Exploring the ad hoc network requirements of an automotive Head-Up Display interface

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***Abstract*— Windshield Head-Up Displays (HUDs) have become a focal point of research in the automotive industry, bearing the promise of augmenting spatial awareness and reducing the driver's reaction time. Such systems would require the deployment of sensory equipment on the vehicle itself as well as inter-vehicle communication facilities to enable a bird's-eye view of road traffic conditions. Since the proposed communications system would have to be decentralised and spontaneous in nature, a mobile ad-hoc network (MANETs) intuitively fits the specification. This paper presents an enquiry, through simulation, into the networking requirements of implementing such a head-up display system using off-the-shelf, 802.11 wireless components. The particular HUD configuration is one we have developed and evaluated through live trials, using scenarios mirrored in the traffic simulations undertaken in this study. Initial results indicate that our HUD system may function efficiently as long as the overhead associated with route maintenance functions is kept low and the routing protocol is tweaked appropriately to provide rapid notification of link updates.**

I. Introduction

The automotive industry has long focused on providing drivers with information to aid spatial awareness and decrease response times. Concentrated efforts have targeted the dashboard (or instrument panel) present in all modern vehicles and enriched its functionality with visual and audio warning cues from proximity systems [3]. A particular area of increasing research activity has been the design and utilisation of visual cues embedded in the vehicle's windshield, which becomes in effect a head-up display (HUD). It has further been convincingly demonstrated in live trials that superimposing useful information on a fully operational HUD results in more rapid and stable driving responses compared to traditional instrument panels or head-down displays (HDDs) [2].

A HUD design mantra largely involves the presentation of new and useful information to the driver in a non-distracting manner. In order for the information to be collected in the first place, a wealth of sensors are deployed and utilised within the vehicle itself. It is, further, of great importance for neighbouring vehicles to exchange that information in a spontaneous and dynamic fashion so that information on the wider area surrounding the vehicle and affecting traffic conditions may be collected and analysed. It can be intuitively understood that connections amongst vehicles would be ephemeral and the formed network self-contained. Such settings, where autonomous nodes of some complexity wish to engage in a mutual exchange of information form the application domain of mobile ad hoc networks (MANETs) [7].

Although substantial previous research has concentrated on the design of HUD systems, the general consensus has been that such functionality would be delivered over specialised communications protocols and transceivers. In this work, we argue that off-the-shelf wireless components and existing MANET techniques could be used to support such designs, with minimal cost. To this end, we have evaluated the requirements of our own HUD design and simulated its data exchange method over MANETs. Our simulations were modelled after live trials to gauge whether the short lived MANET network among vehicles could maintain an adequate level of service for the windshield system to operate. After some parameter adjustments with regards to the routing protocol used, the results have been mostly encouraging.

The rest of the paper is organised as follows. The next section offers a brief overview of a full-windshield oriented design for a HUD system and outlines its main components. Section 3 discusses the communications requirements if any, of each HUD component in the context of MANETs. Section 4 contains a description of the simulation run performed to evaluate the effectiveness of the HUD system in a MANET environment. The simulation results indicate the suitability of a popular routing protocol in MANETs and describes some of the issues that rise from this evaluation. Finally, Section 5 outlines our conclusions and presents a tentative plan for future work.

II. The HUD system

Previous research [4] has suggested that driving is a task almost overwhelmingly visual in nature; thus, several research efforts have concentrated on exploiting visual signals to pass on useful information to the driver ([2], [5]), although other avenues, auditory and haptic, have also been explored [3]. The advantages of HUD systems compared to Head-Down Displays (HDDs) for such purposes have been well documented in the literature ([2], [5]). To avoid being distractive, the majority of existing HUD designs falls into the small projection category, which means employing little estate on the windshield (a few square centimetre's worth) and usually

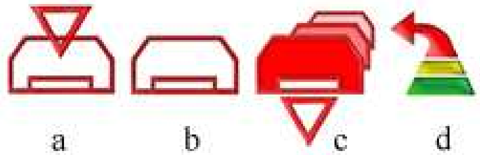

Fig. 1. Symbols used in the full-windshield HUD. Key: (a) lead vehicle on the same lane (b) lead vehicle on a different lane (c) traffic congestion in close proximity (d) road turn in close proximity

well within the driver's central field of view. Although HUDs may be utilised for the depiction of a wealth of information on a larger surface, it may be the case that the driver fails to distinguish between the artificial visuals and the real-life environment if an excessive amount of information is provided.

In this design, we have opted for a full-windshield HUD which utilises a large portion of the area viewed by the driver as opposed to the small projection form described above. Our motivation for this decision stems from research by Steinfeld et al. [5], where the full-windscreen form has been demonstrated to be a valid alternative to small HUDs with comparable performance gains compared to classic HDD instrumentation. Although we have experimented extensively with small form designs, it is unclear how such a small estate could comfortably accommodate the amount of information of traffic conditions surrounding the vehicle; it was deemed more suitable to use a full form design.

The main use case examined and intended area of application for the proposed interface is driving on a motorway in low visibility conditions, as exhibited in weather conditions such as fog, rain or by some other visual impairment factor. As in other work [1], zero visibility conditions are defined here when objects come into clear view in less than 100m distance. Similarly, low visibility conditions are set at below the 250m viewing distance mark; these can cause increased speed variance, which increases crash risk.

Towards designing the HUD display, four pieces of information were initially identified as the most vital for collision avoidance in motorways, namely lane recognition, lead vehicle detection, traffic warning and sharp turn notification. These were visually represented in the HUD design by four symbols. The symbols appear in context in Figure 1 and are described in turn below.

a) Pathway Symbol: The "pathway" display symbol is a simple composition of converging lines, superimposed on the real road lane markings. The constant presence of these aims to prevent the driver from an accidental lane departure by providing a point of reference for the car's position with respect to the road.

Additionally, the lane ("pathway") icon also serves as an obstacle warning system. This is achieved through a colour coding sequence where a green lane strip indicates absence of a vehicle (or obstacle) on that side of the vehicle (potentially including the blind spot at the rear end of the vehicle). This system can provide warning on vehicles overtaking or alert the driver on the presence of hard shoulder lanes and lane barriers.

b) Lead Vehicles Symbols: The stated goal of enhancing driving quality in low visibility conditions necessitated the addition of a leading vehicle warning system. The symbol used for this purpose is a miniature representation of a car outline. The symbol is, ideally, superimposed on the first row of leading vehicle and entails four colour states denoting distance/risk levels: $blue \rightarrow green \rightarrow yellow \rightarrow red$. Notably, it might not be possible to implement such functionality in real life situation due to technology/cost constraints. In such instances, it would suffice to rely on the pathway symbol to indicate incoming neighbouring vehicle activity at close proximity.

c) Traffic Symbol: A common cause of accidents in motorways occurs when leading vehicles rapidly decelerate perhaps as a response to traffic congestion along the road. In particular and in such circumstances traffic congestion might be a cause for alarm for an approaching vehicle other than the one directly in view of the congestion event, as a "domino" effect of slowing vehicles is due to follow and affect several links in the traffic flow chain. Traffic notification may also be useful for traffic congestion around corners or areas otherwise hidden from view (due to low visibility conditions). A traffic symbol is used in our design, representing the clustering of vehicles as a miniature of overlapping lead vehicle symbols.

d) Turn Symbols: Certain parts of the motorway, such as junctions, intersections and hairpin turns, can be particularly tricky to traverse especially under low visibility conditions. As embedding a full projected map in the driver's view span may be distracting, a turn symbol was introduced in the proposed interface in the form of an arrow. Being consistent with the other three symbols, the colour of the symbol initially appears in light blue colour and distinct stripes of green yellow and red are added as the distance to the potentially tricky road turn decreases. As expected, the arrow points in the direction of the upcoming road turn.

III. Requirements

In order to evaluate the effectiveness of the proposed HUD system, we have performed trials using participants of varying driving experience on a number of traffic scenarios. During those trials the reaction time and "correctness" of the driver's reaction to a given situation were measured. Then the test subject was asked to repeat the scenario, only this time making use of the HUD system. After the trial the participant was asked to identify the ways (if any) they felt the additional feedback was useful. A screenshot of the simulator in action is shown in Figure 2 and a depiction of the overall setup is shown in Figure 3.

A brief discussion follows on the functional requirements of each symbol included in the design as outlined in the previous section.

A. Lane Symbols

The "pathway" symbol on the HUD requires only local information to function as intended, i.e. requires data that is available to the vehicle through its own sensors. As such,

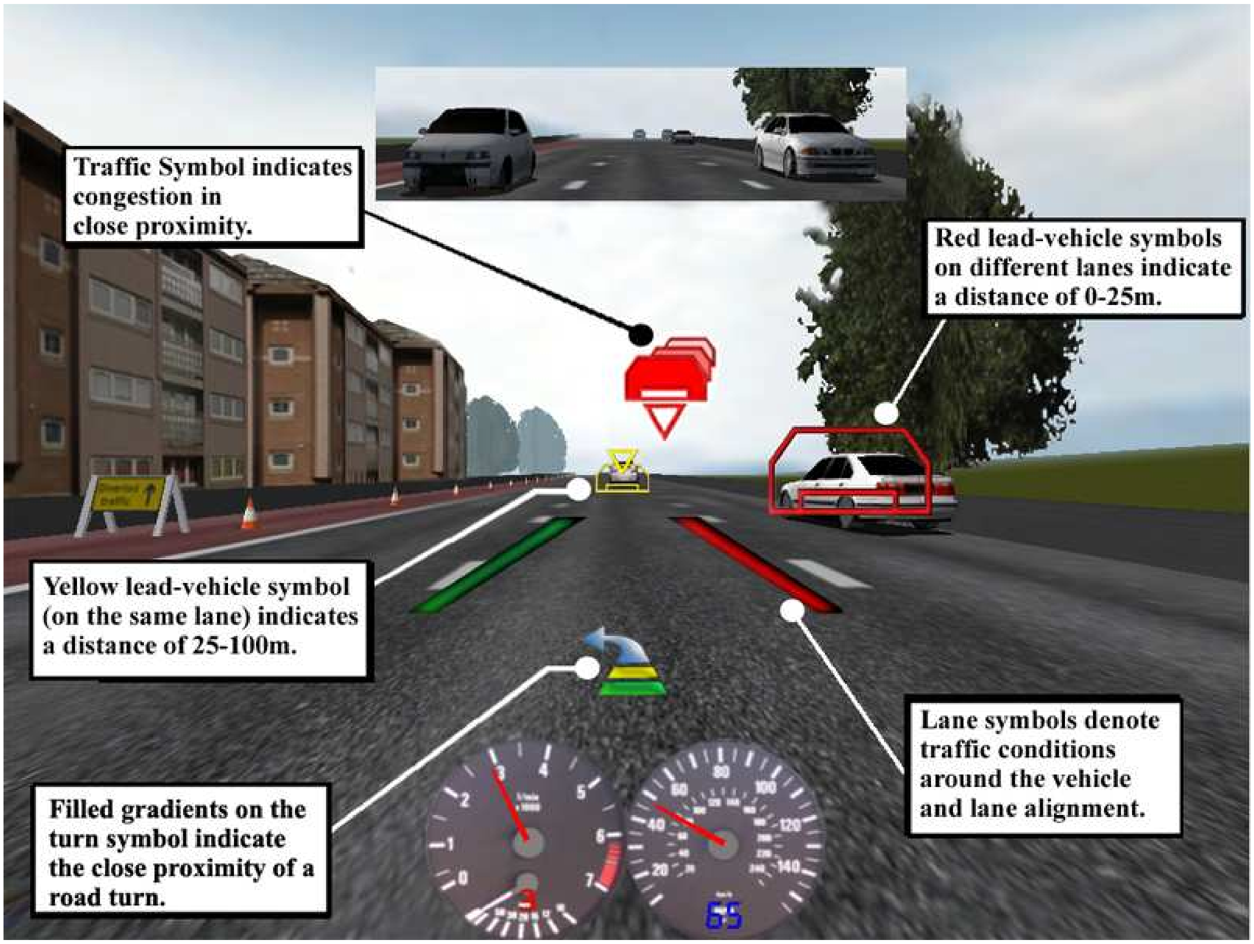

Fig. 2. Driving simulator system

there is no network component to consider. The functionality is expected to be achievable through the use of object detecting sensors in real configurations.

B. Lead Vehicles Symbols

The lead vehicle symbol implementation may be coarse or fine grained in scope depending on the vehicle's on board sensing facilities. In our trials the symbol tracks the leading vehicle's position on the windshield; however, such capability may be prohibitively expensive to implement. An alternate implementation would involve simply judging a leading vehicle's distance without regard to its position in the driver's field of view. In such an instance, the lead vehicle sign would simply be displayed at the top of the windshield. In order to determine distance, exchange of GPS information could occur between vehicles, or an estimation might be made depending on the signal strength of the on-board [8] wireless transmitter.

C. Traffic Symbol

The traffic symbol denoting congestion is the single HUD feature requiring a functioning MANET for its implementation. The main concept is intuitive; as soon as the vehicle detects other vehicles in close proximity, it assumes that congestion is imminent or is already happening. Then, it broadcasts a "congestion-awareness" packet which propagates to its n-hop neighbours. Each vehicle rebroadcasts the message as long as it has more than m-neighbouring vehicles. If it does not, then the packet is only propagated for a further two hop radius, by setting the appropriate time-to-live (TTL) field in the IP packet. Given a fixed radio transmission range of one unit per vehicle, such a scheme ensures that only up to two vehicles away from a congestion spot will be notified of such an occurrence. To avoid continuously flooding this notification there is an associated timer, set by default to 4 secs between broadcasts. The scheme is outlined in Algorithm 1. As nodes, receive the "congestion-awareness" alert, they have sufficient information to highlight the traffic symbol on the HUD, and broadcast the message in turn after updating the TTL field.

As mentioned previously a congestion event creates a domino effect of vehicles slowing down as they join the waiting "queue". The "pull" information model introduced inherently has the disadvantage of introducing a somewhat coarse granularity (4 secs in this case) in the dissemination of information to new vehicles. This is necessary to ensure that flooding does not degrade network performance significantly. A "push" model would have oncoming vehicles requesting notification of possible congestion, but introduces a dependency on the

Fig. 3. Driving simulator setup

Algorithm 1 Congestion Detection algorithm

Require: no_nb is the no. of neighbours of the vehicle, nb_thresh is the broadcast threshold (default:9), timer is a countdown timer set at every broadcast, timer_thresh is a value in secs (default:4)

```
if no_nb >= nb_thresh then
    if timer expired then
        start countdown timer with value timer_thresh
        broadcast "congestion-awareness" packet with TTL = 2
    end if
end if
```

routing protocol to provide a unicast response to the party requesting the information. We are currently investigating the implications of such a method.

D. Turn Symbols

A notification system of the proximity of a turn in the road may be realised through GPS and road mapping software, i.e. a system self-contained within the vehicle. However, such information may also become available in vehicle pairs where only one member has GPS capabilities but is willing to provide its estimate of an incoming turn, in hope that it might be useful to its neighbour.

IV. Simulation and Discussion

A. Rationale

To evaluate the viability of exchanging information pertinent to our HUD system over MANETs we have re-created through simulation one of the scenarios used in our driving experiments. To this end we have used the widely adopted ns-2 packet level simulator to simulate a MANET over the AODV [7] routing protocol. Notably, an actual, real system implementation of AODV was used [6], interfaced with the ns-2 simulator.

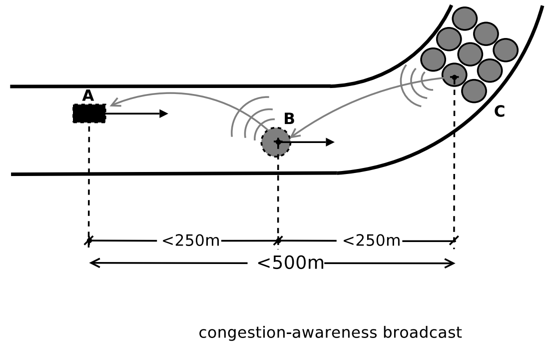

Fig. 4. Sanitised depiction of the congestion warning broadcast. The message reaches vehicle A through a retransmission by vehicle B. Note that broadcast between other vehicles in the traffic jam are not shown to aid clarity.

The scenario examined is depicted graphically in Figure 4. In short, vehicle B, approaches a congested point in the road and is notified of its existence by vehicles participating in the bottleneck (namely vehicle C). Then, it propagates the message through broadcast at a further 2-hop radius (in the manner described described in section III-D), which reaches vehicle A. The bottleneck is detected by each vehicle by sensing its one hop-neighbours through AODV HELLO packets. Note that this functionality caters to the traffic symbols; the rest of the HUD facilities can function through in-car sensors and do not require network communications.

The mechanism as described in section III-D does not require the use of a routing protocol as simply broadcasting messages would suffice. However, the AODV protocol already contains provisions for neighbourhood discovery through the exchange of HELLO packets [6] and does not present any overhead unless unicast communications is required (AODV is an "on-demand" protocol). By adopting such a routing solution we aim to cater for future needs where multicast/unicast exchanges would be needed for added functionality.

We implemented a client program running on each vehicle in the simulator which would broadcast information on the amount of surrounding vehicles if the underlying routing protocol reported a neighbourhood of over 4 vehicles. We assumed that each vehicle contained only a single wireless transceiver participating in our scheme and a unique IP address. This is not a hard requirement, however, as it would be simple to extend the AODV HELLO packets to contain identification information for each vehicle by incurring a slight overhead. The HELLO interval broadcast (i.e the neighbourhood discovery granularity) was left to 1 sec. In order for a neighbour information to be considered obsolete, two HELLO message intervals had to pass without notification. These parameters are the default ones recommended in the AODV RFC [7].

B. Discussion

The congestion-warning notification operated as expected during the simulation run. Vehicle A was notified via B on the congestion conditions at the road turn, approx. 3.3 secs after

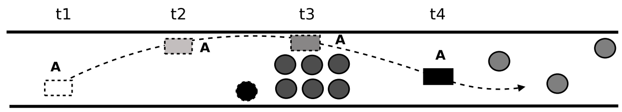

Fig. 5. Even though vehicle A has overcome the congested point at time t_4, the traffic symbol would still indicate congestion as the transceiver can still sense the other vehicles' signal. It is not immediately possible to determine the relative positioning of neighbours using 802.11 transceivers

B had been within transmission range of a vehicle in the congested traffic queue (vehicle C in Figure 4). The notification mechanism was significantly impaired by the coarse granularity of the "congestion-awareness" broadcast packet. Since this broadcast occurs every $4 * AODV\_HELLO\_INTERVAL = 4$ secs (as in Algorithm 1), there is a relatively wide time window for a vehicle to miss the notification (which is in fact what occurred in this case). We repeated the experiment by decreasing the broadcast interval to 2 secs which reduced the notification time to approx. 0.5 sec.

It is noteworthy, however, that if this "tweaked" broadcast parameter became the default, it would mandate very frequent network-wide broadcasts, which increases the possibility of packets being transmitted at the same time resulting in a scrambled signal. This could present a hindering factor in the notification's smooth operation, especially during long traffic jam queues, where multiple vehicles in close proximity of each other would attempt to continuously notify surrounding vehicles of their congestive situation. The problem of packet collisions due to mis-coordinated transmissions could also be further aggravated by the lack of a reliability-ensuring mechanism at the link layer for broadcasts in 802.11 transceivers, unlike in the case of unicast exchanges. As a consequence, congestion notifications may even be lost (or be indecipherable) under heavy vehicle traffic conditions.

A final observation for our congestion-awareness mechanism came due to an artifact introduced by the vehicle's inability to triangulate other vehicle positions using solely 802.11 derived information. GPS functionality non-withstanding, the single source of information for a vehicle on the presence of other vehicles, would be the sensing of other wireless transceivers in near vicinity (i.e. within transmission range). As such, in a situation as the one depicted in Figure 5, vehicle A would still believe itself to be in a congested state (and thus the traffic symbol would be active on the HUD), even after it had by-passed the busy point. This would occur as vehicle A would still detect a multitude of neighbours for sometime until it distanced itself sufficiently from existing traffic. Unless GPS information of adequate accuracy or directional wireless antennas are used, the problem would seem difficult to solve with a distributed algorithm. We are currently exploring other avenues in this respect.

V. Conclusions

This paper has presented an enquiry into the suitability of MANETs as the underlying network architecture for a Head-Up Display (HUD) interface. Through a simulation scenario based on an actual, live trial occurrence, we have shown that a MANET based on the AODV protocol could operate sufficiently to deliver the desired HUD functionality. However, the simulation has highlighted some potential problems stemming from the non-specialised nature of MANETs, which could be dealt with by acquiring more information through other systems (e.g. GPS).

In the future we aim to measure MANET performance in inter-vehicle communications by taking live measurements in such a system. We further plan to enhance our congestion detection algorithm by taking into account intra-vehicle readings such as current speed, or driving pattern (which could indicate driving in a city or on a motorway). Finally, it is our intention to explore further simulation scenarios with regard to the effects of signal congestion during traffic jams or other cases where many vehicles exist in close proximity of each other.

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