Personal Navi: Benefits of an Augmented Reality Navigational Aid Using a See-Thru 3D Volumetric HUD

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ABSTRACT
Augmented reality (AR) is an interface that can potentially provide more intuitive and immersive experiences, particularly for automotive applications. In this paper we present the Personal Navi, a vehicular AR navigational aid designed for use with a see-thru 3D volumetric Head Up Display (HUD). In one study, we found that the Personal Navi visuals helped participants recognize turn locations earlier than when provided with conventional navigation aids alone. The interface also helped keep users' eyes up and fixated on the driving environment more. In a second study, we tested participants' depth perception of AR visuals provided with our prototype 3D-HUD. We displayed the same visuals with a fixed focal depth display (2D-HUD) and found that for applications such as Personal Navi, where the spatial location of AR visuals are an important component of the interface, a dynamically adjustable focal plane (3D-HUD) is necessary for proper registration. We argue that AR-based HUD navigational aids should be implemented only with 3D-HUDs because of inferior depth perception with 2D-HUDs.

Author Keywords
augmented reality; navigation; vehicle; Head Up Display; depth perception

ACM Classification Keywords
H.1.2 User/Machine Systems: Human factors; H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities; H.5.2. User Interfaces: Evaluation/Methodology

INTRODUCTION
In recent years, augmented reality (AR) has become an increasingly popular interface envisioned for navigational applications. AR aims to enhance the real world by augmenting it with artificially generated visual, audio, or tactile elements. Automotive AR can potentially enhance the driver's experience by providing a new visual modality that can overlay information over the driver's field of view. The immersive nature of AR suggests these interfaces are more suitable for helping the primary task of driving (direct operation of the vehicle at various cognitive levels) rather than secondary (mandatory tasks related to driving like turn signaling) or tertiary tasks (not related to driving such as entertainment) [1]. Specifically, AR applications can provide situation awareness without needing to glance away from the windshield (for see-thru Head Up Displays), use generated computer graphics to draw the attention of the driver to important events, annotate location-based information on real-world objects in the driver's view, and unambiguously provide spatial information relevant for driver navigation and vehicle operation [1, 2].

AR Navigation
Vehicle navigation is a prime application where AR can provide benefits. In this scenario, AR can reduce the ambiguity of instructions by directly pointing out intersections and turn locations in context of what the driver sees. This benefit and the public's increasing dependency on GPS systems has resulted in the development of AR applications geared towards navigation such as iOnRoad and many others. One downside of these systems is that the AR visuals are overlaid on a separate camera feed of the visual scene rather than the scene itself so users are still forced to look at an alternate display, such as their smartphone, to experience the augmented reality which can cause driver inattention or distraction.

To address the issue of inattention, other Automotive AR makes use of see-thru Head Up Displays (HUDs). Although there are still technical hurdles to overcome before AR-HUDs are widely adopted, researchers have begun to explore the usability and effectiveness of these interfaces over conventional display systems. Using a simulated windshield navigation system, Kim and Dey [3] found that driver's were able to reduce navigational errors and distraction measures by reducing the cognitive load of needing to switch between the real view and a different map viewpoint. In Frohlich et al. [4], driving simulation studies showed that in urgent situations, drivers preferred direct augmented views over conventional map views. This was also observed in a comparison study between head-up display (HUD) and head-down display (HDD) for a simulation experiment with commercial vehicles in Taiwan [5]. In particular, drivers in the HUD configuration had faster response times in response to urgent events, more consistent speed control and less mental stress than the HDD configuration. Medenica et al. [6] found in simulation that drivers were able to look at the road more often, drive with better steering and lane positions than alternative map-based displays or AR on secondary video displays.

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AR Navigation Visual Designs

As a new visual modality, methods of providing AR navigation information are under explored. Currently, the majority of AR navigation interfaces displays a highlighted path or arrow overlaid directly on the road in front of the driver [3, 4, 7–10]. Although this design provides intuitive correspondence between the AR visuals and the environment, one potential drawback of this visual aid is that if another object or vehicle is in front of the driver, the object occludes the path or the path is overlaid on top of the object, creating a confusing graphic for the driver. To address this issue, another commonly employed visual design is to draw the highlighted path in the sky, where the path is less likely to interfere with other objects in the driver's view [6, 7, 11]. In their observations, Medenica et al. [6] state that one potential drawback of this visual is that it may be distracting to have the path highlighted in a driver's peripheral view at all times. They also note that most AR navigation designs do not provide a global overview of the route and only provides information about what the driver should be doing at that particular instant. Kim et al. [3] uses an interesting hybrid design that combines the path on the road and a global top down view map in the sky, though it may also be distracting. MVS [12] and Pioneer [13] provide road directions in the upper portions of the driver's field of view, removing potential problems with augmented graphics obstructing actual cars or pedestrians on the road. Drawing graphics against a sky backdrop can potentially reduce background clutter as well.

Display Perceptual Issues

The advantages of a HUD over a HDD have been well documented, showing that users are able to keep their gaze on the road longer, leading to faster reaction times, improved driving or task performance, and less mental stress [5,6,14,15]. Currently, HUDs are more prolific in luxury brand vehicles (e.g. BMW, Audi, Mercedes, Cadillac, Lexus), but advancements in display technologies are allowing HUDs to appear in mid-range vehicles. HUDWAY and Sygic are smartphone navigation apps that simulate HUDs by reflecting their screen on the windshield. In addition, several secondary add-on or wearable HUDs have become commercially available (Garmin, Pioneer, Google Glass). Although these HUDs provide the advantages of keeping a driver's eye gaze near the forward scene, the visuals are not truly augmenting the environment. One reason is that the majority of these HUDs have a relatively small field of view and can only display images occupying the lower portion of the windshield viewing area, which makes direct augmentation of the environment difficult.

A more important characteristic of these HUDs are that they project images at a fixed distance in front of the driver's eye (typically around 3 meters). However, the absence of proper depth perception and focal distance is a safety issue that has been overlooked [1, 16, 17]. To properly conceive and design automotive applications using AR, it is important to review the research performed so far on the driver's perception with these interfaces. Fixing the distance of the images results in the omission of consistent depth perception cues, which can lead to discomfort and focus issues [18]. The fixed HUD distance may also affect the accommodation and perception of actual objects while driving [16, 19, 20]. In essence, these types of HUDs require the driver to shift their focus from the virtual image to the real world scenery, which is often at a different focal distance from the image. In an experiment where virtual text was presented at far distances, Gupta [20] reported that the text appeared more blurry to users as the experiment progressed. She conjectures that the blurry vision was a result of eye strain due to the repeated need of the eyes to converge and accommodate. One reason these perceptual issues are often overlooked in research is that most automotive AR systems are studied using driving simulators, where the road environment is a 2D projection on a monitor or large screen and depth cues are not required or present. Therefore, issues in accommodation or focus switching have gone unnoticed. Volumetric 3D HUDs that are capable of generating images at dynamically changing focal planes can eliminate some of these perceptual issues but the availability of volumetric 3D HUDs is very limited.

In addition, the perceptual issues related to viewing AR against a moving, real world backdrop (which describes normal driving conditions) are relatively unknown. Most automotive AR has been tested indoors due to technological and safety constraints; however, Livingston et al. [21] performed AR depth perception experiments both indoors and outdoors and found that outdoors, users tended to overestimate depth, while indoors the effects were the opposite. Tonnis [10] also found that when driving at faster speeds (in simulation), the perceived distance of AR visuals worsened. The increase in speed resulted in faster pixel changes, which affected the user's ability to perceive the AR visuals. These perceptual issues must not be overlooked when designing automotive AR systems and interfaces.

To address some of these perceptual issues, we have built a prototype volumetric HUD that allows us to generate images using movable focal planes from 5 m to infinity and a 20 degree field of view. The ability to project images at accurate focal distances from the user's eyes allows for proper motion parallax cues without the use of head or eye tracking, and the prototype allows us to register virtual images to the real world, reducing visual fatigue. In this prototype, the eye box is located 60-80 cm from the windshield, and is approximately 150 cm in width. Using this system, we designed Personal Navi, an AR navigational aid that helps drivers recognize where to turn quickly and accurately. In this paper, we demonstrate the promise of our design. In a separate perceptual study, we also provide evidence that HUD based AR navigational aids require a 3D display because users are unable to register images with a traditional 2D HUD at the proper distances.

3D AR NAVIGATION INTERFACE DESIGN

The main purpose of a navigation system is to provide instructions on how to get from one point to another. With the parameters of our 3D-volumetric HUD, we designed an interface aimed at helping drivers recognize where to turn earlier and with greater confidence.

In early prototypes, our visual designs resembled the paths on the road or in the sky, much like [4, 6–11], However, we

Figure 1. Personal Navi visual interface. A virtual paper airplane is shown as a navigation guide and a series of virtual planes show the desired path.

observed that the paths, whether they were on the ground or in the sky, drew too much attention to the spatial area directly in front of the driver, and users tended to stare at the visuals. This tendency was also noted in [6]. To avoid the dangers of inattentional blindness and based on prior navigation design findings [4, 6, 22], we developed a set of guidelines to drive our design.

- Show where to turn using a perspective view.
- Provide advanced notice about the turns or upcoming instructions.
- Only provide visual information when it is needed.
- Do not occlude the driver's view.

With these rules in mind, we present the current design (Fig. 1). To keep the AR interface simple, we decided that more complex visuals such as an overview map, should remain on a secondary display. Audio instructions were not the focus of our design efforts, so we assumed that standard audio instructions would be provided as well.

In order to avoid occluding the driver's view and avoid having the visuals interfere with other objects in the environment, we chose to keep the AR visuals in the sky domain rather than highlighting the road directly. The idea of providing a guidance avatar for a driver to follow was conceived to provide some playfulness in the design. Because the visuals appeared in the sky, a paper airplane was chosen as a simple, intuitive, model to act as the avatar. To show the driver where to turn, maneuver, or exit, we show a desired path in the sky with a series of airplanes that fly out ahead of the driver (Fig. 1). If the driver is simply going straight or following the road, no AR visuals are present. Only when a maneuver is impending, do the AR visuals appear. A typical sequence of events is as follows:

- As the driver approaches a turn, the audio instructions provide the earliest warning (*"in a quarter mile, turn right"*).
- Simultaneously, a paper airplane avatar appears in the sky, which represents the heading of the driver.
- As the driver approaches the turn, approximately 200-300ft from the turn, a series of "future planes" fly out ahead of the driver to the location of the turn, providing an attention grabbing cue that the location of the impending maneuver is near.
- As the driver continues, the future planes are more visible and the driver's goal is to have their avatar match the heading of the ghost planes to complete the turn.

We found that this sequence prepared users for an impending maneuver and helped the driver locate where they needed to go. A key distinction between this AR interface and arrows that appear on conventional HUD's is that the virtual airplanes are spatially co-located with the real environment. GPS tracking and localization of 3D geometric elements surrounding the vehicle are required to accurately place the airplanes at correct focal depths ahead of the driver and provide occlusion cues. This AR can potentially help reduce distraction by drawing the driver's attention further ahead to where they need to go, rather than having the driver focus on an arrow projected at a focal plane close up and then transferring their visual attention ahead at the road. A video demonstrating these visuals can be found here: bender.honda-ri.com/personalnavi.

INTERFACE DESIGN EVALUATION

To characterize the effectiveness of the Personal Navi interface, we completed a short study comparing how early participants recognized where to turn using a traditional navigation system and a navigation system with our augmented visuals. We hypothesized that the Personal Navi would help users recognize where to turn earlier and help keep their eyes on the road.

Methods

In order to evaluate the interface, participants viewed short video clips of recorded navigation scenarios. To generate the videos, we drove a vehicle along a pre-determined route and simultaneously recorded the driver's field of view and the in-vehicle navigation system audio and secondary map display with cameras mounted inside the cabin. The recordings were synchronized and split into short intervals that captured specific navigational instructions. The clip lengths varied due to the different traffic situations. To simulate the AR visuals, a graphical overlay adhering to occlusion and perspective cues was manually added to the video clips in post-processing. We chose to simulate the driving experience using video recordings due to the realism of the scenarios and visuals. It was important for this study to see how participants would respond to seeing AR visuals against a real-world backdrop (Fig. 4). Two visual conditions were tested (AR HUD and No HUD). The No HUD condition contained only the traditional navigation interface which was comprised of audio instructions and a secondary map overview of the desired route. The AR HUD condition contained the same traditional instructions but also included simulated AR graphics (Fig. 1). The only difference between the two conditions was the presence or lack of AR visuals.

During the experiment, participants were seated in a car seat positioned approximately 80 cm from a large LCD screen. The video clips were scaled to approximate real-life proportions as closely as possible on the screen. A separate 7 inch screen was placed near the bottom right corner of the larger LCD to display the secondary map view. Audio navigation instructions were played over speakers. During the study, participants were also asked to wear a set of SMI Eye Tracking Glasses (ETG) to record their eye gaze. This setup can be seen in Fig. 2.

Figure 2. Experiment test setup. Participants were seated in front of a large display with a smaller display showing the navigation maps.

Nine experienced drivers completed the study (2 females, 7 males). Ages ranged from 27 to 45, with an average age of 34.2 ± 7.3. Each participant was asked to view a total of 8 different video clips. For this within subjects study, the video clips were split into two groups (A and B) to where each group contained a set of four navigation scenarios. Group A clips were comprised of: 2 left turns, 1 slight right, and 1 exit off the highway (Clip Nos. 1-4 respectively). Group B contained: 1 right turn, 1 slight right, 1 left turn, and 1 exit off the highway (Clip Nos. 5-8 respectively). Participants viewed clips in either A or B paired with one of the visual conditions (AR HUD or No HUD), and then viewed the remaining group paired with the other condition. The conditions and pairings were counter-balanced to reduce biases due to presentation order and clip type. It total, four of the nine subjects were presented with the Group A-AR HUD and Group B-No HUD pairing and the remaining subjects were presented with the opposite pairings.

Prior to the data recording, participants viewed a sample clip of a driving scene to help situate them with the setup and to explain the task. One practice clip was then shown under both visual conditions to demonstrate the AR interface and make sure the participants understood the task. After completing the practice, the experiment began.

Experiment

Because we hypothesized that the AR HUD interface would help drivers know where to turn earlier, we recorded the time at which participants recognized what the navigation system was instructing them to do. As the video clips played, participants were asked to observe the scenario, interpret the audio/visual navigational instructions, and to press a key on a portable keypad to pause the video when they knew where the navigation system was taking them. When the video was paused, the experimenter asked the participant to describe or indicate visually where the navigation instruction was referring to. The experimenter recorded whether the response was correct or incorrect as well as the time at which the participant pushed the key. The experimenter did not inform the participants if their answer was correct. Participants were instructed to continue watching the video and stop the video again if they changed their mind about the instructed path. It is important to note that in each of the video clips, the vehicle did not complete the desired maneuver (e.g. if the instruction was to turn left, the vehicle in the video did not complete the left turn). This was done so that participants could not deduce the navigation instructions from the heading of the vehicle. After the videos in one visual condition were shown, the videos in the remaining condition were presented.

Participants then completed a qualitative survey to record their opinions on the effectiveness of the AR HUD visual interface. The qualitative survey consisted of a series of statements listed below which were rated on a Likert scale ranging from 1 to 7, where 1= strongly disagree and 7=strongly agree. We also asked participants to provide their ideal combination of feedback modalities (AR HUD, secondary display, audio) for a navigation system. General comments and observations were also recorded.

- *I liked the AR HUD concept.*
- *The AR HUD helped me navigate better than using traditional methods.*
- *The airplanes obstructed my view in a negative way.*
- *The AR HUD was distracting and would negatively impact my driving.*
- *I think the AR HUD would increase my cognitive load while driving.*
- *The AR HUD would make me a more cautious/safer driver.*
- *The AR HUD was easy to see and understand.*
- *I felt more confident about knowing where to turn with the AR HUD.*
- *If I had an AR HUD navigation system in my car, I would use it.*

Results

Results were analyzed and compared using a two-way analysis of variance (ANOVA), with two main factors (video clip, visual interface). We use $\alpha = 0.05$ to determine significance. Average values are reported with standard deviation when appropriate.

Time to Recognize Turn

The main variable of interest was the time at which participants recognized where to turn/exit. When examining the average recognition times for the different video clips, we observe that for 5 of the 8 video clips, participants recognized where to turn earlier with the AR HUD interface. Of these five situations, the difference in recognition time was 3.2 ± 1.8 seconds, a considerable amount of distance and advance warning for drivers to make decisions. A summary of the results is provided in Fig. 3. Statistically, visual interface was found to have a significant main effect on the time at which participants recognized where to turn ($p=0.001$, $F(1,56) = 11.93$, $\eta^2 = 0.18$). A significant interaction between the clip and visual interface was also found ($p<0.04$, $F(7,56)$

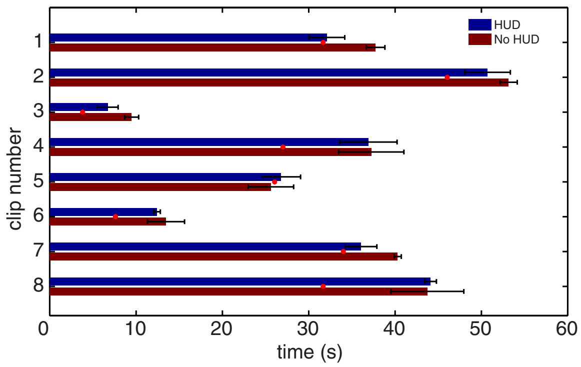

Figure 3. Average time at which participants recognized where to turn for all driving clips. Shorter bars indicate that the participants recognized where to turn earlier. The red dots represent the time at which the virtual airplanes appeared for the AR HUD condition.

Figure 4. Sample screen shots of scenarios were the AR HUD did not improve recognition time: (a) highway scenario where exit is hidden behind overpass and (b) large intersection where the traffic lights helped users recognize where to turn.

= 2.34, η^2 = 0.23), indicating that the effects of the AR HUD visuals varied by clip.

Indeed, clips 4 and 8 showed little difference between the AR HUD and No HUD conditions. The scenario for both these clips was to exit off a highway. Upon further inspection, we noticed that the exits were located behind an overpass for both clips (see Fig. 4a), meaning that the exits were difficult to see. The virtual airplanes in the AR HUD condition were also hidden behind the overpass because users were confused in earlier iterations when the planes were not properly occluded. Occlusion has been known to be a dominant cue for depth [23], but occluding the planes to reduce confusion resulted in participants waiting until the hidden exit was visible before pressing the key, negating any benefits of the AR visuals. It is possible that a difference in recognition time would be seen when the exit is more visible or if the exit location was more easily indicated using other visual methods.

The scenario (Clip 5) in which participants were able to recognize where to turn earlier without the AR HUD interface was a right turn at a heavy intersection. Several aspects of this scenario likely contributed to the result. As seen in Fig. 3, users in the No HUD condition were able to recognize where the turn happened at a time before the virtual planes appeared (indicated by a red dot) in the AR HUD condition. Participants in the No HUD condition described the location of the turn by referring to the large traffic lights and cross traffic that were visible early on (Fig. 4b). In addition, the participant could note that there was only one large upcoming intersection from the secondary map and deduce that the instructions referred to the only visible intersection. It is possible that if the virtual planes appeared earlier in the AR HUD interface, the results would have differed. In addition, it points to the possibility of using other artifacts in the environment, such as traffic lights or signs, to help the driver interpret where to turn. The timing at which the virtual planes in the AR HUD interface appear is an important factor to consider in the system.

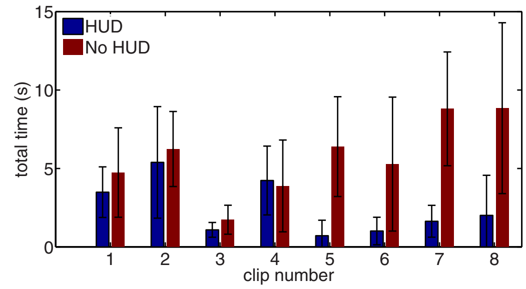

Figure 5. Average total time participants spent fixated on the secondary display for the various video clips with and without the AR HUD interface.

Overall, the video clips in which there was a bigger difference between the two conditions were when no clear street signs were visible, or when the roadways were slightly hidden from normal view. Additional work to study busier and more urban intersections should be explored.

Eye gaze

Prior research has shown that one of the major benefits of a HUD is that time drivers spend with their eyes on the road ahead is increased with a HUD as compared to a Head Down Display (HDD) [6,15,24]. Although improved eye gaze alone does not reduce distraction completely, [6,15,24] also demonstrate performance benefits related to increased on road eye gaze. We sought to verify that our AR HUD interface resulted in similar gaze trends as a preliminary analysis.

Fixation eye gaze data from 8 of the 9 subjects was analyzed. One subject's data was removed because the subject forgot the secondary display was present but did not recall for which condition. Due to the uncertainty, their data was not included in the analysis. Overall, the number of fixations on the secondary display were reduced with the presence of the AR HUD interface. On average, participants fixated on the secondary display 12 ± 10.5 more times when the AR HUD interface was not provided. The overall time spent looking at the secondary display was also less with the AR HUD compared with the No HUD condition (Fig. 5). The time spent fixated on the secondary display was on average 3.3 ± 3.0 seconds more when the AR HUD was not visible. The visual condition was found to have a significant main effect on the number of fixations at the secondary display (p=0.002, F(1,48) = 28.55, η^2 = 0.37). A significant interaction between the clip and visual interface was found (p$<$0.02, F(7,48) = 2.76, η^2 = 0.28). It is not clear why the AR HUD did not help reduce the fixation durations for Clip 4 (exiting a highway).

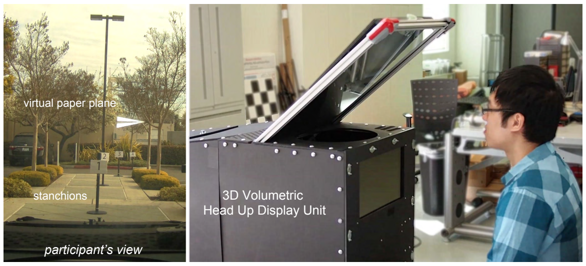

Figure 6. 2D-3D Experiment test setup. Four stanchions are placed at varying depths and the participant is seated behind the 3D HUD for viewing.

Survey Results
The average ratings of all nine participants was calculated. Overall participants rated the AR HUD display favorably (6.3 ± 0.70), indicating that they liked the concept. They thought it was effective at providing instructions (6.1 ± 0.93), increased their confidence in knowing where to turn (6.2 ± 0.97), easy to see and understand (6.6 ± 0.53), and was a system they would use (6.3 ± 1.0). Participants were neutral (4.3 ± 1.5) on whether or not the AR HUD would make them more cautious and if the system would increase their cognitive load (3.8 ± 1.6). They disagreed slightly with the statements that the AR HUD obstructed their view negatively (2.6 ± 0.73) or was distracting (2.6 ± 1.4).

In addition, participants were asked if they had an option between having audio, a secondary map display, and AR HUD for a navigation system, which combination of feedback modalities would be preferred. All participants stated they would prefer to have the AR HUD. 7 preferred to have all three modalities, while the remaining 2 participants preferred to have either audio and AR HUD or secondary map and AR HUD. The secondary display and audio cues can provide long-term high level planning while immediate short-term direct cues are provided by the AR HUD, and we speculate that users desire both types of cuing for navigation.

DEPTH PERCEPTION EVALUATION
Although the previous video-based experiment demonstrated the utility of the Personal Navi design, it was limited to displaying a 2D visual overlay on a video recording. The Personal Navi system is intended for use in the real world which requires the overlay of graphics on a 3D environment. An important component of the system design is the ability of drivers to correlate the AR visuals to spatial locations ahead of the driver. We hypothesize that this co-located relationship between the environment and visuals contribute to the intuitiveness and effectiveness of the Personal Navi design. As a preliminary step towards implementation, we determined if users would be capable of perceiving the location of the virtual airplanes accurately using our see thru 3D HUD. We also presented the same visuals simulating a standard 2D HUD to determine if it could also be used to implement the Personal Navi system.

Setup
In this study, we use our stationary 3D HUD prototype to augment the real world with a virtual paper airplane in the sky, as would happen with the Personal Navi interface. We ask participants to indicate where in the real world environment they believe the airplane is hovering over. To generate the visuals, we used a 3D combiner-HUD prototype with a dynamic range of focal depths (Fig. 6).

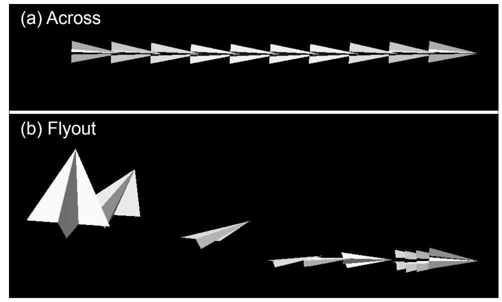

Figure 7. Sample image of the graphics viewed from the participant's point of view. Paper airplane graphics are overlaid against real-world environment.

Four stanchions (labeled 1, 2, 3, 4) were placed outdoors at distances of 9, 14, 18.7, and 26 meters from the user (Fig. 6). The stanchions were staggered so that the participants could easily read the numerical labels. The 3D HUD prototype was positioned so that the graphics would be overlaid against the outdoor backdrop (Fig. 6).

Methods
A total of four conditions were tested. Two different visual conditions and two different animations.

Visual Conditions
We tested participants' ability to judge the location of the virtual airplanes using both a 2D and 3D HUD. To simulate the 2D HUD system, we fixed the focal plane of our 3D HUD at 9 m, so that the images appeared over the first stanchion. In the 3D condition, the focal plane was allowed to move dynamically to the appropriate depths. In both visual conditions, the size, perspective, and lighting of the visuals were consistent with a simulated 3D graphical environment and the graphics presented in each condition were identical. The only difference was the changing focal plane.

Animations
Because apparent motion of virtual objects can help provide depth cues, we showed each participant two types of animations. First a simple animation in which a paper airplane appeared on the left side of the viewing area and flew across the scene in a straight line (Across), in which case there was no additional apparent motion cues (Fig. 7a). A second animation showed the plane flying out into the environment and changing depth (Flyout) before banking right over a desired stanchion (Fig. 7b). The virtual plane was clearly visible throughout it's trajectory, unobstructed by the stanchion or other objects.

Experiment
Participants were asked to watch the animations and indicate which stanchion they believed the virtual airplane was hovering closest to. The animation and visual conditions were paired to create four different test groups (2D-Across, 3D-Across, 2D-Flyout, 3D-Flyout). Within each group, participants were shown animations of the airplane flying over each

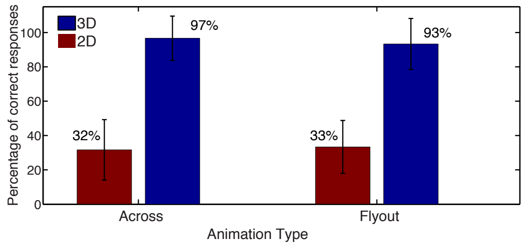

Figure 8. Percent of correct responses for the various conditions

of the four stanchions, for a total of sixteen trials. The order in which the airplanes flew over the stanchions was randomized within each test group. Each subject experienced all four groups. The orders in which the visual conditions were presented were counterbalanced to reduce order biases but the Across animations were shown prior to the Flyout animations. After each trial, the experimenter recorded the participant's response. No practice trials were conducted and participants were not provided any information about the animations they would be seeing prior to the experiment. Qualitative observations and comments were also recorded. A video demonstrating the experiment and conditions can be found at bender.honda-ri.com/personalnavi.

Results

Data from 15 participants was collected (3 females, 12 males). Participant ages ranged from 27 to 50 with an average age of 35.3 ± 8.4. To analyze the participants ability to perceive the location of the virtual airplanes, we determined the percent of correct responses for the various conditions. Results were analyzed and compared using a repeated measures analysis of variance (ANOVA), with two main factors (visual condition, animation type). We use $\alpha = 0.05$ to determine significance unless noted otherwise. Average values are reported with standard deviation when appropriate.

The overall results are shown in Fig. 8, where it is clear that participants were able to perceive the location of the airplane with much greater accuracy using the 3D HUD as compared to the 2D HUD. The visual condition (2D vs. 3D) was found to have a significant main effect ($p < 7e^{-10}$, F(1,14)=218.75, η^2 = 0.94) and the animation type (Across vs. Flyout) did not have a significant effect. No significant interactions were found.

When we examine the breakdown of correct responses according to the different stanchions (Fig. 9), it is clear that the bulk of correct responses under the 2D condition occurred when the airplane flew over Stanchion 1. This is not surprising since the focal depth for the 2D condition was placed at Stanchion 1. However, this breakdown highlights the inability of participants to perceive depth of images in a 2D HUD.

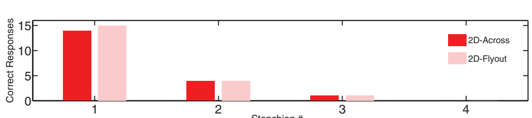

Figure 9. Distribution of correct responses according to Stanchion Number (depth) for both all conditions

For the Across, and 2D condition, several participants commented that although the size of the airplane appeared to be smaller, the airplane itself did not seem to be flying further out. The Flyout animation further confounded participants. They stated that due to the initial outward motion of the trajectory, they anticipated that the airplane would end up hovering over one of the Stanchions further away, yet when the airplane finished the trajectory it somehow appeared back at Stanchion 1. Though the motion cues provided some cognition of depth, the focal depth cues override size and perspective cues at the distances tested here.

CONCLUSIONS AND FUTURE WORK

In the first study, we found that the Personal Navi shows promise in helping drivers recognize where to turn. Although the results varied according to the scenarios, in general participants were able to pinpoint turn locations earlier with the AR visuals. They were able to keep their eyes up ahead for a greater amount of time, potentially increasing the likelihood of detecting other hazards while driving, and they found the interface intuitive and non-intrusive. The design of the interface can be improved to take advantage of environmental landmarks such as traffic lights, signs, or overpasses. The second study showed preliminary steps taken to implement Personal Navi 3D using our see-thru volumetric 3D HUD. The lack of depth perception with a fixed distance 2D HUD is clear and AR interfaces such as the Personal Navi will not be effective without a 3D HUD. In fact, a 2D HUD can be quite dangerous and these perceptual issues must be considered in automotive AR.

Future plans include ecological implementation and testing of the Personal Navi interface. The increased outdoor stimuli and cognitive load present during real world driving may affect a driver's ability to use the Personal Navi. Motion cues from driving may actually enhance depth perception by offering strong motion parallax cues; however, latency in AR graphics and asynchrony between the visuals and the moving environment may cause perceptual issues not seen in these preliminary studies. Future studies can also demonstrate driving performance benefits of the HUD Furthermore, perception of the visuals at greater depth distances will be tested. We will also optimize when the virtual airplanes appear, and enhance their saliency by varying sizes and colors. We look forward to testing the interface in a more realistic setting to fully demonstrate the effectiveness of our system.

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