PAPER

Effects on Productivity and Safety of Map and Augmented Reality Navigation Paradigms

Kyong-Ho KIM[†*a)], ***Member and*** **Kwang-Yun WOHN**[†], ***Nonmember***

SUMMARY Navigation systems providing route-guidance and traffic information are one of the most widely used driver-support systems these days. Most navigation systems are based on the map paradigm which plots the driving route in an abstracted version of a two-dimensional electronic map. Recently, a new navigation paradigm was introduced that is based on the augmented reality (AR) paradigm which displays the driving route by superimposing virtual objects on the real scene. These two paradigms have their own innate characteristics from the point of human cognition, and so complement each other rather than compete with each other. Regardless of the paradigm, the role of any navigation system is to support the driver in achieving his driving goals. The objective of this work is to investigate how these map and AR navigation paradigms impact the achievement of the driving goals: productivity and safety. We performed comparative experiments using a driving simulator and computers with 38 subjects. For the effects on productivity, driver's performance on three levels (control level, tactical level, and strategic level) of driving tasks was measured for each map and AR navigation condition. For the effects on safety, driver's situation awareness of safety-related events on the road was measured. To find how these navigation paradigms impose visual cognitive workload on driver, we tracked driver's eye movements. As a special factor of driving performance, route decision making at the complex decision points such as junction, overpass, and underpass was investigated additionally. Participant's subjective workload was assessed using the Driving Activity Load Index (DALI). Results indicated that there was little difference between the two navigation paradigms on driving performance. AR navigation attracted driver's visual attention more frequently than map navigation and then reduces awareness of and proper action for the safety-related events. AR navigation was faster and better to support route decision making at the complex decision points. According to the subjective workload assessment, AR navigation was visually and temporally more demanding.

key words: *map navigation, AR navigation, productivity, safety, driving performance and situation awareness*

1. Introduction

1.1 Motivations

Navigation Paradigms: Map and Augmented Reality. The ground-vehicle or car navigation system providing route-guidance and traffic information is one of the most widely used driving assistance system these days and the installation rate is increasing rapidly. The conventional navigation system plots the driving route on the abstracted two-dimensional electronic map, and we call this paradigm of navigation system ***map navigation***. Cartography is considered as a process of information communication and is considered the 'vehicle' for that communication. In this definition, map plays a role of medium for the recipient (map reader) to understand the geographic environment [1]. As a medium for communication between cartographer and percipient, map is a symbolized and abstracted representation of the real world. As a result, it is cognitively hard to interpret the abstracted information and translate to the real world information. Usually, the electronic map utilized in map navigation is represented as more simple and easy to understand form than the conventional paper map. Because the main purpose of map navigation is to guide driver to proper route, the additional features of map except for the road network are generally simplified or eliminated deliberately. So it may not so hard to understand the electronic route map as the paper map, the cognitive process of decoding is also expected to be required. On the other hand of this cognitive load, map navigation provides large scale exocentric orthogonal view of the world and thus allows driver aware global spatial situations.

A new navigation paradigm introduced recently is utilizing the augmented reality (AR) technology representing driving route by superimposing virtual graphic objects on the real scene image, and we call this ***AR navigation***. AR navigation is a mixture of image and graphic, but the dominant component is image, therefore it inherit the image paradigm. Image is easier than the abstracted graphic to understand and imposes less cognitive load. Moreover, the fact that the real scene image represented by AR navigation is very similar with the forward view of driver, makes that AR navigation is expected to be recognized with less cognitive load than map navigation. However, AR navigation provides relatively small scale egocentric view of the world, thus allows driver aware local spatial situations.

Like this, these two navigation paradigms have their own innate characteristics as fundamental methods of visual representation from the human cognition point of view. Thus these two are not in the relationship of competitive but complementary, so we thought that the well designed navigational strategy utilizing the characteristics and pros of these two navigation paradigms will provide better navigational assistance to driver. To design this strategy, it should be investigated first that which character of navigation paradigm affects how to achieving driving goals. However, it is hard to find the related work about this topic till

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[†]The authors are with the Dept. of Computer Science, KAIST, 335 Gwahagno, Yuseong-gu, Daejeon, 305–701, Republic of Korea.

[*]Presently, with the Dept. of Vehicle-IT Convergence Research, ETRI, 138, Gajeongno, Yuseong-gu, Daejeon, 305–700, Republic of Korea.

a) E-mail: kkh@etri.re.kr

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now. So we studied on this topic by experimental analysis comparing effects of map navigation and AR navigation on driving.

Goals of Driving: Productivity and Safety. It is important to note that driving typically involves two competing goals: ***productivity*** and ***safety*** [33]. By Wickens et al (2004), productivity involves reaching one's destination in a timely fashion, which may lead to speeding and safety involves avoiding accidents, which is sometimes compromised by speeding [33].

The productivity can be restated in other term: ***driving performance***. Driving performance is about how to drive well and effectively to get the goals of driver. The driving performance is proportional to the successful completion of all three levels of driving tasks: strategic task (deciding where to go, when to go, and how to get there), tactical task (speed selection, the decision to pass another vehicle, and the choice of lane), and control task (maintaining a desired speed, keeping the desired distance from the car ahead, and keeping the car in the lane) [21].

Safety involves avoiding accidents, which is sometimes compromised by speeding. One of the most important factors for the safety is ***situation awareness*** of safety-related events [6]. For driver, the situation awareness may imply the perception of, identification of, and reaction for the various kinds of elements in the road environment such as sign board, traffic light, nearby vehicle, pedestrian, and obstacle on the road. These elements may be static (e.g. sign board, speed bump, etc.) or dynamic (vehicle, bicycle, pedestrian, traffic light, etc.) causing safety-related events. Driver's situation awareness of the safety-related events can be influenced by the cognitive load. In the case that driver's cognitive load is high especially when the visual attention is required by something, situation awareness of the events occurring nearby can be declined.

As the driving assistance system, navigation should support these goals of driving: productivity and safety, or at least not obstruct driver to achieve them. So in this work, we are going to analyze the effects of map navigation and AR navigation according to these two criteria: driving performance and situation awareness.

1.2 Hypothesis and Goals

Hypothesis. One of the most critical differences between map navigation and AR navigation is their views. Generally, map navigation is based on two-dimensional exocentric view [34]. So it can provide global spatial awareness. However, AR navigation is based on three-dimensional egocentric view. So it may be confined to local spatial awareness.
On the basis of these facts, we hypothesized as follows.
Map navigation:

- *(global spatial awareness)* may require driver's attention less frequently, because it can provide anticipatory information about the route (look ahead the route to go and keep it in working memory, and prepare actions required). And as a result,
- *(global spatial awareness)* may be better for driver's situation awareness of the events occurring on the road.
- *(two-dimensional exocentric)* may be weaker to support route decision making at the complex decision points such as junction, overpass, and underpass.

AR navigation:

- *(local spatial awareness)* may require driver's attention more frequently, because it cannot provide anticipatory information about the route. And as a result,
- *(local spatial awareness)* may be worse for driver's situation awareness of the events occurring on the road.
- *(three-dimensional egocentric)* may be stronger to support route decision making at the complex decision points.

Goals. The goals we are trying to achieve in this work are to:

- find how the map navigation and AR navigation affect to the driving performance including decision making at complex decision points.
- find how the map navigation and AR navigation affect to the situation awareness of safety-related events. And based on these findings,
- suggest navigational strategy utilizing both map and AR navigation paradigms.

Note that the information modality in regard in this work is visual modality. There are many reference studies about the effects of multimodal navigational assistance. Utilizing multimodalities including auditory and haptic can provide more efficient navigational assistance. However, we focused on the visual modality because visual information is most important for driver based on the facts that: over 90% of the information that a driver has to process is visual [30], visual distraction is the most severe problem for driver, and collision occurs mostly by the visual distraction [17].

The objective of this work is to investigate how map and AR navigation paradigms have an effect on achieving driving goals: productivity and safety. For this objective, we performed comparative experiments using driving simulator and computers with subjects, and assessed driver's subjective workload.

2. Background

2.1 Navigation Technology

Evolution of Navigation Paradigm. Paradigm of navigation system for ground vehicle has been evolved from simple turn-direction guidance to real scene-based route guidance (Fig. 1).

Turn-direction guidance [22] represented by simple turn symbol provides only local guidance information at intersection and it does not provide overall route information from start to destination. 2D map navigation [20] is the

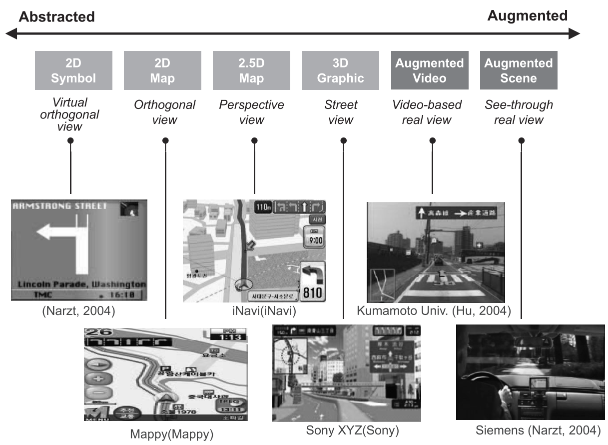

Fig. 1 Evolution of navigation paradigms.

most representative paradigm of car navigation and has been used most widely till now. It is based on the typical map paradigms with orthogonal point of view and as a result, provides more global spatial awareness information than turn-direction guidance.

To add some reality to 2D map navigation, 2.5D map was utilized [12]. It provides perspective bird's view but the viewpoint is fixed and the geographical objects (i.e. buildings) are built simple extrusion of 2D polygons. To enhance the reality more, 3D graphic navigation was developed [14], [27]. It utilizes the full functionality of 3D graphics so the virtual scene appears more elaborate and realistic. Theoretically, the viewpoint can be located anywhere in the virtual world so it can provide any views (orthogonal or perspective). Most effective view it provides is street view that is aligned well to that of driver. All navigation paradigms from 2D map navigation to 3D graphic navigation are based on the map (or graphic) paradigm.

As a new paradigm of navigation, AR navigation was introduced recently. AR navigation provides navigational information by imposing graphical information on real scene image. There are two types of AR navigation. The first type is augmented video type [10]. It overlays the graphical information on the video captured by camera mounted on a vehicle in real-time. This type is usually implemented on in-vehicle navigation terminal and provides video-based real view. The second type is augmented scene type [22]. It provides virtual navigation information by overlaying it directly on the real scene seen through the wind-shield. This type utilizes the Head-Up Display (HUD) technology, however, there are a lot of technological difficulties like natural scene understanding, registration between virtual object and real scene, and cognitive problems like attentional tunneling [2].

AR Navigation Technology and Its Applications. AR navigation technology has been applied to almost all kinds of moving objects such as robot, human, and vehicle.

Among these application areas, vehicle like airplane, vessel, and car is the most representative and noticeable area. To increase efficiency and enhance situation awareness during airport surface taxi operations The Taxiway Navigation and Situation Awareness (T-NASA) system which is a prototype augmented reality commercial airline cockpit display suite was developed by NASA [7]. AR navigation system for maritime navigation in which all chart and navigational data such as a buoys and routes are presented graphically overlaid upon the real scene in the display was developed to provide an intuitively understood presentation that works in all weather conditions [4].

Our main interest is the AR navigation for car. A well established prototype of AR car navigation system named INSTAR (Information and Navigation System Through Augmented Reality) was developed by Siemens. The in-vehicle navigation terminal displays the annotation of the route superimposed on a live-stream video showing the road ahead. The INSTAR system uses the GPS position and orientation, the maps, the topography information and the route and calculates a three-dimensional depiction of the street as it may look from the driver's perspective. This approach is advantageous in terms of daylight conditions because it only visualizes pure, measured data and does not utilize image recognition technology [22]

Kumamoto University developed a prototype AR navigation system called VICNAS (Vision-based Car Navigation System) which employs AR technique to superimpose virtual direction indicators and traffic information bulletins into the real driver's view. VICNAS uses a hybrid camera pose tracking method combining vision, GPS and 3D inertial gyroscope technologies [11].

Another approach proposed by KAIST was the Location-based Augmented Reality for Car Navigation System [13]. This system utilized the 3D scene model to extract the point-of-interest data and generate the 3D text image which is to be overlaid on the building in video stream.

2.2 Driver's Behavior and Cognition

It is hard to find the previous work directly related to this work, the comparative analysis of the effects of map navigation and AR navigation. However, several studies have been done in traffic and transport psychology, automotive, and HCI field to investigate how the various aspects of in-vehicle information sources like map, navigation, night vision and so on affect to driver's behavior and cognition.

Sullivan et al (2004) experimented on the driver performance and workload using a night vision system [29]. They investigated how the position of display (head-up vs. head-down) of night vision system affects to the secondary task performance of spatial detection using field test.

The effects of information modality especially the visual modality versus auditory modality are the most frequently researched topic. Kim and Lee (2000) studied the modality effect of navigation system by comparing visual, auditory, and audio-visual information of navigation system using measurement of driving performance and subjective workload [15]. Several results about the modality effect for driving performance have been presented: auditory information is less distractive than visual information [16], auditory information can be annoying, so should be used restrictively [28], sensory motor reaction is quicker for visual stimulus than auditory stimulus [5], regardless of modality, most information demand processing resources and increase driver workload [3].

Comparative experiments for the effects of paper map versus electronic map, in addition to the effects of the scale of display of navigation system for driving task performance was performed using desktop-type driving simulator [31]. Lee et al (2005) studied on the effectiveness of a variety of contextually optimized route map visualizations in a simulated driving context [18].

Cognitive research for the mental rotation or cognitive transformation was performed by comparing the north-up map and head-up map [34]. Wickens and Carswell (2006) argued that the information transformation needed to understand north-up map is effortful, time consuming, and provide sources for error [34]. Wickens et al (2005) also studied about the mental transformations and situation awareness provided by egocentric and exocentric viewpoints in an aircraft display [35].

These studies show that various features of information representation such as modality, position, orientation, scale, viewpoint and so on can affect on driver's behavior and cognition.

3. Method

3.1 Study Design

We designed two objective experiments for driving performance and situation awareness, and a subjective assessment for driver's workload. The first experiment is to find effects on driving performance and situation awareness and was performed using high-fidelity driving simulator. The second experiment is to find effects on driver's decision making at the complex decision points, as a special case of driving performance. Driver's subjective workload was measured using DALI(Driving Activity Load Index).

Thirty eight subjects between the ages of 19 and 28 (avg. 24.7) with driving license were participated (35 male, 3 female) in the first experiment (Exp. 1) and subjective workload assessment. Another group of 38 subjects between the age of 27 and 52 (avg. 37.8) with driving license was participated (29 male, 9 female) in the second experiment (Exp. 2). The experiment condition was within-subjects to compare the effect of map navigation and AR navigation.

3.2 Experimental Apparatus

Driving Simulator and Peripherals. A 3DOF motion-based, high fidelity driving simulator was used to conduct the experiment. The simulator uses a 2009 Hyundai Genesis coup vehicle that has been modified to include force

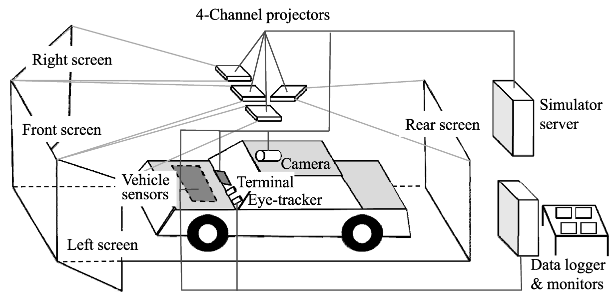

Fig. 2 Driving simulator and peripheral devices.

feedback and rich 3D audio environment. Three channel displays for front, left, and right screen provide 130 deg. × 40 deg. full scale field-of-view, and one channel display for rear screen provides 60 deg. × 40 deg. real view seen through room mirror and side mirrors.

The fully textured graphics are generated by $SCANNeR^{TM}$ software, which delivers a 60 Hz frame rate at 1024 × 768 resolution. It can simulate various kinds of traffic scenarios like motion of nearby vehicles, pedestrian, motor-cycle, and traffic light signal and so on. Various kinds of vehicle data like location, motion, velocity, acceleration, RPM, brake, steering wheel and so on were collected by vehicle sensors at a rate of 50 Hz.

A $faceLAB4.6^{TM}$ eye-tracking system is installed on the dash board of simulation vehicle to track driver's head and eye movement. An LCD panel is installed in the centerpecia of simulation vehicle, that is size of 7 inch and resolution of 800 × 480 to display map navigation and AR navigation. A CCD camera is installed on top of simulation vehicle to capture the front screen image that is used to implement AR navigation.

Figure 2 shows the overall environment of experiment.

Map Navigation and AR Navigation. The map navigation system was implemented modifying the commercial navigation system $GINI^{TM}$ of the M&SOFT Inc. It runs by gathering the coordinate of simulation vehicle position at 1 Hz rate and output the display to LCD panel in simulation vehicle. For the fidelity of the map navigation paradigm and visual modality only, several additional features like sound alarm, voice instruction, turn signal, 3D images, and so on were set off. The viewpoint of the map navigation system is fixed to orthogonal top-view because the orthogonal view represent best the map paradigm inheriting cartographic heritage which is exocentric. The most core characteristic of map is that it has inevitably ubiquitous viewpoints and at the same time no specific viewpoint to communicate geographic knowledge with another [32].

The typical paradigm of AR navigation has not been established yet. There may be a lot of way to represent navigation information augmented on the real scene. To design AR navigation for our experiment, we got a hint by looking at the paradigm of map navigation. The most important information map navigation provides is route and turn. Route

Fig. 3 Screen shot of the AR navigation.

is continuous information represented by linking all nodes from start to destination. Turn is discrete information guide the direction to go at the branch node.

This concept can also be applied to AR navigation because the final goal of the both navigation paradigms is the same: guide driver from start to destination successfully. The continuous route information can be represented as a form of line, surface, or 3D beam [22]. The discrete turn information can be represented by arrow augmented on the road surface [13].

In this work, we adopted the arrow representation because of that AR navigation paradigm has egocentric view and has strength on local spatial awareness therefore, the discrete turn information is more suitable to AR navigation paradigm. There is also a technical reason that to represent the continuous route on multi-lane road, the current driving lane should be identified first. However, it is not easy to implement for the experiment. As a result, we designed two kinds of arrows (left-turn and right-turn) that is red colored 3D graphic object of which the head is skewed facing driver's eye to be identified easily. Arrow is augmented on the scene image captured by camera on top of simulation vehicle in real time (Fig. 3).

We aligned the arrow object with the scene image by matching the camera parameter of simulation vehicle with that of virtual camera in graphic world containing the arrow to minimize the registration error. Finally, the augmented image is captured again and output to LCD panel in vehicle. There may be a little disparity between the view of AR image displayed on the LCD panel and the driver's front view, but the effect caused by this disparity is too small to affect the fundamental characteristic of the egocentric view of AR navigation paradigm.

Note that the AR navigation system built for this experiment is deliberately well-designed. As Yamaguchi et al (2007) state, several problems such as registration error, inappropriate brightness, image blur, and limited visibility can occur in real driving situation and these degrade the quality of AR navigation [36]. How to cope with these problems can be important research issues in developing robust and practical AR navigation system. However, this is another research issue because the key point of this experiment is to perform the comparative analysis of the two navigation paradigms: map and AR. The map navigation system we used in this experiment is a high-end commercial product, so not to make map navigation condition more beneficial than AR condition, we had to eliminate those problems which can be occurred in real driving situation.

It should also be noted that the AR navigation type investigated in this experiment is the augmented video type which uses head-down display. As mentioned in the background chapter, the augmented scene type which uses head-up display is the more evolved one and more appropriate for the concept of AR. There is related work investigated how the position of display (head-up vs. head-down) affects to the driver's performance and workload [29], and AR navigation system on windshield head-up display is also in development [25]. However, the focus of this study is to investigate the fundamental effects of the two navigation paradigms in comparison, so we fixed deliberately the type of display to head-down type because the position of display can affect as another control factor.

3D Graphic Scene Database. For the experiment we built 3D graphic scene database covering about 3.5 Km by 1.2 Km area in Ilsan district which is near from Seoul city of Korea. The Digital Elevation Model (DEM) was not built, so all objects such as building, road, tree, road lamp, and so on are placed on flat surface. To enhance the fidelity of simulation, 3D graphic scene was modeled as same as the position, shape, and texture of real scene.

3.3 Experiment 1: Driving Performance and Situation Awareness

In this section, we describe the experimental configuration and procedure related to driving performance and situation awareness.

Scenario and Procedure. Each of 38 participants drives the simulation vehicle from start to destination two times for each navigation condition of which the order is counter balanced.

During experiment, subjects are encouraged to follow the guidelines: observe traffic signal, keep speed limit indicated by sign board, avoid collision with vehicle, bicycle, and pedestrian, and pass slowly over the speed bump.

Driving route for experiment is planned on the real road in 3D graphic scene database. Total length of the route is 7.13 Km and the average driving time for one navigation condition was about 12minutes. The route was planned deliberately to be complex enough to keep the subjects from remember the route (It contains 13 left turns and 13 right turns) (Fig. 4).

We designed 9 events for situation awareness including 4 static events and 5 dynamic events. The position of events are shown in Fig. 4 (from E1 to E9), and the detail is described in Table 1. Note that the event E6 and E7 are duplicated and repositioned to E6' and E7' alternatively for each navigation condition to minimize the learning effect on the position of events.

Dependent Variables. During experiment, vehicle data, eye-tracking data, and video-data are collected. Vehicle data are collected from the simulator and include velocity, steer-

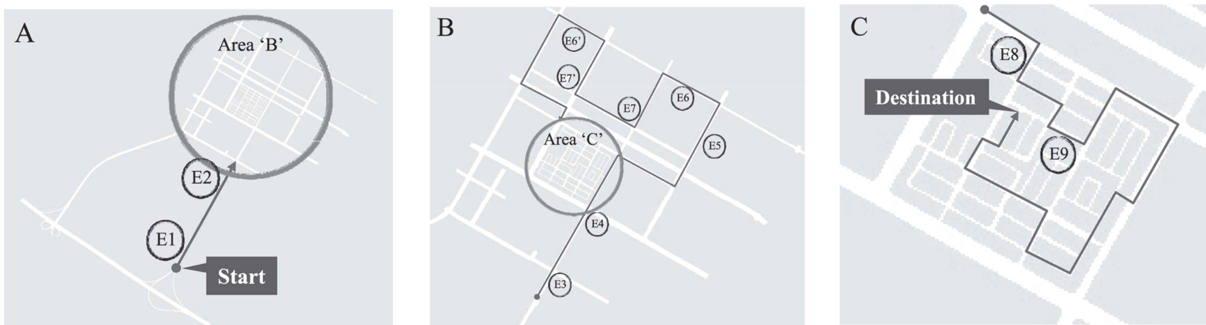

Fig. 4 Driving route for experiment.

Table 1 Event description.

Event ID	*Event explanation*	*Attribute*
E1	Sign board (speed limit 100 Km/h)	Static
E2	Sudden stop of preceding vehicle	Dynamic
E3	Sign board (speed limit 70 Km/h)	Static
E4	Traffic light change(from green to yellow)	Dynamic
E5	Cut-in of other vehicle	Dynamic
E6	Bicycle crossing the road (illegal)	Dynamic
E7	Pedestrians crossing the road (legal)	Dynamic
E8	Sign board (speed limit 30 Km/h)	Static
E9	Speed bump	Static

Table 2 Dependent variables for driving performance.

Dependent variable	*Related driving task*
Total driving time	Strategic
Number of driving error	Strategic
Number of lane change	Tactical
Variation of velocity	Control (longitudinal)
Number of brake (including sudden brake)	Control (longitudinal)
Variation of steering wheel angle	Control (lateral)
Number of lane departure	Control (lateral)

ing wheel angle, accelerator and brake angle, vehicle position and motion, and so on. Eye-tracking data include head position and orientation, gaze orientation, gazing region, fixation time, and PERCLOSE. For verification of data video image of quad camera (front-right side of driver, navigation display, screen, and timer) are recorded.

Seven dependent variables for driving performance are selected to cover the three level of driving tasks: 2 for strategic, 1 for tactical, and 4 for control task (Table 2).

Dependent variables for situation awareness are selected for each event from E1 to E9 (Table 3). These dependent variables are to measure the driver's cognitive and motor ability to percept, recognize, and react on the safety-related events, but are so closely related to the driving performance also.

To investigate driver's visual attention and cognitive load for navigational assistance, average fixation time and mean glance number are measured using eye-tracker.

3.4 Experiment 2: Decision Making at Complex Decision Point

By Golledge (1992), the two important components in the

Table 3 Dependent variables for situation awareness.

Event ID	*Dependent variable*
E1	Average velocity to E3 point
E2	Time to brake from the stop of preceding vehicle
	Collision or not
E3	Average velocity to E8 point
E4	Time to brake from yellow light turn-on
	Stop or not
E5	Time to brake from the cut-in of other vehicle
	Collision or not
E6	Time to brake from bicycle movement
	Time to steering from bicycle moving
E7	Time to brake from pedestrian movement
	Time to stop from brake
	Position of stop
E8	Average velocity to destination
E9	Average velocity when passing over speed bump

cognitive process of acquiring spatial knowledge are place recognition and way-finding. Way-finding is the process linking places locationally separated [8]. For the successful way-finding, place recognition must be succeeded first. Especially, the designation of choice points where changes of direction or speed are desirable is such an important process.

In this work, we are going to state the choice point as decision point, and classify into two categories: ***simple decision point*** and ***complex decision point***. Simple decision point is defined where change of direction or choice of route is easily performed and as a result, requires low cognitive load of driver. Complex decision point is defined where change of direction or choice of route is hard to be performed and as a result, impose high cognitive load to driver. Complex decision point may include these cases:

- When its topological geometry is three dimensional with depth in z-direction (i.e. underpass and overpass).
- When its topological geometry or shape is difficult to recognize (i.e. complex junction).
- When it is placed where hard to be anticipated (i.e. located in a complex road network in downtown)

We experimented in the case of underpass, overpass, and junction that are the most common complex decision points in a city. The goal in this experiment is to find the effects of map and AR navigation on the driver's decision making at a complex decision points. Decision making for correct

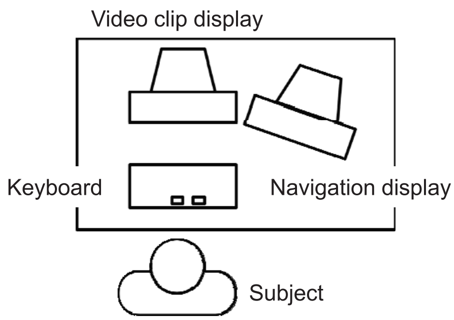

Fig. 5 Simulation environment for Exp. 2.

Fig. 6 An example of experiment condition for the Exp. 2.

route at decision point should be considered as an important factors of driving productivity.

Apparatus. It might be better to include complex decision points into the route of Experiment 1. However, the database built in the Experiment 1 is based on the real world data, and it did not include complex decision points. Therefore, we designed this experiment as a computer-based simulation.

We took videos and photographs of real road in Daejeon-city, Korea with vehicle equipped with two video recorders (one is located in the right inside of vehicle and the other is on the roof). The video clips and photographs were edited to be utilized as driver's forward view and AR navigation. Several screen shots of map navigation were also prepared. The simulation environment is shown in Fig. 5.

Scenario and Procedure. Thirty eight subjects were participated in this experiment. Eight simulation conditions are prepared including 3 overpasses, 3 underpasses, and 2 junctions. For each simulation condition, experiment was performed two times once with map navigation and once with AR navigation. The order of experiment was randomly assigned from the matrix of 8 simulation conditions by 2 navigation conditions (totally 16 experiment conditions).

Video clip is displayed on the left monitor simulating forward view. At the decision point, lane selection indicator (red dot) shows and beeps, and at the same time map or AR navigation image is displayed on the right monitor. Subject decides the route and moves the virtual vehicle icon to the proper lane as informed by navigation by pressing arrow keys as fast as possible. The elapsed time from the indicator show-up to the key press and success or fail of decision are recorded.

Running time for each experiment is varied from 20 seconds to 50 seconds and the lane selection indicator shows up at different time to make the learning effect of the subject the least. Figure 6 shows an example of experiment condition.

Dependent Variables. Dependent variables in this experiment are the elapsed decision and reaction time and success or fail to decide correct lane.

3.5 Subjective Workload

One of the most widely used subjective workload assessment method is NASA-TLX (Task Load Index) that was designed to assess pilot workload in the aviation domain in 1988 [9]. Main six factors of NASA-TLX are mental demand, physical demand, temporal demand, performance, effort, and frustration.

Pauzie (2008) mentioned that some factors of NASA-TLX is not relevant to apply to driving task and suggested a new revised version of NASA-TLX adapted to the driving task: DALI (Driving Activity Load Index) [23]. DALI is composed of seven factors to assess driver workload: effort of attention, visual demand, auditory demand, tactile demand, temporal demand, interference, and stress.

We assessed participant's subjective workload after Experiment 1 using DALI. As a first step, we assessed the magnitude of each of the seven factors on a scale, and then, performed pairwise comparisons between these seven factors, in order to determine the higher source of workload factor for each pair.

4. Results

4.1 Driving Performance and Situation Awareness

Results indicated that there was no significant difference between the two navigation paradigms on driving performance except for the deviation of steering wheel angle (Table 4).

For situation awareness to percept, recognize, and react for the safety-related events, map navigation was better than AR navigation. By McNemar test, we found that for the static events like sign board and speed bump, there was no significant difference. However, for the dynamic events like cut-in of other vehicle, bicycle and pedestrians crossing the road, map navigation showed significant difference in driver's action for brake. An interesting result is that for the dynamic events related to people (E6: bicycle rider and E7: pedestrian), map navigation showed very conspicuous strength over AR navigation. For these two events E6 and E7, a lot of subject who braked in map navigation condition did not brake in AR navigation condition (Table 5).

For visual distraction, AR navigation attracted driver's visual attention more frequently than map navigation. There was no significant difference in average fixation time, but the mean number of glance was more in AR navigation condition (M = 114.84, SD = 60.36) than map navigation condition (M = 97.47, SD = 53.33) with significance p = 0.01.

4.2 Decision Making at Complex Decision Point

Results show that AR navigation is much better than map navigation to support driver's decision making at complex decision points. Decision time was faster and the rate of correct decision was higher in AR navigation condition with very high significance (Table 6).

Table 4 Results for driving performance ($N = 38$).

Measured Value	*Navigation Condition*	*M*	*SD*	*P-value*
Total driving time	Map	690.09	88.52	0.90 (-)
	AR	688.50	88.72	
# of driving error	Map	1.08	0.27	0.66 (-)
	AR	1.05	0.23	
# of lane change	Map	67.18	6.56	0.75 (-)
	AR	66.84	5.95	
# of lane departure	Map	58.13	9.26	0.57 (-)
	AR	59.08	10.22	
Deviation of velocity	Map	19.87	2.87	0.27 (-)
	AR	19.43	2.30	
# of brake	Map	14.79	8.97	0.41 (-)
	AR	13.95	9.60	
# of sudden brake	Map	4.40	4.29	0.16 (-)
	AR	3.71	3.49	
Deviation of steering wheel angle	Map	84.66	13.80	0.04 (**)
	AR	79.57	9.61	

-=not significant, $* = p < 0.1, ** = p < 0.05, *** = p < 0.01$

4.3 Subjective Workload

Participants reported that they felt visual demand and temporal demand more in AR navigation condition. The other factors showed no significant difference. The global score of workload was also higher in AR navigation condition (Table 7).

5. Discussion

We think that almost all of the results of this experiment can be explained by the innate difference between map navigation paradigm and AR navigation paradigm. As the result shows, AR navigation requires cognitive attention more frequently because it provides egocentric view and as a result, driver is able to aware just local spatial situations. This frequent visual distraction may not be confined to the visual

Table 6 Results of decision making at complex decision point ($N = 38$).

Measured Value	*Navigation Condition*	*M*	*SD*	*P-value*
Response time	Map	1.67	0.66	0.000(***)
	AR	1.37	0.37	
Correct proportion	Map	83.88	15.63	0.003(***)
	AR	91.78	11.36	

-=not significant, $* = p < 0.1, ** = p < 0.05, *** = p < 0.01$

Table 5 Results for situation awareness ($N = 38$) (McNemar test).

Measured Value	*Event ID*			*AR Navi.*		*P-value*
				Non-Operation	*Operation*	
Braking or not	E2	*Map Navi.*	*Non-Operation*	6	11	0.21(-)
			Operation	5	16	
	E4	*Map Navi.*	*Non-Operation*	17	10	1.00(-)
			Operation	9	2	
	E5	*Map Navi.*	*Non-Operation*	18	3	0.09(*)
			Operation	10	7	
	E6	*Map Navi.*	*Non-Operation*	9	1	0.001(***)
			Operation	14	14	
	E7	*Map Navi.*	*Non-Operation*	10	3	0.004(***)
			Operation	16	9	
Stopping or not	E7	*Map Navi.*	*Non-Operation*	12	8	0.38(-)
			Operation	13	5	
Over speed or not	E3	*Map Navi.*	*Not*	24	6	0.51(-)
			Over speed	3	5	
Over speed or not	E8	*Map Navi.*	*Not*	36	1	1.00(-)
			Over speed	1	0	

-=not significant, $* = p < 0.1, ** = p < 0.05, *** = p < 0.01$

Table 7 Results of subjective workload (N = 38).

Measured Value	***Navigation Condition***	***M***	***SD***	***P-value***
Global score	Map	27.62	7.36	0.08(*)
	AR	30.31	7.01	
Effort of attention	Map	56.67	20.74	0.38(-)
	AR	60.09	18.36	
Visual demand	Map	59.47	26.10	0.09(*)
	AR	69.30	22.91	
Auditory demand	Map	6.40	7.29	0.14(-)
	AR	4.82	5.84	
Tactile demand	Map	12.72	15.50	0.84(-)
	AR	13.25	21.99	
Temporal demand	Map	12.81	15.91	0.03(**)
	AR	20.70	29.26	
Interference	Map	1.84	4.63	0.74(-)
	AR	2.19	6.81	
Situational stress	Map	43.42	31.99	0.72(-)
	AR	41.84	27.57	

-=not significant, $* = p < 0.1, ** = p < 0.05, *** = p < 0.01$

resource only, but the driver's overall cognitive resources by compelling continuously to look down at the terminal until driving is ended. This is supported by the result of subjective workload assessment: participants' temporal demand is high in addition to the visual demand. This cognitive workload burdened by AR navigation hinder driver from recognizing and interacting with the events occurring on the road environment.

The strength of map navigation in spatial awareness can be thought to be based on the anticipation which is an important factor of spatial knowledge. The global spatial awareness based on exocentric view of map navigation makes it possible for driver to anticipate what happens in near future, and this disburden cognitive load much.

The reason why there is little difference of the effects on driving performance for three levels of tasks may be explained by multiple resource theory. The recent extensions of multiple resource theory identified separate visual processing resources: ambient and focal. In driving, ambient vision supports lane keeping and focal vision is critical for event detection [19]. Performing driving tasks are more based on the ambient vision than focal vision. Therefore, regardless of the paradigm, glancing at the navigation consuming focal vision resource can be considered to have little effect on driving tasks than situation awareness of safety-related events.

We may also think about the result of which the fixation time of two navigation conditions has no significant difference. From the cartographic point of view, map needs more cognitive load to decode the abstracted geographic information and then compare with real world environment than image or photograph. However, the base map of map navigation is generally simpler than the conventional map. And the driver usually attends to the driving route represented graphically more conspicuously than other geographical elements of base map, so the cognitive load may not become severe. Meanwhile, in case of AR navigation, it is based on the image paradigm, but is mixture of image and graphic, so it also needs some degree of cognitive load. This problem can be worse if the registration of virtual object with image is not done well.

Based on the overall result of our experiment, we suggest a strategy of composite navigational assistance utilizing both map and AR navigation paradigms. In this strategy, the navigation modes are to be switched according to driving situation. Map navigation is recommended to be used as a basic strategy. The general case is that the place recognition and way-finding process for navigation burden not so much cognitive load on driver. In this case, map navigation imposing less cognitive loads (visual and temporal) and attentional distraction is better for driver especially from the safety point of view. AR navigation is recommended to be used as an alternative strategy. In the case of complex decision point, AR navigation can support fast and correct decision making sacrificing cognitive load. We expect that the automatic selection and switching of navigation mode based on spatial situation awareness will become a promising function of advanced navigation system in the future.

5.1 Future Works

The fundamental limitation of our work is that the AR navigation we have implemented cannot be guaranteed as a typical paradigm of AR navigation. As we mentioned before, the typical paradigm of AR navigation has not been established yet, and it is hard to find the previous related work on the effectiveness and usefulness of AR navigation. Therefor it is so important to study about the AR navigation itself by asking how to represent the navigation information in most effective way.

In this work, we have chosen the discrete turn guidance rather than continuous route guidance. We think that the former is more suitable to AR navigation paradigm than the latter, but this thought must be verified by objective experimental investigation.

Another works needed to be investigated is on the problem of trade-off between the usefulness and the aesthetics of AR navigation information representation. There was study about bridging the gap between useful and aesthetic maps in car navigation systems [26]. It was concluded that an appropriate map design for the automotive context has to be adapted in its function and its graphic representation according to the user's information needs and the cognitive load of the situation. Considering this finding in map navigation, the methodology of effective information representation of AR navigation from the perspectives of human cognition and driving goals should be studied.

HUD (Head-Up Display) type see-through AR navigation projecting augmented information on the windshield is such a promising navigation paradigm. It can reduce driver's attentional distraction and as a result enhance safety. However, it can cause very dangerous cognitive problem such as the case that the real object on the road (vehicle or pedestrian) is confused with or covered by the graphic object. Therefor, investigating the effects of HUD type AR navigation on the safety and driving performance is very meaningful future work to develop safe and reliable AR navigation system.

6. Conclusion

Throughout this paper we have shown that the map navigation paradigm and AR navigation paradigm affects to achieving driving goals, the productivity and safety, differently due to their own characteristics of paradigm. It became clear by this work that these two paradigm is not in the competitive relationship but complementary. Map navigation can be accepted for the general cognitive process of place recognition and way-finding. AR navigation can complement the weakness of map navigation by supporting place recognition and decision making at complex decision points. We comment that the multi-paradigm navigation will be a promising choice of next generation navigation technology.

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Kyong-Ho Kim received Ph.D. degree in Computer Science from KAIST, Korea in 2010. He received B.S. and M.S. degrees in Electronic Engineering from Kyungpook National University, Korea in 1993 and 1995, respectively. Since 1995, he has been a research member of Electronics and Telecommunications Research Institute (ETRI). His research interests include Virtual Reality, Augmented Reality, and HCI.

Kwang-Yun Wohn received Ph.D. degree in Computer Science from University of Maryland in 1984 and M.S. degrees in Computer Science from University of Wisconsin, USA in 1981. He received B.S degree in Applied Physics from Seoul National University, Korea in 1974. He was researcher of Harvard University during 1984~1986 and professor of University of Pennsylvania during 1986~1990. He is currently professor in the Department of Computer Science and the Graduate School of Culture Technology, KAIST, Korea. His research interests include Computer Graphics, Virtual Reality, HCI, and Culture Technology.