Towards Augmented Reality Navigation Using Affordable Technology

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ABSTRACT

Augmented reality (AR) navigation systems are likely to improve the driving experience compared to today's personal navigation devices on the dashboard, as they don't require glances away from the road ahead. As technology is not yet capable to deliver an affordable and seamless HUD AR solution, we explore an inexpensive version of augmentation, which would have a similar benefit of reduced distraction. We propose using an LED (light emitting diode) matrix in the periphery of the driver's vision to indicate turns on the road. We find that such a system produces better results in visual attention, driving performance and in subjective measures compared to standard navigation devices.

Categories and Subject Descriptors

H.5.2 [Information Interf. And Presentation]: User Interfaces.

General Terms

Algorithms, Measurement, Experimentation, Human Factors.

Keywords

Driving Simulator, Navigation Aids, Driving Performance.

1. INTRODUCTION

Unless cars drive themselves, there will be a continued need for in-car personal navigation devices (PNDs) in the future. Most of today's commercially available solutions display a map on a screen either in the dashboard of the vehicle or on top of it. The problem is that these systems introduce visual distraction: the drivers have to point their gaze towards the screen to acquire navigation information. In order to reduce glances away from the road, it would be beneficial to have the navigation cues integrated in the observed world using augmented reality (AR). However, such head-up display (HUD) AR is not yet affordable for a commercial in-vehicle navigation product. Therefore, in this study we explore a simple system that could provide a low-cost navigational aid, which mimics AR. This system is a matrix of LEDs on top of the windshield that provides turn-by-turn directions. We will explore this system by comparing it to a standard PND (SPND), which uses a head-down display to present directions on a 2D map of the world. We propose three hypotheses:

(H1) The LED navigation system will allow drivers to spend more time looking at the outside world than the SPND.

(H2) The LED navigation system will allow better driving performance than the standard PND.

(H3) Users will prefer the LED navigation system over the SPND.

2. BACKGROUND

Augmented reality HUD navigation devices show a navigation route directly on the windshield of the vehicle. These devices hold the promise of a less distracting driving environment. Steinfeld et al. [8] showed that AR HUD in-car displays shorten the reaction time to sudden events which is crucial in avoiding accidents. In a driving simulator experiment Liu [6] confirmed that drivers react faster to accidental events when using HUD, both for a higher and lower level of workload. Horrey et al. [3] compared HUD systems to using head-down displays (HDD). They found that HDD decreased driving performance, i.e. drivers reacted slower to unexpected events compared to HUDs. They concluded that the lack of focal vision on the road ahead is responsible for slower reactions. Medenica et al. [7] compared a simulated AR navigation device to a HDD Google StreetView-like navigation device and a standard map-based HDD. They found that HDD caused the drivers to divert their gazes from the road ahead significantly more than for HUD. Cross-correlation analysis showed that the increased number of glances away from the road when using HDD caused deterioration in driving performance.

What can be said about different implementations of AR for in-vehicle services? Kim and Dey [4] presented a simulated HUD AR system which could benefit the elderly. In their solution both the immediate directions and a section of the upcoming road map was displayed on the windshield. They reported a reduction in navigation errors compared to a head-down map-based navigation system. Tangmanee and Teeravarunyou [9] explored how the position and shape of graphical elements of a HUD AR system influence driver attention. Subjects in a simulator-based experiment paid more attention to guiding arrows located close to the middle of the screen than ones further to the side.

While the above results are encouraging for HUD AR, this technology is not yet available in cars. Instead, elements of AR navigation are available. In a road study Fröhlich et al. [1] investigated the presentation of real-time telematics services using three modalities, including HDD AR. Results indicated that participants valued the AR visual display. Commercially a HDD AR solution for smartphones is the Wikitude Drive app [12], which overlays a simulated navigation route on the image acquired from the phone's camera. This technology, displayed on a dashboard-mounted screen still suffers from the need to divert one's gaze away from the road. Another, less sophisticated solution for guiding drivers are so-called light-bar guidance systems used in agricultural vehicles such as tractors, e.g. GreenStar Lightbar by John Deere [2]. This is essentially a row of
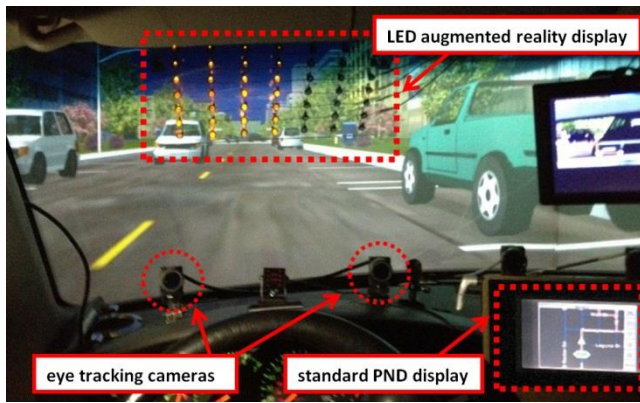
Figure 1. Locations of devices in the simulator cab.

LED lights directing the operator of the vehicle in such a way that ensures full coverage of an agricultural field, row by row. Our solution presented below is similar to these low-tech AR devices, but instead of a row of lights we present a matrix of LEDs. The space between these lights is transparent, i.e. the world is visible through the matrix.

3. EXPERIMENT

Subjects drove in our driving simulator in a city scenario while receiving driving directions from two different navigation aids. Our experiment used the same equipment, and very similar methods, as our prior experiments described in [5] and [7].

3.1 Equipment

The experiment was performed in a high-fidelity driving simulator with a 180° field of view screen and a full-width automobile cab. The cab sits on top of a motion base which simulates car movements for braking and accelerating as well as bumps on the road. As shown in Figure 1, the simulator was equipped with an eye-tracker which tracks subjects' gaze and head position using a pair of cameras mounted on the dashboard. Figure 1 also shows the location of the in-car LCD screen which was used as the display for the standard PND, and the LED matrix used as the AR device.

3.2 Method

3.2.1 Participants

Fifteen university students participated in the experiment. We excluded data for five of them, because they either could not finish the experiment due to feeling simulator sickness or they could not master operating the driving simulator. The ten remaining participants were between 18 and 22 years of age (mean age 20.1 years, standard deviation 1.37 years). As compensation, each received a $20 gift card to an online store.

3.2.2 Navigation Aids

Each participant performed navigation with both of the following personal navigation devices:

1. LED Augmented Reality PND (LED PND). The LEDs were mounted in 8 rows and 7 columns on a sheet of transparent plastic approximately 28cm x 15cm in size, see Figure 1. They were remotely controlled by an experimenter seated behind the simulator, see Figure 2. The experimenter initiated turn signaling based on the location of the participant's car in the simulated world which was displayed on the experimenter's LCD screen. When the subjects needed to turn left, first the four left LED columns lit up and started blinking. After 3 seconds, the blinking turned into the four leftmost columns lighting up one after the other creating an apparent leftward animation (see video [10]).

Similar cues were given for turning right, with the difference that the four rightmost columns participated in a rightward animation. When the drivers needed to continue driving straight (which was the default mode), the three middle columns of LEDs were on.

2. Standard PND (SPND). Similar to the most basic PNDs, our LCD screen (Figure 1) presented users with a real-time map of the surrounding environment as well as the position of the vehicle in a simulated world. The 2D map was presented in a dynamic, exocentric, forward-up view. The car (represented by a small triangle on the map) always remained in the center of the screen, while the road moved about it (see video [11]). The diameter of the screen was 7 inches (18cm) and the size of the screen was 15cm x 9cm. The LCD screen was placed to the right of the steering wheel, which is a common place for contemporary built-in PNDs and smart phones with navigation capabilities. While driving with the SPND, the LED matrix was removed from the simulator.

We didn't use spoken directions in this experiment with either navigation device. We did so to explore purely the visual component of the two systems.

3.2.3 Procedure

After filling out the consent form and personal information questionnaire, participants proceeded to driving the simulator in a city environment. They completed two experimental runs, one for each PND. They trained using these systems for 5 minutes before each run, on roads similar to the experimental ones. To prevent ordering effects, we counterbalanced the presentation order of the PNDs between subjects. Participants drove on two-lane city streets. The second route traveled was the same as the first, but in reverse direction. Each route also included two unexpected events. After each PND the participants filled out a NASA-TLX questionnaire. At the end of the experiment they also ranked their agreement with statements pertaining to their experience with the two navigation devices using the Likert-scale, and provided written and/or verbal comments.

3.2.4 Design

The independent variable in our within-subjects factorial design was the PND type, *Nav*.

We measured multiple dependent variables:

- *Percent Dwell Time (PDT) on four areas of interest: the outside world, the LED display, the LCD display and other*. Using the eye tracker on the dashboard we calculated the time drivers spent looking at these four areas. In the simulator environment we defined looking at the outside world as looking at one of the three projection screens (front, left, right). A low value of PDT on the outside world indicates that the driver is distracted,
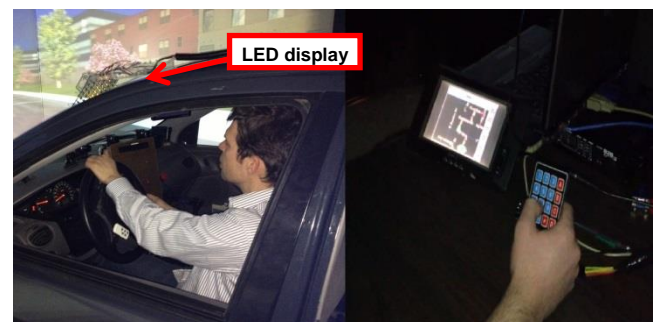

Figure 2. Driving with LED (left) and controlling the display (right).

Table 1. Percent dwell time on different areas.

	outside world	LED matrix	LCD (SPND) display	other
LED	94.38 %	0.49 %	0.01 %	5.12 %
SPND	86.27 %	0.02 %	10.12 %	3.59 %

which in turn can lead to collisions. In calculating the PDT on LCD we classified gazes at the area of 35cm x 25cm approximately centered on the LCD display as gazes towards the LCD display. Similarly we classified gazes at the 28cm x 17cm area approximately centered on the LED display as gazes towards the LED display. We made both of these areas larger than the corresponding LCD and LED objects. Thus, gazes that are close to the objects are classified as gazes at the objects.

- *Steering wheel angle variance (SWV),* which measures how much the angle of the steering wheel changes over time. Higher values indicate worse driving.
- *Lane position variance (LPV),* which measures how much the drivers swerve in their lane. As for SWV, higher values indicate worse driving.
- *Subjective measures (NASA-TLX score, and level of agreement with preferential statements).*

3.2.5 Calculation

The city routes in our experiment can be broken up into segments by treating roads between two intersections as separate segments. We calculated the results using data from 13 short segments, each 200 meters long. As discussed in [5] and [7], these segments required similar driving and participants did not encounter unexpected events in any of them.

In analyzing these segments, we excluded data collected over the first 60 meters and the final 40 meters of a segment, and analyzed data generated over (200–60–40) = 100 meters. This was done because driving performance is different between the excluded and analyzed portions of the segments. For example, at the beginning of a segment, drivers are completing the turning maneuver that is necessary to get through the previous intersection. And at the end of a segment, they are decelerating before entering the next intersection. Thus, the resulting variances can be much larger than those encountered away from intersections, which makes it difficult to compare excluded and analyzed portions of segments.

We calculated all three observed dependent variables (PDT, SWV and LPV) separately for each of the 10 subjects in each of the 13 segments. Then we averaged all 13 segments for each subject to end up with 10 averages of each PDT, SWV and LPV on which we performed statistical analysis.

For each participant, we rejected segment values which were more
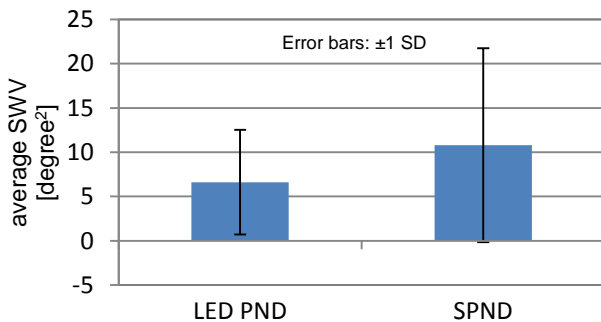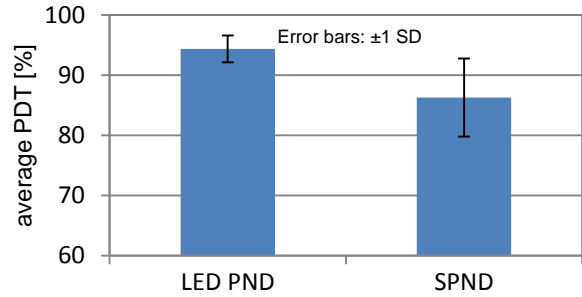

Figure 3. Average percent dwell time on outside world.

than 3 standard deviations away from the average of the values of all segments for that participant. We rejected the 2 segments for the SWV data, 1 for the LPV data, and none for the PDT data.

4. RESULTS

4.1 Visual Attention

We calculated the percent dwell time (PDT) of the driver's gaze on four areas of interest as shown in Table 1. It can be observed that the subjects did not look at the LED matrix any significant amount of time (≤0.49% in either condition). They did look at the LCD display (10.12%) while they were using it for navigation in the SPND condition. The 'other' column includes gazes at the speedometer, steering wheel, rear view mirror, etc.

We conducted a repeated measures ANOVA to assess the effect of the two PNDs on visual attention using PDT on the outside world as the dependent variable. The analysis revealed a significant main effect on PDT for *Nav* ($F(1,9)=16.35$, $p = 0.003$). The average PDT for LED PND was 94.38%, while it was 86.27% for SPND, see Figure 3.

4.2 Driving Performance

We also applied repeated measures ANOVA on driving performance measures. We found a significant difference for SWV (Figure 4) between LED and SPND ($F(1,9)=5.17$, $p=0.049$). The difference between these two devices was marginally significant for LPV ($F(1,9)=4.98$, $p=0.052$), see Figure 5.

4.3 Subjective measures

The NASA-TLX workload assessment tool did not yield any significant results. The Likert-scale questionnaire at the end of the experiment informed us that 7 of 10 participants preferred the LED compared to the SPND. Six of 10 agreed that they needed to use only their peripheral vision to acquire information from the LED display.

Nine of 10 participants provided either written or verbal feedback that indicated a preference for the LED display over the SPND.
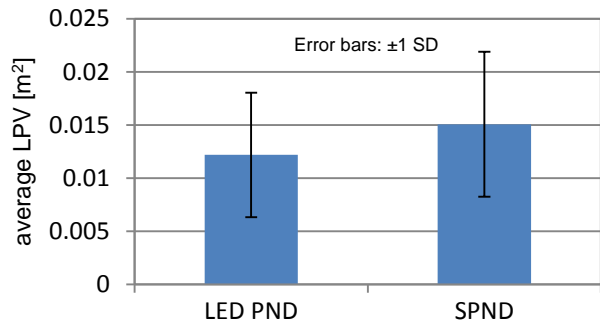

Figure 4. Average steering wheel angle variance.

Figure 5. Average lane position variance.

Quote 1 (Q1) of a written comment by participant 1 (P1) shows that he found the LED display easy to use and did not need to glance at it.

> Q1 (P1): The LEDs were a lot easier to follow since I didn't have to go out of my way to look at it."

P7 agreed with P1 that the LED display was easier to use, and further added that he would personally consider purchasing something like this if it were closely priced to a commercially available PND.

> Q2 (P2): "I saw improvement in reaction times when using an LED display. It was significantly easier to use and I would consider using it myself if it was similarly priced."

Some of the participants also pointed out aspects they disliked about the LED display and made suggestions for improvement. Q3 is from P5, and shows that he liked the LED display but would still like to have the feel of a standard PND. P12 was excluded from the study due to poor driving skills. However, we include this participant's comment as it was the most negative comment, and points out that there is more work to be done to improve the system.

> Q3 (P5): "I suggest adding the LED in addition to a standard GPS display.

> Q4 (P12): "Too high up, too bright, no indication of future turns. Flashing distracting."

5. DISCUSSION

We started this study by proposing three hypotheses. We will now consider these hypotheses in light of our results.

(H1) The LED navigation system will allow drivers to spend more time looking at the outside world than the SPND.

The average percent dwell time (PDT) on the road ahead was higher for the LED PND (94.38%) than for the SPND (86.27%). Clearly, the LED PND allowed users to look at the road ahead more instead of being distracted by the SPND. While using the SPND, the drivers spent a considerable amount of time looking at the LCD device displaying the map (10.12%), which might pose a safety hazard because their gazes were not scanning the road ahead. We also found that the LED matrix did not draw any significant amount of visual attention (0.49%) which indicates that drivers used their peripheral vision to detect directions from the LED PND. These PDT values are consistent with the ones we obtained in two previous studies [5, 7].

(H2) The LED navigation system will allow better driving performance than the standard PND.

Variance of steering wheel angle was significantly lower for the LED PND than for the SPND. A lower variance indicates better driving performance. This improvement can be attributed to the fact that drivers spent more time observing the road ahead while using the LED PND, because they did not need to divert their gaze to a map as in the SPND condition. Lane position variance was also lower for the LED display; however this difference was only marginally significant. In fact the p-value of both performance measures was close to .05, indicating that it would be useful to include more participants in the study.

(H3) Users will prefer the LED navigation system over the SPND.
More subjects preferred the LED system than not, but some of them had reservations towards using it as a sole navigation device.

6. CONCLUSION

With the LED PND our participants had a higher PDT on the outside world, and better driving performance, than when they used the standard PND. Furthermore, as shown in Table 1, when using the LED PND, they hardly ever looked at the LED array. This indicates that they used their peripheral vision to gather information from the LED PND. Thus, our results suggest that using a peripheral means of navigation, such as the LED PND, might be a better alternative to a standard PND. Subjective assessments also favored the LED PND, and participants felt that with it they relied on their peripheral vision (which is confirmed by the data in Table 1).

These results encourage us to continue exploring augmented reality, even in its current unsophisticated form, as a potentially useful technology for in-car navigation.

7. ACKNOWLEDGEMENTS

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