its image over a wider area. Steinfeld and Green (1998) note that based on the results of one previous experiment (Williams and Green, 1992), the response times of drivers to navigation information were typically almost 10% less for a conventional small-angle HUD than for baseline in-vehicle instrument panels. Moreover, Steinfeld and Green (1998) found that response times decreased even more (at least 20%) over the instrument panel displays for full-windshield HUDs. The latter HUD configuration offered a wider field of view to drivers than the conventional HUD.

1.8.3) Angle of Depression

The angle of depression of a display device describes the angle at which the device appears below an observer's line of sight. Past experiments suggest that there is not necessarily an angle of depression for a HUD that optimises readability, but rather a number of trade-offs exist. In one experiment by Ward, Parkes and Crone (1995), the ability of thirty individuals to correctly identify the orientation of superimposed symbology was tested for two simulated HUDs. One HUD had a zero angle of depression, while the other HUD had a small non-zero (three degree) angle of depression. Participants were asked to track the location of a lead vehicle in video footage captured from the viewpoint of a real driver. At the same time, they were asked to identify the orientation of target icons displayed intermittently in different locations, for each HUD. Results showed that the legibility of the HUD with a three degree of angle of depression was superior. The reason suggested for this was that the latter HUD projected its image onto a less complex background scene (the road) that was more conducive to correct recognition than the other HUD. However, it was noted that the latter HUD increases the need for eye re-accommodation (Cole and Hughes, cited by Ward *et al.*, 1995). Furthermore, Sojourner and Antin (cited by Ward *et al.*, 1995) argue that a zero angle of depression permits faster response times.

Okabayashi, Sugie and Hatada (1999) investigated the effect of angle of depression on the ability of ten participants to recognise two simultaneous views. One simulated view represented objects observed in the forward view when driving; in this view, participants were asked to identify the orientation of simple shapes known as Snellen figures. The other simulated view was a superimposed HUD image of two green random numbers. Okabayashi *et al.* (1999) found that when participants correctly recognised the Snellen figures, their ability to also correctly recognise the HUD image decreased as the HUD angle of depression increased from zero to twenty degrees. However, when the task of Snellen figure recognition was removed, they found that correct recognition rates improved as the angle of depression increased from zero to five degrees. One suggested explanation for this finding was the significantly faster convergence response (eye re-accommodation) of the participants when the angle of depression was five degrees.

1.8.4) Distance to Image

Research suggests that the best recognition of HUD images is achieved when the projected image is collimated (focussed) at near-infinity. This configuration minimises the amount of eye re-accommodation needed as a driver diverts their attention between the HUD image and forward view of the road. In a simulated HUD experiment, Okabayashi and Sakata (1991) found that average correct recognition rate for a HUD image improved monotonically as the distance to the HUD image was increased from 0.7 metres to five metres. However, Okabayashi suggested in a paper written six years later (Okabayashi *et al.*, 1999) that very long display distances are not preferable. This finding was based on subjective evaluation data obtained from an experimental vehicle equipped with a HUD. Almost all drivers experienced a feeling of inconsistency between the HUD image and the forward view when the display distance was large (this distance was not specified). Okabayashi *et al.* (1999) also noted that the space restrictions of automobiles restrict the practical image distance to 1.5-2.5 metres.

1.8.5) Attention Tunnelling

Attention tunnelling describes an observer's fixation on a HUD image to the exclusion of other events in the real world, particularly unexpected events (Harrison, Ishii, Vicente and Buxton, 1995). This is perhaps the most commonly highlighted disadvantage of HUDs. In one aircraft-based experiment, Foyle, McCann, Sanford and Schwirzke (1993) tested the effect of information location on the ability of fourteen participants to concurrently process superimposed HUD symbology and "out-the-window" (real world) information. A computer simulated the out-the-window view by plotting shapes on the ground that participants were asked to track as closely as possible. At the same time, participants were asked to maintain a constant altitude by continually monitoring their current altitude displayed by a HUD. Simulated wind disturbances were presented during each trial. Foyle *et al.* (1993) found that when the altitude information was directly superimposed on the ground path, the ground-tracking performance of participants declined. The results showed no evidence that the trade-off in performance when the altitude was displayed in the lower position was due to visual masking (that is, reduced ability to see the ground shapes). This suggested that attention tunnelling was causing participants to focus too much attention on the altitude maintenance task. However, when the altitude information was superimposed in two other positions above the ground path, the performance of the altitude maintenance task did not change significantly, and the ground-track performance was no worse than when the altitude information was not displayed at all. Foyle *et al.* (1993) suggested that in the latter positions, the need for participants to visually scan their vision between known areas, rather than fixate their vision in one area, broke the effect of attention tunnelling. Gish *et al.* (1999) also found evidence of "HUD-induced cognitive capture" (p18), particularly in younger participants (25-54 years old). They state that it is possible that users would become less susceptible to cognitive capture as their experience with using the HUD increased. Harrison *et al.* (1995) also note that practice seems to improve the simultaneous monitoring performance of users.

1.8.6) Contrast interference

In a study of 36 participants by Gish *et al.* (1999), older observers (55 years and older) had particular problems seeing images displayed on a simulated HUD during simulated daytime trials. This suggested that the HUD contrast was somewhat interfered with by the brightness of the background. Gish *et al.* (1999) suggest that because the brightness in the simulation was less than what would be encountered while driving in the real world, their study underestimated the magnitude of the contrast interference problem.

1.8.7) Background complexity

The results of research into the effect of real-world background complexity on HUD perception are mostly predictable. The effect of background complexity was touched on in the discussion of HUD angle of depression in (1.8.3) above. In the same experiment by Ward *et al.* (1995) as that described in (1.8.3), the performance of participants for the target identification task was measured for varying background complexities. Recall that this task required identification of the orientation of target icons displayed intermittently in different locations on a simulated HUD. The background complexity was varied by changing the video footage of the actual driving scene observed. Ward *et al.* (1995) found that for the HUD placed at a zero degree depression angle, target identification performance significantly decreased as background complexity increased. Surprisingly, however, they found very little decrease in performance for the HUD placed at a three degree depression angle. The number of false positive identifications also increased as background complexity increased. In a separate task, participants were asked to identify specific changes in their current speed which was displayed on the HUD image. Again, the performance of participants for this task decreased significantly as background complexity increased. The number of false positive identifications was actually higher for a moderate complexity than a low or high complexity.

1.8.8) Implications for Virtual Road Signs

The number of factors that can affect HUD perception is greater than expected. The wider field-of-view of a full-windshield HUD would appear to make it the preferred option over a conventional HUD. A suitable angle of depression for display of virtual signs appears to be slightly lower than the driver's line of sight. This position is likely to make signs more readable due to the simpler background of the road scene, and may reduce the effect of attention tunnelling, even though it slightly increases the need for eye re-accommodation. The collimated distance to virtual sign images does not appear to be a critical factor. The effects of contrast interference and attention tunnelling are considered to be the most significant factors that will dictate whether it is practical to use a HUD, or indeed any AR device, to display virtual road signs to drivers.

It is worth pointing out that none of the experiments described in (1.8.2) to (1.8.7) used a real HUD, and most were conducted in simulated vehicle settings. Also, most of the experiments displayed simulated HUD images that were simplified for the purpose of experimentation, and which did not resemble the likely appearance of virtual road signs. The only sure way of working toward an answer as to whether virtual road signs may be feasible is to conduct our own experiments using real display devices in real vehicles. This was well beyond the budget and scope of this research. Therefore, development of a VRS system, as it is described in this thesis, was based on the assumption that virtual road signs may one day become a feasible option.

1.9) Summary

Conventional road signs are far from ideal as a means of communicating information to road users, and they are subject to a number of problems. Advanced traveller information systems are increasingly catering to the information needs of drivers, but there is still ample room for improvement to reduce the level of driver distraction and inattention they contribute to. Virtual road signs address these problems and aim to improve the safety of road users. They introduce a number of new opportunities for keeping road users informed. Augmented reality is the research area that makes virtual road signs possible. By developing a software prototype, the major design decisions involved in construction of a VRS system are examined and the technical feasibility of such a system can be assessed. A HUD is likely to be the most suitable display device for a VRS system. In the next chapter, we consider a high-level overview of the components of a VRS system and how such a system might operate.