ARS VEHO: Augmented Reality System for VEHicle Operation

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Abstract

The increasing use of personal in-car technologies has created more opportunities for driver distraction. Communication and navigational systems exact a high cognitive price for the assistance they provide to the driver. Starting from existing research in the areas of augmented reality and context-aware systems, this paper proposes a system designed to assist the driver in the primary task while mitigating the effects of secondary systems. The core of the system includes a calculated interruptibility metric, which in conjunction with a driver profile system allows the system to postpone or eliminate secondary tasks when the primary task demands the driver's full attention. The navigational system's output is seamlessly integrated into the driver's field of vision, eliminating the need to shift between 2D and 3D spatial representations or translate audio information to a spatial context. This paper presents the problem in detail, the proposed solution and excerpts from the software model.

1 Introduction

Driver distraction has become a major issue in traffic safety. It has become more urgent with the proliferation of cellular phones, navigation systems, in-car entertainment products and similar technologies [1], [2]. It is apparent that "secondary tasks," such as dialing a cellular phone, can significantly impact the primary driving task in a negative way [3], [4], [5]. Such secondary tasks have become an integral part of many drivers' day, and eliminating them entirely would require behavioral changes far beyond the scope of available technology or resources. But it should be possible to mitigate the effects of these new devices through more careful interface planning, keeping the driver's heavy visual-mode cognitive workload in mind [6], [7]. Predictive modeling, borne out by user studies, indicates that certain interface modalities would impact driving behavior less than others [8]. Beyond standard protocols and human factors guidelines, assistive technologies would help offset the burden imposed by these secondary systems. This paper proposes a system built around a context-sensitive interruptibility index, calculated in real time. This index is used to moderate the information presented to the driver and reduce secondary-task cognitive requirements in difficult traffic situations. While the use of a heads-up display to display navigational data is nothing new [9], [10], it is not enough to present the information within the driver's field of vision. Such information should be seamlessly integrated into the environment, using an annotation approach borrowed from previous augmented-reality work [11], [12]. Finally, the amount of data captured by any in-car assistive technology becomes far more powerful if combined with data from other vehicles on the road. If a small number of vehicles on the road were to be equipped with even a low-bandwidth networking technology, there should be no need for the expensive installation of traffic monitors. The traffic would report on itself [13]. In the following section, we elaborate on the effect of new technologies on driver attention and specific human-interface issues. We then propose a design for ARS VEHO, using the software modeling approach described by Arlow and Neustadt [14], augmented by plus and minus scenarios, as proposed by Bødker [15]. Next we compare our approach to several similar designs and proposals, including several projects in the early implementation stages. Before presenting our conclusions, we detail several avenues of further research.

2 The Problem

People, particularly in the industrialized nations, are spending more time in their cars. According to U.S. Census data, over the past 40 years both the percentage of the population commuting to work in an automobile and the mean travel time has increased [16]. Such long commute times have fueled a new market in products (such as audio books) designed or adaptable to in-car use, all of which fall in the general category of secondary tasks. Combined with the pervasive presence of cell phones, the increased time spent in a vehicle also implies that more telephone conversations will be conducted there. Even without the introduction of new technologies, controls for the most pervasive secondary systems in vehicles – radios – require a significant cognitive workload [17]. Driver inattention is already the largest single cause of serious traffic accidents [18]. Government regulations and market demand have spurred automobile manufacturers to make their vehicles safer to operate, but as of yet no products have emerged with the primary goal of reducing the general cognitive demand of secondary tasks. Navigational systems would seem to fall in this category, but they introduce the cognitive load of the average small-screen computing application into a situation with little room for additional complexity. Current implementations raise many safety issues [19], [20]. Console-mounted devices already require the driver to avert their gaze to read the screen; the increasing use of touch screens then deprives the driver of useful haptic information for input routines [6].

3 The Solution

ARS VEHO (Augmented Reality System for VEHicle Operation and Latin for "the art of driving") is designed to function as a driver's assistant by providing a number of efficient secondary-task interfaces while minimizing potentially dangerous distractions from the primary task. Specifically, ARS VEHO addresses the problems of navigation and communication, two secondary tasks that also play important roles in supporting the driving task. From a usability perspective, ARS VEHO is designed to be both efficient and safe by minimizing driver distractions. Conventional navigational systems are extremely dependent on visuals, and current navigational systems make heavy use of console-mounted displays. These systems' high potential to distract has already been noted, particularly when such systems fail to use haptic clues in their interface [6], [19]. By contrast, ARS VEHO s primary navigational interface is a "yellow brick road" annotation on a heads-up display (HUD) [21]. The route is projected in such a way that it appears to be "painted" on the road surface. The driver need only follow the line to the destination. Although the system employs a keyboard interface to enter destinations at the outset of travel, subsequent interaction is voice-driven, where the system attempts to pose yes/no questions wherever possible. Another central component is communication and the interruptibility of the driver. ARS VEHO uses navigational information, vehicle metrics and such data sources as PIMs to estimate the driver's cognitive workload, and defers communications such as system dialogs, phone calls until such time the driver is deemed interruptible. In this sense, the system acts as a personal secretary, maximizing the situational awareness of the driver. Information from the ARS-VEHO-equipped vehicle is then distributed to other ARS VEHO-equipped vehicles to allow those systems to construct a real-time traffic model and adjust navigational choices accordingly (Figure 1).

Figure 1: Aerial map displaying ad-hoc network of ARS VEHO systems. (Courtesy of USGS).

4 Specification

To model the solution of this problem, we have applied a simplified (streamlined) software development approach. For the bulk of the specification, we have followed the style outlined in [14]. In the following, we start with a series of functional and non-functional requirements, and then present a UML use case diagram for the system (Figure 2). For illustration purposes, a use case scenario and one of its secondary scenarios (Figure 3) are presented in detail. Given the emphasis on interaction, we also include plus and minus scenarios similar to those proposed in [15].

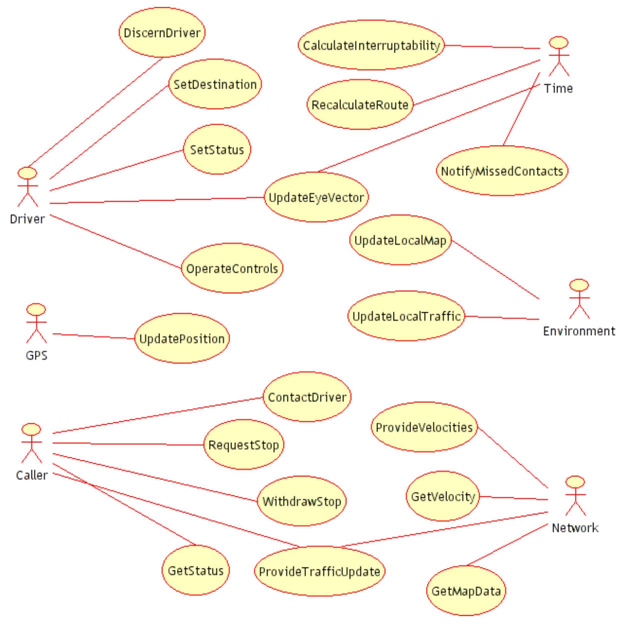

Figure 2: ARS VEHO UML use case diagram.

4.1 Functional Requirements

The main functional requirements of the system are as follows:

1. ARS VEHO shall keep track of the following in-car information: speed, compass orientation, steering, accelerator and brake input from driver.
2. ARS VEHO shall keep track of the vehicle's absolute position.
3. ARS VEHO shall plot the fastest or shortest route to a given destination, or set of destinations, entered by the Driver in order of visitation.
4. ARS VEHO shall calculate the estimated time of arrival at the next or final destination in a route.
5. ARS VEHO shall communicate the car's current velocity to a central location.
6. ARS VEHO shall send discovered road data (contours and curvature) to a central location.
7. ARS VEHO shall use the velocity information from other ARS VEHO-equipped vehicles along with other traffic information to plan and change routes.
8. ARS VEHO shall project a "yellow-brick-road" view of the current route onto a heads-up display, synchronized with the actual driver view of the road.
9. ARS VEHO shall calculate the interruptibility of the driver and use this to screen calls and status information to the driver.
10. ARS VEHO shall provide a training mode to let the driver fine-tune the interruptibility algorithm(s).
11. ARS VEHO shall allow the driver to enable or disable the interrupt screening feature at any time.
12. ARS VEHO shall allow the driver to enable or disable the navigation view at any time.
13. ARS VEHO shall allow the driver to enable to disable the entire system at any time.
14. ARS VEHO shall keep track of multiple drivers per vehicle and save different settings (interruptibility, preferences) for each driver.
15. ARS VEHO shall use audio prompts and limited-vocabulary voice recognition to initiate and respond to interactions with the driver. '
16. ARS VEHO shall screen all outside communication requests with the driver, and allow calls through only if the driver is deemed interruptible.
17. ARS VEHO shall allow selected numbers or callers to request via the Internet or phone system one or more stops along the driver's route, and attach notes for the driver regarding those stops.
18. ARS VEHO shall notify the driver of the stop request if the driver is deemed interruptible, and allow the driver to assent to or decline the request.
19. ARS VEHO shall keep track of surrounding vehicles and their distance and velocity relative to the ARS VEHO-equipped vehicle.

4.2 Nonfunctional Requirements

Several non-functional requirements for ARS VEHO have also been considered during the specification process, among them the following:

1. ARS VEHO shall project all navigational and status displays in no less than 25 frames per second.
2. The navigational "yellow brick road" view shall match the actual view of the road in real time.
3. GPS shall be used to calculate the car's absolute position.

4.3 User Scenarios

In additional to regular software engineering scenarios of the type shown in Figure 3, we have also included two user scenarios in the specification, more precisely a plus and a minus scenario. User scenarios are a relatively recent addition to the toolbox of software specification and design [15], but they can be a powerful means of both articulating the system s vision and exploring the consequences of design decisions. The plus scenario essentially presents the ideal situation and has an established historical presence in design documents and proposals. The minus scenario,

Use case: ContactDriver
ID: UC11
Actors: Caller Driver
Preconditions: 1. The Driver is in the vehicle.
Flow of events: 1. The use case begins when a Caller attempts to contact the driver over the phone. 2. The system uses the Driver's interruptibility metrics and the Caller's identity to determine whether the call should go through.. 3. The system determines the call should go through and alerts the Driver. 4. The Driver accepts the call. 5. The Caller is connected to the Driver.
Postconditions: 1. A conversation has been initiated between the Caller and Driver.

Use case: ContactDriver **Secondary Scenario: DriverBusy**
ID: UC11.1
Actors: Caller Driver
Preconditions: 1. The Driver is in the vehicle.
Flow of events: 1. The use case begins in step 2 of the use case ContactDriver when the system determines the Driver is not interruptible. 2. The system notifies the Caller that the Driver is busy and allows the Caller to leave a message. 3. The system saves the missed call information, with the optional message, in the database.
Postconditions: 1. A missed-call reminder has been saved in the database.

Figure 3: ContactDriver use case and DriverBusy secondary scenario.

on the other hand, is a useful tool for discovering potential design errors and limitations. Both present the system in a distorted and subjective form. Their relationship to the overall system description is analogous to the relationship of instances to classes.

4.3.1 Plus Scenario

The plus scenario we have created to highlight the benefits of using ARS VEHO is the following:

> Sam has to drive down to Sacramento to meet a potential client. At the same time, his firm is in the middle of a complicated installation of its product in another city. The other field engineers are not as well versed in some of the details. Luckily, Sam's ARS VEHO system is already adapted to his preferences and driving style. The other engineers call him several times as he drives down I-80. Traffic is light, so the system knows he is interruptible, and automatically mutes the car's audio system when they call. As Sam gets closer to his client's office, the "yellow brick road" navigational annotation shows up on his heads-up-display. Until now, it has been disabled because the trip followed I-80 for a long, straight stretch. The system has already modified the route Sam will take in order to avoid a potential slowdown encountered by several other ARS VEHO-equipped vehicles in the area. The system does not know whether the issue is an accident or construction delays, but since Sam is on a tight schedule it has found an alternate route. Sam is not aware of any of these details, but simply follows the yellow line on the HUD to his client's office. As Sam gets closer to his destination, he ends up on a busy street in moderate traffic. One of his colleagues attempts to call him with another question, but the system has determined that Sam's attention is probably focused on the left turn he is about to make. It sends the call to his voice mail. Five minutes later Sam parks the car, is notified of the missed call, and sends his reply via email. He is a few minutes ahead of schedule, so he has some time to review his presentation before the meeting.

4.3.2 Minus Scenario

The counterpart of the above scenario is the following minus scenario that we have designed to pinpoint potential issues with the operation of the ARS VEHO system:

> Sam is already slightly late for a meeting with a potential client in Sacramento, and is hoping to make good time down I-80. The ARS VEHO system in his car seems to be acting up and keeps popping up the navigational view in an effort to get him to leave the freeway; Sam has told it to disable the display three times, and is already getting irritated. Finally Sam sees why

the system was so keen to get him off the freeway; two tractor-trailers have collided and traffic has been reduced to one lane 10 miles down the road. Traffic has slowed to a crawl. Finally Sam decides to take the system's advice, and re-enables the "yellow brick road" display. Sam follows the yellow line down unfamiliar roads, but he is making good time. When he stops at a light, he finds he has missed three calls, including one from his supervisor. The system screened the calls even though Sam has been driving in light traffic since he left the freeway. Annoyed, Sam pulls over into a shopping center and returns the calls; by the time he gets back to the freeway he is running 15 minutes late. By the time Sam pulls into his client's parking lot, he gets another call. This time it is the client, wondering where he is. Sam had not called because he assumed ARS VEHO would have automatically updated the client with his status. But the system somehow failed to find a good time to ask him for his permission to provide the update to the client.

5 UI Design

The UI design of ARS VEHO makes the following assumptions:

- Vehicle-based interfaces and systems designed for secondary tasks (communication, navigation and entertainment) will only increase in popularity.
- Any distraction from the primary driving task is a potential hazard.
- The visual mode is overloaded, and visual-motor tasks require an unacceptable cognitive workload for the driver.
- It is possible to incorporate visual head tracking and close-proximity road mapping systems in real time.

The primary conceptual model employed by ARS VEHO is conversational: Most two-way interaction involves a dialog between the driver and the system. This supports the driver's situational awareness by placing the burden on the auditory rather than the visual mode. Further support is provided by a context-sensitive module that takes the driver's interruptibility into account. The navigational task, on the other hand, is obviously one of manipulating and navigating, with the caveat that the manipulation of the route is strictly limited to the following situations:

- By the driver, when the vehicle is stationary.
- By a remote non-driver, with the driver's explicit permission.
- By the system, in the event of a departure from the route.

Even though the navigational display involves the visual mode, it is integrated into the driver's view in such a way that it minimizes the cognitive workload. Two primary interface metaphors are employed by the system: The first is the "bread crumb" or "yellow brick road" concept, which covers the navigational task. The route to be followed is virtually "painted" on the driver's view through the windshield and eliminates the need for a cognitive transformation of the route from a 2-D to a 3-D representation. It is anticipated that this form of annotation would also outperform voice guidance, which is becoming more common in navigational systems [20]. The primary interaction mode with the system can be summed up with the "virtual secretary" idea; the system acts as a personal assistant and uses contextual information to both assist the driver and mitigate the effect of interruptions. The key elements of the system are the driver's windshield-mounted HUD and the voice-recognition module. A context-sensitive interruptibility calculator underpins all interactions with the driver, and a constant connection to the network assists the system in both communication and navigation. In addition, gaze-tracking and road-mapping cameras allow the system to project appropriate navigational views onto the HUD. We propose usability studies to determine the most appropriate choice of annotation on the HUD. The simplest method would be to make use of a virtual "string," which eliminates some of the issues of perspective (Figure 4).

Alternately a more realistic projection would simulate a painted line more closely, but it also presents problems at longer distances (Figure 5). Including a destination display would also assist the driver in understanding the route and estimating drive time (Figure 6).

Obviously this prototype makes several simplifications, most notably involving the HUD. As of yet devices covering the windshield in its entirety are not commonly available and may present a significant cost barrier. A head-mounted display could serve as an alternative, but this approach was considered too intrusive. For the sake of brevity, the design does not delve too deeply into the details of the keyboard interface and interaction with the display, but this is assumed to be the easiest human-factor problem to tackle in the design.

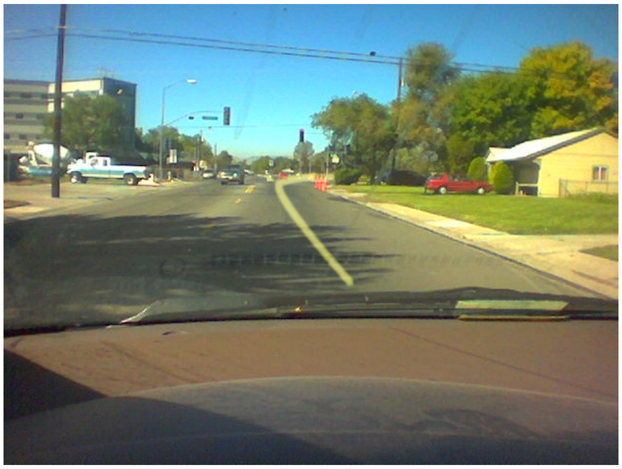

Figure 4: Simple navigational annotation with virtual "string."

Figure 5: More realistic perspective route projection.

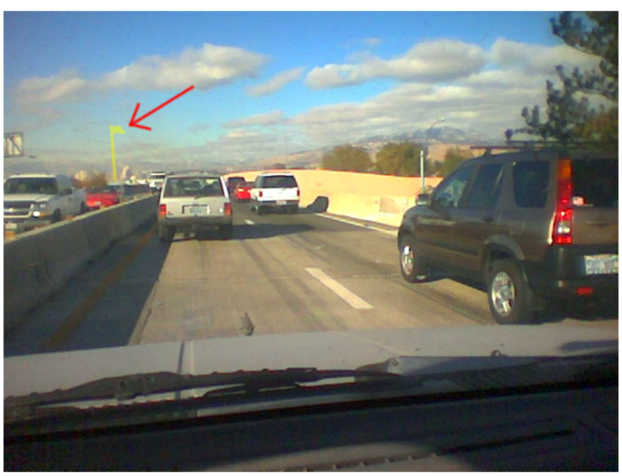

Figure 6: Navigational annotation showing destination flag.

6 Similar Approaches

Similar proposals making use of HUDs and audio interfaces already exist, notably the GM Deep Blue [9] and RIMS systems [10]. RIMS's overhead view requires a conceptual shift between two and three dimensions. GM Deep Blue uses time-sensitive visual instructions that may become ambiguous when streets are closely adjacent. Neither of these proposals integrates navigational information into an augmented-reality display. In addition, these proposals do not posit the vehicle as an extensive information producer, although the RIMS system does propose a "buddy list" networking component allowing for passenger pickup requests. We have taken a more general approach to outside interaction with the system. The data gathered by the vehicle, whether for navigational purposes or in order to gauge the interruptibility of the driver, becomes more useful when shared with similar systems in the same metropolitan area. The concept of true-perspective navigational annotation using a HUD has been proposed [11] but not as thoroughly illustrated as we have done here. GM Deep Blue suggests the "yellow-brick-road" concept advanced here as an avenue for future work. Augmented reality annotations have been suggested as one of a number of scenarios for a windshield HUD [22]. Finally, MIT, Daimler-Chrysler and Motorola have assembled a test bed for determining which sensors provide the most effective means of assessing a driver's cognitive workload [23], but as of yet have not released results.

7 Future Work

This project has started in the Department of Computer Science of the University of Nevada, Reno (UNR) as a joint work involving the resources of the Virtual Reality and Parallel and Distributed Computation Lab (VR-PAD) and the Software Engineering Lab. Although the specification and design of ARS VEHO has been largely covered, the implementation of the system is in its early stages. A dedicated website for this project is already in place [24]. Furthermore, we have looked at a number of potential development issues and future enhancement aspects, as described below. Any number of sensors might be used to determine a driver's interruptibility and the current state of the vehicle, so we suggest that a pilot Wizard of Oz study, similar to those already performed in an office environment, would be the fastest means of determining which sensors provide the most accurate predictions [25]. An in-vehicle study could take a nearly identical approach, save for the addition of a GPS sensor. The study would also have to take into account the shorter time spans and other limitations imposed by the driving task. One of the first issues to resolve for the navigational annotations would be the recognition of the road to the immediate front of the vehicle, so as to frame navigational annotations in the proper perspective, and recognize the road boundaries. This would also aid in mapping roads not appearing on the entire system's maps, and provide an additional metric for the interruptibility index. Displaying the information to the driver is another, though lesser concern. Commercially available products already exist for head, pose and gaze detection. Significant progress is being made on heads-up display units capable of the sort of navigation visualization proposed here [26]. Although the networking features would seem the simplest component, the unique demands of real-time peer-to-peer traffic reporting and distribution make for an interesting project, especially given bandwidth and other limitations in current wide-area wireless networks. Another idea would be to incorporate higher-bandwidth (but shorter-distance) technologies and assembling ad hoc wireless networks on the fly. Physical traffic would, in essence, become another medium to carry virtual traffic. We also suggest a usability study of the voice interface. While a previous study of cell-phone dialing has found that voice-driven interfaces create less of a cognitive load for short-term tasks [8], another study of simulated conversations found otherwise [27]. Research is ongoing into gesture interfaces for secondary tasks [28], but this may not eliminate the burden of carrying on a conversation with the system. Future enhancements could include a system to identify aggressively driven vehicles in the vicinity, either by using the network-supplied information from ARS VEHO-equipped vehicles, or vehicle-mounted external sensors that measure relative distance and acceleration. Aggressive and potentially dangerous vehicles could be marked as such on the HUD.

8 Conclusion

This paper has presented a specification and low-fidelity prototype for a system designed to assist a driver with the primary task. We advocate a context-sensitive and integrated approach to managing secondary-task distractions. We also suggest that the system's visual elements be limited to augmented-reality annotations of the driver's surroundings, to reduce the total cognitive workload. The data collected by the system in the course of its operation is put to further use by distributing it to surrounding vehicles in the metropolitan area. Although further research is needed for several components of the system, many of the technologies required are either commercially available or the subject of current research. Augmented-reality annotation has shown promise in an instructional setting, and instructions are at the core of a navigational system.

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